IGU

Promoting Earth System Sciences



ABSTRACT VOLUME

63rd Annual Convention

on

Advances in Geophysics from Geodynamics to Metallogeny, and Green Energy Transition

2-4 November 2026

Jointly Organized by

Indian Geophysical Union (IGU)

Department of Earth Sciences

Indian Institute of Technology Bombay (IITB), Mumbai

Indian Institute of Geomagnetism (IIG), Mumbai

Ministry of Earth Sciences
Government of India

NATIONAL CENTRE FOR POLAR AND OCEAN RESEARCH

Ministry of Earth Sciences, Government of India

Indian Gateway to the Polar Regions



The National Centre for Polar and Ocean Research (NCPOR), an autonomous institute under the Ministry of Earth Sciences, Government of India, is the country's leading R&D organization for polar and ocean studies. It spearheads scientific research in Antarctica, the Arctic, the Southern Ocean, the Indian Ocean, and the Himalayas. NCPOR conducts multidisciplinary expeditions and operates India's research stations in these regions, supporting advanced studies in climate change, glaciology, marine ecosystems, and related fields.



ANTARCTICA

The Indian Antarctic Programme is a collaborative initiative that unites experts from diverse fields to study Antarctica's environment and its global significance.



ARCTIC

The Arctic Programme explores climate change, its impacts, and adaptation, extending from Svalbard to the Canadian High Arctic, Greenland, and the North Pole.



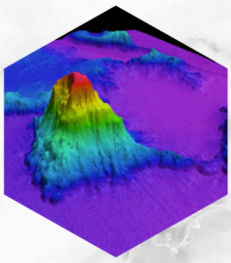
HIMALAYA

The Himalayan Cryospheric Programme facilitates systematic, long-term scientific investigations of Himalayan glaciers.



SOUTHERN OCEAN

The Southern Ocean Programme focuses on interactions within natural systems, environmental variability, dynamic processes, ecological patterns, and past climate changes.



GEO-EXPLORATION

The Marine Geoscience Programme explores the deep-sea environments, hydrothermal sulphide deposits at mid-oceanic ridges, and geodynamic processes.



National Centre for Polar and Ocean Research,
Ministry of Earth Sciences, Govt. of India
Headland Sada, Vasco-da-Gama, Goa 403 804, India

+91-832-2525511 www.ncpor.res.in info@ncpor.res.in

@ncpor.goa
@ncaor_goa
@ncpor.goa

ABSTRACTS

63rd Annual Convention of

Indian Geophysical Union

on

"Advances in Geophysics from Geodynamics to Metallogeny, and Green Energy Transition"

02-04 November 2026

Venue:

Indian Institute of Technology Bombay, Mumbai

SPONSORED BY

Ministry of Earth Sciences (MoES), New Delhi
CSIR-National Geophysical Research Institute (NGRI), Hyderabad
National Centre for Polar and Ocean Research (NCPOR), Goa
Indian Institute of Tropical Meteorology (IITM), Pune
Indian Institute of Geomagnetism (IIG), Navi Mumbai
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CSIR-North-East Institute of Science and Technology (NEIST), Jorhat

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CSIR-NGRI CAMPUS, HYDERABAD

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For Copies
Write to:
Hon. Secretary
Indian Geophysical Union
CSIR-NGRI Campus, Uppal Road
Hyderabad - 500 007, India
igu123@gmail.com

Dr. Abhey Ram Bansal. Hon. Secretary, IGU
Dr. ASSSRS Prasad, Organizing Sect, IGU
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AGI american geosciences institute
connecting earth, science, and people

AGU
ADVANCING EARTH AND SPACE SCIENCE

Asia Oceania Geosciences Society
www.asiaoceania.org

Deutsche Geophysikalische Gesellschaft
German Geophysical Society (DGG)
gegründet / founded 1922

EUROPEAN ASSOCIATION OF GEOCHEMISTRY

EGU European Geosciences Union

geochemical society

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ASSOCIATION GÉOLOGIQUE DU CANADA

THE GEOLOGICAL SOCIETY OF AMERICA®

The Geological Society

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Promoting Earth System Sciences

International Union of Geodesy and Geophysics
IUGG UGGI
Union Géodésique et Géophysique Internationale

IUGS

Japan Geoscience Union
Earth, Planetary, and Space Sciences

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Vice-Presidents
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A.P. Dimri
Director
IIG
New Mumbai
apdimri@hotmail.com

Sushma Rawat
Former Director (Exploration)
ONGC
New Deli
rawat_sushma@ongc.co.in

T. Srinivasa Kumar
Secretary
MoES
New Delhi
secretary@moes.gov.in

Hon. Secretary
Abhey Ram Bansal
Scientist G
CSIR-NGRI
Hyderabad
hsec.igu@gmail.com

Joint Secretary
M. Radhakrishna
IITB
Mumbai
mradhakrishna.iitb@gmail.com

Organizing Secretary
A.S.S.S.R.S. Prasad
CSIR-NGRI (Retd)
Hyderabad
atreya2002@gmail.com

Treasurer
Md. Rafique Attar
CSIR-NGRI
Hyderabad
rafiq.attar@yahoo.com



Dear Esteemed Colleagues and Participants,

It is my great pleasure to welcome you to the 63rd Annual Convention of the Indian Geophysical Union (IGU) at IIT Bombay, from 2 to 4 November 2026. This year's theme, "Advances in Geophysics from Geodynamics to Metallogeny, and Green Energy Transition", reflects the questions that matter most to our science and our society today.

Our Union has a proud history of fostering scientific research, collaboration and knowledge exchange. This convention is a testament to our commitment to advancing the frontiers of science and technology. It is a platform to share our ideas and discoveries, discuss emerging trends, and inspire one another in our collective pursuit of knowledge.

I am confident that the presentations, discussions and interactions during this event will contribute significantly to advancing our discipline. Advances in observation networks, both in-situ and satellite, together with high-performance computing and AI/ML, are opening opportunities that earlier generations could only imagine.

I would like to express my heartfelt gratitude to the organisers, the sponsors and, most importantly, each of you who has contributed to the success of this convention. Your dedication and enthusiasm for scientific exploration are truly inspiring. I am especially delighted to see so many young scientists, students and early-career researchers among us. You carry the future of this Union.

I encourage you all to engage fully, make new connections and explore new avenues of research. I am certain that the knowledge and experiences you gain here will benefit your endeavours and the wider scientific community. I look forward to the exchange of ideas and the collaborations that will undoubtedly emerge from this gathering. Together, we can make a positive impact on our world through the power of science.

Thank you for being part of the Indian Geophysical Union and for your unwavering commitment to the pursuit of knowledge. Wishing you a successful and enriching convention.

Sincerely,

Dr. M. Ravichandran
President
Indian Geophysical Union (IGU

Office:	Phone:	Grams:	Fax:	E-mail:
Secretary	040-27012810	Geophysics	040-27171564	igu123@gmail.com

CONVENOR MESSAGE

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INDIAN INSTITUTE OF GEOMAGNETISM
(AN AUTONOMOUS BODY UNDER THE DEPT. OF SCIENCE & TECHNOLOGY, GOVT. OF INDIA)
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प्रो. ए. पी. डिमरी
निदेशक
PROF. A.P. DIMRI, FASc, FNA, FNASc
DIRECTOR



It gives me immense pleasure to welcome all delegates, distinguished scientists, academicians, researchers, industry professionals, and students to the 63rd Annual Convention of the Indian Geophysical Union (IGU), to be held at Indian Institute of Technology Bombay (IITB) from 2nd to 4th November 2026. Jointly organized by IIT Bombay and Indian Institute of Geomagnetism (IIG), the convention aims to bring together the geoscience community to exchange ideas, share recent scientific advances, and foster collaborations across diverse disciplines of Earth and Planetary Sciences.

The central theme of this year's convention, "Advances in Geophysics from Geodynamics to Metallogeny, and Green Energy Transition," reflects the expanding role of geosciences in understanding Earth's dynamic processes, exploring mineral resources, addressing environmental challenges, and supporting the transition towards sustainable and clean energy. The scientific programme encompasses four broad themes, including the main theme, Solid Earth Geosciences, Marine Geosciences, and Atmospheric, Planetary & Space Sciences. These themes will provide a platform for discussing emerging scientific frontiers, innovative methodologies, and interdisciplinary approaches to contemporary geoscientific challenges. A special scientific session jointly organized by IIG and Space Physics Laboratory (SPL), Indian Space Research Organisation, will further enrich the programme by bringing together researchers working in complementary areas of geophysical and space sciences.

Recognizing the importance of nurturing young talent, a pre-conference workshop on 31 October and 1 November 2026 is being organized for postgraduate and PhD students in Geophysics, Geology, Physics and Earth Science. The workshop is envisaged as an opportunity for early-career researchers and students to strengthen their scientific foundations, gain exposure to emerging techniques, analytical methods, and data-driven approaches in geosciences and interact with experts from academia and research institutions.

Indian Institute of Geomagnetism (IIG), an autonomous research institution under the Department of Science and Technology, Government of India, is a premier centre dedicated to research in Geomagnetism and allied areas of Earth and space sciences. IIG has a rich legacy of over 180 years in the observations and applied research in Geomagnetism towards unraveling the processes that operate and specialize in the Earth's near-space environment and the interior of the Earth. Through its contributions to fundamental research, advanced observations, scientific instrumentation, and human resource development, IIG continues to advance our understanding of the Earth and its space environment. Recently, IIG has launched an integrated MS(R)–PhD programme in Physics (Space Physics), offering students a unique opportunity to explore the fundamental processes governing space, planetary, and astrophysical environments. Its collaboration with IIT Bombay in organizing this convention reflects a shared commitment to scientific excellence, interdisciplinary research, and the development of future generations of geoscientists.

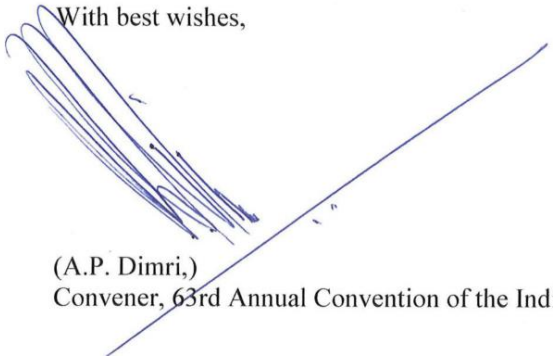
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Magnetic Observatories : Alibag, Gulmarg, Jaipur, Nagpur, Puducherry, Sri Vijaya Puram, Rajkot, Silchar, Visakhapatnam, Mussoorie, Hanle
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I warmly invite you to participate in this convention and contribute to the scientific discussions, exchange of ideas, and collaborative opportunities it will offer. I am confident that the 63rd Annual Convention of IGU will be an enriching and memorable experience for all participants, strengthening our collective efforts to advance geophysical research and address the scientific and societal challenges of our time.

I wish the 63rd Annual Convention of IGU great success and a highly productive outcome. I hope all participants have an enriching experience and enjoy their stay in Mumbai.

With best wishes,



(A.P. Dimri,)
Convener, 63rd Annual Convention of the Indian Geophysical Union

CONVENOR MESSAGE



It gives me immense pleasure to welcome all delegates to the 63rd Annual Convention of the Indian Geophysical Union (IGU), being held during 2–4 November 2026 at IIT Bombay, Mumbai. The convention provides an excellent platform for sharing scientific knowledge and recent advances in geophysics. The theme, *"Advances in Geophysics: From Geodynamics to Metallogeny and Green Energy Transition,"* highlights the growing significance of geophysical research in addressing scientific and societal challenges. I am confident that the technical sessions, invited lectures, and poster presentations will encourage meaningful discussions and collaborations. I sincerely thank IIT Bombay, the collaborating institutions, the IGU Executive Committee, and all sponsors for their valuable support. I also appreciate the contributions of the conveners, reviewers, and organizing team. My special thanks go to all researchers and students for their active participation. I wish the convention great success and all delegates a fruitful and memorable experience.

M.S BR.

Prof. M. Radhakrishna
Convener
63rd Annual Convention of IGU
IITB, Mumbai

PREFACE

The Indian Geophysical Union (IGU), established in 1963, was founded with the blessings and guidance of eminent scientists such as Prof. K. R. Ramanathan, Prof. S. Bhagavantham, Prof. M. S. Krishnan, and Dr. S. Balakrishna. Since its inception, IGU has played a significant role in promoting geophysical research, fostering scientific collaboration, and providing a common platform for the exchange of knowledge and ideas among researchers and professionals in the Earth sciences. The Annual Convention is one of the Union's major scientific activities, bringing together experts from diverse disciplines to share recent advances, discuss emerging challenges, and explore new opportunities for collaborative research.

This year, IGU is pleased to organize its 63rd Annual Convention from 2–4 November 2026, in collaboration with the Department of Earth Sciences, Indian Institute of Technology Bombay (IIT Bombay), Mumbai, and the Indian Institute of Geomagnetism (IIG). In conjunction with the Annual Convention, a two-day workshop will be conducted on 31 October and 1 November 2026, in collaboration with CSIR–National Geophysical Research Institute (CSIR-NGRI), IIG, and IIT Bombay. The workshop aims to familiarise postgraduate students with recent developments, emerging technologies, and current trends in geosciences.

The theme of this year's convention, "Advances in Geophysics: From Geodynamics to Metallogeny and Green Energy Transition," is both timely and relevant. Geophysics plays a vital role in understanding the dynamic processes of the Earth, exploring mineral and energy resources, assessing natural hazards, and supporting sustainable development. The scientific deliberations during the convention are expected to encourage innovative approaches, promote interdisciplinary research, and highlight the application of geophysical knowledge to address important societal and environmental challenges.

We are delighted to note the enthusiastic participation of scientists, faculty members, research scholars, and students from various institutions and organizations. Their contributions through oral presentations, poster sessions, and scientific discussions will enrich the convention and strengthen professional interactions within the geophysical community.

The three-day convention will feature keynote lectures, invited talks, award lectures, and technical sessions covering a wide range of topics in Earth sciences and geophysics. More

than 280 research papers are expected to be presented, with over 320 delegates anticipated to participate. The convention will provide valuable opportunities for interaction among eminent scientists, young researchers, and students, thereby fostering the exchange of ideas and the development of future research collaborations. On behalf of IGU, we encourage the authors to submit full-length manuscripts based on their presentations for consideration for publication in the *Journal of Indian Geophysical Union* (JIGU), subject to its established editorial policies and rigorous peer-review process.

We express my sincere gratitude to the President and the Executive Committee of IGU for their continued guidance and support. We also convey my appreciation to the host institutions, IIT Bombay and the Indian Institute of Geomagnetism, Mumbai, along with all the organizing committees, conveners, reviewers, sponsors, and volunteers for their valuable contributions and dedicated efforts in organizing this convention.

We are particularly grateful to the Secretary, Ministry of Earth Sciences (MoES), and the Directors of CSIR-NGRI, NCPOR, IITM, NCESS, INCOIS, and CSIR-NEIST, IIG, IITB, who have extended financial, scientific, and organizational support to the convention. Their encouragement and cooperation have been instrumental in facilitating this important scientific gathering. We are equally thankful to all the participating delegates for their valuable contributions and enthusiastic involvement.

We sincerely hope that the 63rd Annual Convention of IGU will provide a stimulating scientific environment, promote fruitful collaborations, inspire young researchers, and contribute meaningfully to the advancement of geophysical sciences in India and beyond.

Dr. Abhey Ram Bansal
Hon. Secretary, IGU

Dr.A.S.S.S.R.S. Prasad
Org. Secretary, IGU

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ORAL

ADVANCES IN GEOPHYSICS FROM GEODYNAMICS TO METALLOGENY, AND GREEN ENERGY TRANSITION

DOUBLE HYBRID OPTIMIZATION BASED SEISMIC INVERSION FOR CO_2 MONITORING: A COMPARATIVE STUDY OF GENETIC ALGORITHM AND SIMULATED ANNEALING METHODS AT THE SLEIPNER FIELD

S.P. Maurya[1],*, Raghav Singh[1], and K.H. Singh[2]
1Department of Geophysics, Institute of Science, Banaras Hindu University, Varanasi-221005, U.P., India
2Department of Earth Sciences, IIT Bombay, Mumbai-400076, Maharashtra, India
*mauryasatya@bhu.ac.in

ABSTRACT

Increasing $CO2$ concentrations in the environment is one of the biggest challenges facing the world. One of the commercial-scale solutions for reducing this concentration in the environment is carbon capture, utilization and sequestration (CCUS). However, this technology requires substantial scientific understanding. The technology involves capturing $CO2$ from the environment and injecting it into a geological formation. After injection, the $CO2$ must be monitored periodically to determine its location as certain geological processes may cause it to leak back into the environment. This would result in a loss of time and money, most importantly, could harm the surrounding population. The present study proposes a new technology to monitor the injected $CO2$ using seismic inversion based on double hybrid optimization techniques. There are many inversion algorithm available, but double hybrid optimization-based inversion is relatively new in the field of $CO2$ monitoring and have the capacity to provide very detailed, high-resolution information. The objective of this study is to compare double hybrid optimization methods based on the genetic algorithm (GA) and simulated annealing (SA) for $CO2$ monitoring. The analysis was performed in two steps. First, the methods were applied at the well locations to optimize the parameters. Second, they were used to invert the entire seismic volume. The results at well locations showed very good agreement with the well log data for both methods, with SA performing slightly better than GA. Analysis of the entire seismic datasets using both methods showed that the injected $CO2$ remains at its location. The statistical analysis revealed that the results obtained using SA-based inversion had higher resolution and required less computational time as compared with GA-based inversion methods. The study is very helpful for estimating the $CO2$ plume at very high resolution using both methods (GA & SA) although SA produced slightly better results and require less convergence time than GA.

Keywords: Seismic inversion, simulated annealing, genetic algorithm, optimization, hybrid optimization, CCUS, $CO2$ plume

WHAT DYKE GEOMETRY REVEALS ABOUT MAGMA OVERPRESSURE AND SOURCE DEPTH: FROM MODE-I TO MIXED MODE I-III EMPLACEMENT

Tridib Kumar Mondal[1*], Anubhab Dey[1], Sirshendu Kumar Biswas[2]
[1]Geological Studies Unit, Indian Statistical Institute, Kolkata, India, tridibkumarmondal@gmail.com, anubhab.kv@gmail.com
[2]Earth and Planetary Systems Science Program, Graduate School of Advanced Science and Engineering, Hiroshima University, Japan, biswassirshendu@hiroshima-u.ac.jp
*Presenting Author: tridibkumarmondal@gmail.com

ABSTRACT

Magma overpressure influences many volcanic hazard parameters, including eruption probability and the likelihood of large landslides or caldera collapse. Dykes provide a key means to estimate magmatic

overpressure and emplacement depth. Under the canonical Mode-I fracture model, dyke opening is predicted to be elliptical. Its aspect ratio can further be used to estimate magma overpressure and depth of origin. However, partial exposures, as commonly encountered in nature, hinder reconstruction of complete dyke dimensions.

We present two geometric approaches to reconstruct dyke dimensions from partial exposures. For exposures with at least one visible tip, coordinate points are designated along the exposed dyke margin, and ellipses are generated through all possible pairs of these ground points, with the exposed tip as the origin of the coordinate system; complete dimensions are derived from the mean length and width of the resulting ellipses. For exposures lacking either tip, we solve the differential equations of the ellipse with its discrete derivative representatives to determine the total length, maximum thickness, and thereby the aspect ratio from limited outcrop measurements.

We validated both the approaches using completely exposed felsic dykes from the CGGC, India, and published dyke data from Miyake-jima volcano, Japan, and applied them to partially exposed mafic dykes intruding the younger granites of the Dharwar Cratons, India. We further extend the single-tipped approach to mixed Mode I-III dykes, whose en-échelon geometries, with characteristic horn development resulting from imposed shear during emplacement, depart from ideal elliptical opening. We recognize the relict ellipticity of the primary Mode-I opening is preserved within the subsequent mixed-mode geometry. Tests using natural examples and numerically simulated cracks show the potential to reconstruct the original geometry from single-tipped mixed Mode I-III exposures.

STRUCTURAL CONTROLS ON MINERAL ENDOWMENT ZONE IN EAST DHARWAR CRATON, INDIA: INSIGHTS FROM AN INTEGRATED ANALYSIS OF GEOLOGICAL, SATELLITE, AND GEOPHYSICAL DATA

T.R.K. Chetty[1✹], B. Ravi Kumar[2], J.V. Rama Rao[3]
[1.] Formerly, CSIR-National Geophysical Research Institute, Hyderabad.
[2.] Geological Survey of India, Shillong
[3.] Formerly Geological Survey of India, Hyderabad
✹trkchetty@gmail.com

ABSTRACT

The spatial distribution of Earth's mineral deposits ranging from craton-scale to camp scale is fundamentally governed by lithospheric scale processes. The deep-seated, transcrustal structures provide pathways for the transport and emplacement of mineralizing fluids and magmas. The East Dharwar Craton (EDC), characterized by a thick cratonic root and a relatively deep lithosphere–asthenosphere boundary (LAB), provides a favourable setting for the development of diverse mineral systems. Large strike-slip faults and associated restraining bends are widespread crustal features that produce localized zones of transpression, crustal shortening, uplift, and basement exhumation. They significantly favour the formation of mineral endowment zones. However, recognizing such structural features within deeply eroded Archean terrains remains challenging.

We present an integrated geological, satellite remote-sensing, gravity, and aeromagnetic investigation of a major structural domain in the EDC. For the first time, we identify a WNW–ESE trending transcontinental strike-slip fault that extends across the South Indian Shield, transecting the Archean

fabric of the Dharwar craton and the Proterozoic Cuddapah Basin. This structure runs through Sangli-Gooty- Cuddapah and is designated as SGCF master fault. A second, relatively short, subparallel and overlapping fault in the north extends through Gogi–Atmakur–Somasila. These two distinct faults are interconnected by NE–SW-trending transfer faults, represented by Krishna River Fault in the west and Veldurthi–Kalva–Gani Fault in the east, together defining a rhombohedral shaped mega-restraining bend termed here as the Krishna Restraining Bend (KRB).

The KRB encompasses diverse lithological assemblages, including gneisses, greenstone sequences, calc-alkaline to potassic granitoid plutons (2560–2520 Ma), and Paleo- to Mesoproterozoic mafic dyke swarms. Significantly, the KRB hosts a diverse suite of mineral deposits, including Gadag and Jonnagiri gold deposits, Machanur copper deposit, four kimberlite clusters, lithium-bearing pegmatites, and other Fe–Cu–Au occurrences. Satellite imagery, terrestrial gravity, and aeromagnetic datasets are integrated to delineate the crustal architecture, structural displacements, topographic expressions, and evidence for multiple phases of tectonic reactivation in and around the KRB.

The geophysical results reveal and substantiate a deep-rooted trans-crustal fault system and associated igneous intrusions that may have acted as conduits for the migration of mineralizing fluids and magmas. Mid-crustal gravity lows associated with magnetic highs are interpreted as potential signatures of concealed intrusive bodies and/or mineralizing systems. Quantitative source-parameter estimates derived from aeromagnetic anomalies, together with regional gravity modelling, provide constraints on the depth and geometry of the identified mineralized domains.

The proposed KRB provides an innovative concept with a new structural framework for understanding the localization of mineral deposits, regional epeirogenic uplift, and deep magmatic–hydrothermal processes beneath the Dharwar Craton. The recognition of a trans-crustal strike-slip fault and associated mega- restraining bend architecture together with the involvement of deep magmatic–hydrothermal pathways have significant implications for predictive regional mineral exploration and for understanding the tectonic and metallogenic evolution of the East Dharwar Craton.

SOLID EARTH GEOSCIENCES

METAHEURISTIC OPTIMIZATION-BASED 4D SEISMIC INVERSION FOR CO_2 PLUME DELINEATION

Ajay Pratap Singh[1], S. P. Maurya[1], and M. K. Srivastava[1]
[1]Department of Geophysics, Institute of Science, Banaras Hindu University, Varanasi-221005, Uttar Pradesh, India
Presenting author: ajaygeop21@bhu.ac.in

ABSTRACT

Climate change is one of the global problems and one reason behind this is increase concentration of CO_2 in the environment. There are many technologies are grown in recent times to reduce this CO_2 concentration from the environment and on such technology is carbon capture and storage (CCS). Although, the success of CCS depends on the ability to reliably track the injected CO_2 within the subsurface geological layer hence continuous monitoring of CO_2 behavior in reservoirs is therefore essential. The monitoring is used to verify containment, assess storage performance, and ensure the long-term safety of CCS operations. This study presents a comparative approach to monitor CO_2 plume injected in geological formation using two metaheuristic optimization techniques namely particle swarm optimization (PSO) and harmony search (HS). These methods are new in the field of CO_2 monitoring and have capability to provide high resolution subsurface information. These methods are used to invert time-lapse seismic data into subsurface acoustic impedance from both baseline (before injection) and monitor data (after injection) acquired in 1994 and 2010, respectively. Both methods were first, applied at the well-locations across two time periods (1994 & 2010) and the results indicate that both optimization algorithms achieve good results with very high correlation. The PSO method yielded average correlation coefficients of 0.83 and 0.85 for the 1994 (baseline) and 2010 datasets, respectively, while the HS method produced average correlation coefficients of 0.81 and 0.82 for 1994 and 2010 datasets, respectively showing consistent improvement in correlation from baseline to monitoring stage for both methods. However, when extended these algorithms to across the 3D volume in second phase, clear differences can be noticed between the two techniques as PSO successfully delineates a low-impedance layer corresponding to the zone of CO_2 injection, whereas HS fails to resolve this low-impedance anomaly at the injection zone. The statistical analysis shows that while both methods work well at well locations, the PSO is better at mapping the spread of CO_2 across the full 3D area away from the wells. These results suggest that PSO is a more reliable tool for tracking the CO_2 plume during CCS monitoring project.

DEEP CRUSTAL 3D VELOCITY STRUCTURE BENEATH THE 2001 BHUJ EARTHQUAKE EPICENTRAL REGION OF KACHCHH, WESTERN INDIA: INSIGHTS FROM LOCAL EARTHQUAKE TOMOGRAPHY

Alle Shiva Kumar[1,2], Rema Vaishali[1], Ashok Maripireddi[1], Madhusudhana Rao Katlamudi[1*], Udaya Laxmi Gakka[2]
1. Institute of seismological research, Gandhinagar, Gujarat.
2. Department of Geophysics, Osmania University, Hyderabad, Telangana.
* Presenting author (alleshivakumar5@gmail.com)

ABSTRACT

Tomographic inversion resolves three-dimensional and depth-dependent variations in Vp, Vs, and Vp/Vs, providing valuable insights into crustal heterogeneity and its relationship with geodynamic processes and earthquake nucleation. Kachchh is a structurally complex intraplate region characterized by pre-existing fault systems and persistent seismic activity. In this study, we performed local

earthquake tomography using 4,378 earthquakes recorded by a 50-station broadband seismic array deployed across the epicentral region of the 2001 Bhuj earthquake. The dataset comprises 94,460 P-wave and 96,621 S-wave arrival times, enabling detailed imaging of the subsurface velocity structure. The tomographic results reveal distinct depth-dependent velocity anomalies that are spatially associated with major pre-existing fault systems across Kachchh. In the upper crust, the Kachchh Mainland region, encompassing the Kachchh Mainland Fault (KMF) and Katrol Hill Fault (KHF), is characterized by low Vp and low Vp/Vs, accompanied by relatively high Vs. These velocity characteristics may indicate fractured and fluid-influenced crustal zones and suggest a relatively thin crustal section beneath this region. The Samakhiali Graben exhibits pronounced mechanical heterogeneity, where fluid-assisted crustal weakening and a mafic-rich lower crust may contribute to localized stress accumulation and deformation. In the mid-crust, the Wagad region is characterized by relatively high Vp and Vs and low Vp/Vs, which may reflect the presence of intrusive bodies, potentially including gabbroic intrusions associated with magmatic emplacement. In contrast, the lower crust beneath much of the study area is characterized by elevated Vp/Vs and reduced Vs, a velocity signature that is consistent with the presence of partial melts and/or magmatic underplating. This interpretation is further supported by the regional occurrence of high heat flow, elevated electrical conductivity, and a pronounced reduction in intra-crustal S-wave velocity. The contrasting velocity signatures observed at different crustal depths highlight the complex interplay among pre-existing crustal heterogeneity, fluid and partial-melt migration along major fault systems, and magmatic underplating. These processes may contribute to variations in crustal strength and stress localization, potentially influencing the reactivation of pre-existing faults and the spatial distribution of present-day seismicity across the Kachchh region.

Keywords: Local earthquake tomography, partial melts, Fluid filled microcracks, Magmatic underplating

INTEGRATED GRAVITY–MAGNETIC–THERMAL ASSESSMENT OF THE SOUTHERN BUNDELKHAND CRATON–CENTRAL INDIAN TECTONIC ZONE TRANSITION, CENTRAL INDIA

Ananya Parthapradip Mukherjee* and Animesh Mandal
Department of Earth Sciences, Indian Institute of Technology Kanpur
*Presenting author: ananyam@iitk.ac.in

ABSTRACT

The transition between the southern margin of Bundelkhand Craton (BnC) and the Central Indian Tectonic Zone (CITZ) records a complex history of Proterozoic rifting, crustal modification, and subsequent fault reactivation along the Narmada–Son tectonic corridor. Despite extensive seismic, magnetotelluric, gravity and thermal studies across parts of the CITZ and the Son–Narmada Lineament, the crustal-scale structural linkage among the southern BnC, the North and South Son–Narmada faults (SNNF and SNSF), and the northern CITZ remains poorly constrained. This study integrates regional gravity and magnetic data interpretations along with 3D Moho depth inversion, Curie Point Depth (CPD) analysis, and 2D gravity forward modelling along the Hirapur–Mandla profile to investigate the crustal architecture and tectono-thermal characteristics of this transition zone. The complete Bouguer anomaly reveals alternating gravity highs and lows across the southern and southeastern sectors, broadly parallel to E–W to ENE–WSW-trending structural corridors associated with the SNNF and

SNSF. The reduced-to-equator anomaly further delineates the sharp magnetic gradients and contrasting crustal magnetic domains across the fault-controlled transition zone. The 3D Moho depth model indicates substantial crustal thickness variations, with depths ranging from 30.8 to 42.9 km and relatively deeper Moho beneath the southern and southeastern sectors. CPD estimates range from 23.9 to 31.4 km, and corresponding estimated conductive heat flow varies from 66.3 to 93.1 mW m^{-2}. Shallow CPD values of about 24–27 km spatially coincide with alternating gravity highs and lows over regions of relatively deep Moho, suggesting a thermally perturbed magnetized crust of heterogeneous thickness. The 2D gravity model across the Hirapur–Mandla profile reveals lateral density variations, comprising Bundelkhand-related basement and upper crust in the north, crystalline basement south of the structural corridor, and a relatively dense lower-crustal component. The lower-crustal body is interpreted as modified mafic lower crust, potentially representing magmatic underplating. Collectively, the results refine the crustal-scale geometry of the BnC–CITZ boundary and indicate that the previously recognized zone of magmatic underplating beneath the southern BnC may extend further south towards the CITZ.

CRUSTAL STRUCTURE VARIATION ACROSS THE SRI LANKA THROUGH TELESEISMIC RECEIVER FUNCTION ANALYSIS

Anu Priya Dahal* and Nagaraju Kanna
Department of Earth Sciences, Pondicherry University, Puducherry, India-605014
*****presenting author's E-mail: officeanu1998@pondiuni.ac.in

ABSTRACT

In the present study, we investigated crustal structure of Sri Lanka using teleseismic earthquake data recorded over a temporary network of 29 broadband seismic stations deployed across the island during 2016-2017. The receiver function (RF) analysis technique was carried out along two seismic profiles. One extends from south-eastern to western part of Sri Lanka, whereas another trends from south-eastern to northern, transecting all three major lithotectonic units: The Wanni Complex (WC), Highland Complex (HC), and Vijayan Complex (VC).

We applied Common Conversion Point (CCP) and Slant stacking (H-K stacking) to provide seismic crustal structure (crustal thickness and composition) using RF waveforms. The results reveal significant variation in crustal thickness and composition, ranging from ~30 to 40 km and Vp/Vs ratio varies between 1.584 to 1.838 throughout the study area. A thickened crust (~39 to 40 km) is found in the central part of the HC with high elevation and low Vp/Vs ratio (1.638-1.688) which suggests a felsic crustal composition. A thin crust (30-36 km) is observed beneath the western part of WC and interpreted to reflect crustal thinning associated with extensional tectonics during the development of the Mannar basin. The CCP image shows a high positive prominent intra-crustal layer gently dipping from central HC to VC in the depth range of 12-20 km, indicating thrusting of HC towards the VC. The high crustal thickness (~37 to 39 km) with high Vp/Vs ratio (1.740 – 1.828) in the VC reveals more heterogeneous crust. We observe that higher crustal thickness (36 - 39 km) with low Vp/Vs ratio (1.722-1.774) in the northern part of Sri Lanka whereas in the southern a thinner crust (34-36 km) with high Vp/Vs ratio (1.800-1.836). Spatial variations in Vp/Vs ratios further suggest significant compositional heterogeneity and variable metamorphic conditions within the Sri Lankan crust.

Keywords: Receiver function; CCP stacking; H-K stacking; Sri Lanka; crustal structure

UNDERSTANDING CRUSTAL STRUCTURE BENEATH WESTERN TIBET FROM AMBIENT NOISE SURFACE WAVE TOMOGRAPHY

Arjun, Niptika jana, Anubhabh Sen
Department of Applied Geophysics,IIT ISM Dhanbad,IISER Pune
Presenting author: 23dr0227@iitism.ac.in

ABSTRACT

The western Tibetan Plateau, where the Karakoram Fault (KKF), Indus–Yarlung Suture (IYS) and Bangong–Nujiang Suture (BNS) converge across the Himalaya, Lhasa and Qiangtang terranes, is collisionally distinct from central and eastern Tibet yet less well resolved. We image the upper and middle crust using four years (2007-2011) of continuous broadband recordings from the 31- station Y2 array, at station spacings of 40-100 km. Vertical and horizontal-component records were cross-correlated following temporal normalization and spectral whitening, and empirical Rayleigh and Love-wave Green's functions were inverted for frequency-dependent group velocity dispersion. Group velocity maps at 3, 5, 8, 12, 18 and 24 s were obtained by Ambient Noise Surface-Wave Tomography (ANSWT) and inverted for shear velocity to 30 km, jointly for isotropic Vs and independently for Vsv and Vsh.

Rayleigh group velocity reverses between 12 and 18 s and Love between 18 and 24 s, an offset consistent with the shallower depth sensitivity of Love waves; the two independently place the top of a mid-crustal low-velocity zone at 15-20 km. Above this depth the velocity field follows mapped lithology; below it the strongest low-velocity anomaly underlies the Cenozoic volcanic belt of the southern Lhasa terrane, with a second in the BNS corridor and southernmost Qiangtang terrane. No anomaly boundary follows the surface trace of the KKF, BNS or IYS at any imaged period or depth.

The Love-Rayleigh difference widens with sampling depth from 0.08 to 0.40 km s^{-1}, so no single isotropic model satisfies both datasets. Radial anisotropy $\xi = (Vsh/Vsv)^2$ exceeds unity over most of the array at 2-5 km and reaches 1.65 at 10 km beneath the southern Lhasa terrane, coincident with the strongest low-velocity anomaly, falling to 0.70 on the western margin. We interpret a weak, melt or fluid-bearing middle crust carrying a sub-horizontal fabric.

UPSCALING HYDROCHEMICAL HETEROGENEITY FOR REGIONAL RECHARGE DECISION SUPPORT: AN INTEGRATED MACHINE LEARNING–MAR FRAMEWORK FOR FRACTURED CRYSTALLINE AQUIFERS

Prashant Kumar[1], Sayandeep Banerjee[2], Arkoprovo Biswas[1*]
[1]Geological Studies Unit, Physics and Earth Science Division, Indian Statistical Institute (ISI), Kolkata-700108, India; [2]Department of Geology, Institute of Science, Banaras Hindu University, Varanasi, 221005, U.P., India
Presenting author: arkoprovo@gmail.com

ABSTRACT

The evolution of groundwater and recharge dynamics in fractured crystalline aquifers is difficult to understand because of the interplay among geogenic processes, structural heterogeneity, and anthropogenic pressures. This study develops an integrated hydroinformatics framework comprising Self-Organizing Maps (SOM), multivariate statistics, geochemical modeling, groundwater-level fluctuation (WLF) analysis, and Managed Aquifer Recharge (MAR) assessment to explore groundwater systems in the semi-arid Chotanagpur Granite Gneiss Complex (CGGC), eastern India.

Beyond traditional point-based assessment, we analyzed a multi-dimensional dataset of eighteen hydrochemical parameters, recharge-control variables, and seasonal groundwater fluctuations for structured hydrochemical facies modeling and quality-quantity integrated decision support. The optimized SOM deconvoluted groundwater chemistry into three consistent facies: Fresh (54.5%), Transitional (34.7%), and Impacted groundwater (10.8%). The SOM-based facies framework, ionic ratios, Gibbs diagrams, Chloro-Alkaline Indices, SOM-based Pearson correlations, Principal Component Analysis (PCA), and Hierarchical Cluster Analysis (HCA) indicated that silicate weathering, mineral dissolution, and ion-exchange processes are the dominant processes controlling groundwater evolution, while high concentrations of NO3−, Na+, and Cl− ions characterize localized anthropogenic impacts. In addition, integrating SOM classification with PHREEQC thermodynamic modeling, hydrochemical indices, and Piper facies provides a process-based framework to quantify mineral saturation, dominant hydrogeochemical reactions, and the progressive evolution of groundwater chemistry in the identified facies. The SOM field transformation reduced localized analytical noise while preserving regional hydrochemical signatures, and RF outperformed Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) in capturing localized non-linear hydrochemical variability. The coupled SOM-MAR-WLF decision-support maps derived from SOM-based facies integration with MAR suitability and WLF identified priority recharge zones with favorable groundwater quality, high recharge potential, and recharge-responsive aquifer conditions. The proposed framework offers a transferable and explainable approach to climate-resilient groundwater management and strategic MAR planning in fractured hard-rock aquifers globally.

Keywords: Self-Organizing Maps; Hydrochemical facies; Managed Aquifer Recharge; Groundwater decision support; Geochemical Modeling; Fractured crystalline aquifers.

SEISMICITY CHARACTERIZATION AND STOCHASTIC GROUND-MOTION SIMULATION OF A HYPOTHETICAL M_W 7.4 EARTHQUAKE IN THE CENTRAL HIMALAYAN SEISMIC GAP

Arpita Biswas[1*], Nitin Sharma[1], Prakash Kumar[1]
[1] CSIR-National Geophysical Research Institute, Hyderabad, Telangana-500007, India
[*]Presenting author: arpitabiswas0312@gmail.com

ABSTRACT

The Central Seismic Gap (CSG), located between the rupture zones of the 2005 Muzaffarabad and 2015 Gorkha earthquakes, represents a critical segment of the Himalayan arc with significant potential for future large earthquakes. This study integrates catalogue-based seismicity analysis, probabilistic magnitude estimation, and stochastic finite-fault ground-motion simulation to assess the seismic hazard associated with a potential major earthquake in the CSG. A homogeneous and declustered earthquake catalogue spanning 1505-2026 has been compiled from multiple national and international sources. The magnitude of completeness has been estimated using the maximum curvature method, while Gutenberg-Richter parameters have been determined using the maximum likelihood approach. For the entire CSG, the estimated *b*-value, *a*-value, and minimum magnitude of completeness (M_C) are 1.01±0.03, 7.503, and 4.5, respectively, with spatial variations of 0.37-1.26, 3.48-7.85, and 2.9-4.8. Distinct low-*b*-value anomalies within the Garhwal-Kumaun sector indicate localized stress

concentration and possible asperity development. The region has further been subdivided into three seismotectonic zones: Zone 1 (Kashmir-Kangra), Zone 2 (Central Garhwal-Chamoli-Uttarkashi), and Zone 3 (Eastern Uttarakhand-Western Nepal). The Kijko method yielded maximum-magnitude estimates of 7.91±0.32, 8.06±0.34, and 8.65±0.01 for Zones 1, 2, and 3, respectively, compared with 9.18±1.07 for the entire region. Probabilistic analysis indicates a most probable maximum magnitude of M_W ~7.4 within 50 years, consistent with the estimated M_W ~7.4 at 10% probability of exceedance over the same period. Considering the prominent low-*b*-value anomaly in the Chamoli region, the 1999 Chamoli earthquake has first been simulated using a stochastic finite-fault model to constrain source, path, and site parameters against available observations. These calibrated parameters have subsequently been used to synthesize a hypothetical M_W 7.4 scenario earthquake at the Chamoli source. Ground motions have been estimated using topographic-gradient-based site class-dependent amplification factors at 1°×1° grid spacing. The resulting PGA distribution identifies the towns of Chamoli and Gopeshwar as particularly vulnerable, with PGA exceeding ~0.4 g. The integrated results provide important constraints for seismic hazard assessment, preparedness, and risk mitigation in the north-central Himalaya.

Keywords: Central Seismic Gap, Himalaya, Seismicity, b-value, EXSIM, Ground Motion Simulation, Seismic Hazard.

NATIONAL WATER SECURITY THROUGH WATERSHED CHARACTERIZATION AND MANAGEMENT: A CASE STUDY OF KJ WATERSHED, NORTH INDIA

Dr. B. S. Chaudhary
Senior Professor & Chairman
Department of Geophysics, Kurukshetra University, Kurukshetra -136119
Email: bschaudhary@kuk.ac.in

ABSTRACT

India receives an average annual precipitation of approximately 117 cm, corresponding to an estimated per-capita freshwater availability of about 1,720 m³. However, the highly heterogeneous spatial and temporal distribution of precipitation poses major challenges for equitable water availability and necessitates scientifically informed strategies for water conservation, augmentation, and efficient utilization. At present, only about 12% of the country's annual precipitation is reported to be effectively utilized, highlighting substantial scope for improving water-resource management through integrated and technology-driven approaches to ensure national water security.

The state of Haryana encompasses drainage systems associated with the Yamuna, Ghaggar, and internal drainage basins, which form parts of the broader Ganga and Indus river systems. The contrasting regional slopes of northern and southern Haryana converge towards a broad latitudinal depression extending approximately along the Sirsa–Fatehabad–Hisar–Jind–Rohtak–Delhi axis. This characteristic, saucer-shaped physiography exerts a strong control on the regional hydrological regime and creates contrasting land- and water-resource management challenges. The central part of the state is particularly susceptible to flooding, waterlogging, and secondary salinization, whereas areas with relatively fresh groundwater in northern and southern Haryana are experiencing a progressive decline in groundwater levels due to increasing extraction and demand.

In this context, GeoAI, representing the synergistic integration of geospatial technologies, remote sensing, GIS, and Artificial Intelligence (AI), provides a powerful framework for spatially explicit assessment, modelling, and sustainable management of land and water resources. Since the early 1990s, watershed-based planning has increasingly been advocated for natural-resource assessment and management because administrative boundaries often fail to correspond with natural hydrological processes. A watershed represents a relatively well-defined natural hydrological unit, thereby enabling the integrated assessment of surface-water and groundwater systems, land-use dynamics, drainage characteristics, terrain attributes, and resource-development interventions. Consequently, watershed-based planning has gained widespread acceptance as an effective approach for holistic and sustainable management of land and water resources.

The Koshalya–Jhajhara (K–J) River Watershed, located in northern India and extending across Panchkula district of Haryana and Solan district of Himachal Pradesh, was selected as a representative study area. The watershed covers approximately 134.92 km². Multi-source geospatial datasets, including satellite imagery, ASTER Digital Elevation Model (DEM), Survey of India (SOI) topographic maps, and ancillary thematic information, were integrated to generate key spatial datasets encompassing land use/land cover (LULC), geology, geomorphology, drainage density, slope, and other relevant terrain and environmental parameters. Temporal analysis of LULC between 1999–2000 and 2015–16, representing an approximately fifteen-year interval, revealed substantial landscape transformation. The area under built-up land increased markedly from 7.12 km² to 24.84 km², indicating considerable urban and infrastructural expansion and its associated implications for water demand, runoff generation, and groundwater recharge. In contrast, the forest-covered area declined from 109.35 km² to 96.78 km², reflecting significant land-cover alteration within the watershed. These changes underscore the need to incorporate land-use transitions into long-term water-resource planning. A Groundwater Potential Zone (GPZ) map was subsequently developed through the integration of geology, geomorphology, drainage density, slope, and LULC using the Analytical Hierarchy Process (AHP). The resulting spatial assessment indicates that approximately 61.83 km² of the K–J watershed falls within the poor groundwater-potential category, while another 37.87 km² is classified as very poor in terms of groundwater availability. These findings demonstrate the limited groundwater potential over a substantial proportion of the watershed and emphasize the need for systematic groundwater conservation, artificial recharge, and demand-management interventions.

To complement the groundwater assessment, a Surface Water Resource Map was developed to identify potential locations for decentralized water-harvesting and recharge structures. The analysis identified 14 suitable sites for check dams and 15 potential sites for percolation tanks. Strategically implemented, such structures can enhance surface-water retention, facilitate groundwater recharge, moderate runoff, and improve local water availability, particularly during periods of seasonal water stress. The integrated analysis demonstrates that GeoAI-enabled watershed assessment can provide an effective decision-support framework for addressing the complex and interconnected challenges of land-use change, groundwater scarcity, surface-water management, and climate variability. In the K–J watershed, the combined interpretation of terrain, geology, geomorphology, drainage characteristics, LULC, groundwater potential, and surface-water resources provides a scientifically robust basis for prioritizing conservation and recharge interventions. Considering the emerging climate-change scenario, sustainable water management in the watershed should emphasize the conjunctive and integrated utilization of surface water and groundwater, enhancement of artificial recharge, protection and restoration of forested areas, regulation of groundwater

abstraction, adoption of water-efficient land-use practices, and systematic monitoring of hydro-environmental changes using geospatial and AI-based technologies. The proposed interventions provide a framework for science-based watershed planning, improved water security, and sustainable utilization of land and water resources, with potential applicability to other environmentally sensitive watersheds experiencing rapid land-use transformation and increasing water stress.

Key Words: National Water Security, GeoAI, Watershed conservation and management, Sustainable Resources Management, K-J Watershed, Haryana

COMMON REFLECTION SURFACE STACK IMAGING OF THE INDIAN SHIELD: A REVIEW OF DEEP CRUSTAL ARCHITECTURE FROM ARCHEAN TO MESOZOIC TERRAINS

Biswajit Mandal[*1,2], V. Vijaya Rao[1], P. Karuppannan[1], Kolli Laxminarayana[1,2], Prakash Kumar[1,2]
[1] CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500007, India
[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
*Corresponding author: Biswajit Mandal, Email: bisuman@gmail.com

ABSTRACT

Deep seismic reflection imaging is an important tool for understanding the structure and evolution of the continental crust. It helps identify deep geological boundaries, faults, crustal reflectors, and the crust–mantle boundary (Moho). However, imaging the deep crust using conventional Common Midpoint (CMP) processing is difficult in complex regions such as the Indian Shield that contains fold belts, paleo-rifts, folds, faults, and suture zones. The CMP processing depends strongly on a reliable velocity model, which is difficult to obtain where seismic velocities vary laterally and the crust is structurally heterogeneous. The problem is further increased by short source–receiver offsets relative to target depths and low data fold caused by acquisition and economic limitations. Conventional normal-moveout (NMO) correction may also become less effective for dipping, curved, and irregular interfaces, reducing the continuity and strength of deep reflections.

Common Reflection Surface (CRS) stacking provides an effective alternative to conventional CMP processing. CRS stack is independent of an explicit stacking-velocity model and uses three parameters that describe the direction and curvature of seismic reflection events. These parameters allow CRS stack to better image dipping and curved reflectors and reduce the need for separate dip-moveout (DMO) correction. By combining traces from a wider neighbourhood around each CMP, CRS stack increases coherent signal stacking, improves the signal-to-noise ratio, and enhances the continuity and visibility of weak deep reflections. These advantages make CRS stack particularly useful for low-fold, noisy, and structurally complex deep seismic datasets. Although widely used in hydrocarbon exploration, its application to deep crustal and tectonic studies remains comparatively limited.

This review synthesizes results from CRS-processed deep seismic reflection profiles across major geological regions of the Indian Shield, covering Archean cratons, Proterozoic fold belts, and sedimentary basins, including the Mesozoic Kachchh rift basin.

In the Dharwar Craton, CRS imaging reveals contrasting crustal architectures between the Western and Eastern Dharwar Cratons. The Western Dharwar Craton mainly shows gently dipping to nearly

horizontal reflectors, whereas the Eastern Dharwar Craton contains oppositely dipping reflections, a dipping Moho, and crustal-scale thrust structures, indicating Neoarchean convergence and accretion. Crustal thickness varies from about 38 km in the west to 36 km in the east. In the Aravalli–Delhi Fold Belt, CRS clearly images the Moho and major upper- and middle-crustal reflectors, including the deeper continuation of the Jahazpur thrust, with crustal thickness of about 38–50 km.

In the Vindhyan Basin, CRS imaging identifies up to ~7.5 km of sediments, volcanic units, a deep granitic basement, the Great Boundary Thrust, and a newly identified Chambal thrust. The crust is ~40–44 km thick, suggesting significant crustal modification and possible magmatic underplating. Across the Central Indian Suture, CRS reveals contrasting crustal blocks and prominent suture-related reflections. Beneath the Bastar Craton, deep imbricated reflections suggest northward-directed subduction, while the Southern Granulite Terrain records evidence of subduction, accretion, collision, and later extension.

In the Kachchh Basin, CRS imaging reveals a ~15-km-thick reflective lower crust, crustal-scale doming, 0.15–6.5 km of sediments, and crustal thickness of ~35–45 km, indicating rift-related modification and magmatism.

Overall, the results show that crustal architecture and thickness reflect not only crustal age but also a long history of subduction, collision, accretion, magmatism, rifting, and tectonic reworking. CRS provides a powerful approach for extracting coherent deep-crustal information from challenging seismic datasets and improving our understanding of Indian continental crustal evolution from the Archean to the Mesozoic.

Keywords: CRS Stack, Indian Shield, CMP Stack, Crustal Thickness

HYBRID METAHEURISTIC OPTIMIZATION FOR SEISMIC IMPEDANCE INVERSION USING PARTICLE SWARM AND ARTIFICIAL GORILLA TROOPS OPTIMIZATION

Brijesh Kumar[1], S. P. Maurya[2] and Ajay P. Singh[2]
[1]Airborne Geosciences International Private Limited
[2]Department of Geophysics, Banaras Hindu University
Presenting author: bkgeophysics09@gmail.com

ABSTRACT

Seismic impedance inversion is a nonlinear and non-unique inverse problem that plays an important role in quantitative reservoir characterization. Accurate estimation of subsurface impedance from seismic data is challenging because of limited bandwidth, noise, non-uniqueness, and the complex relationship between seismic responses and reservoir properties. This study presents a comparative hybrid optimization framework for seismic impedance inversion based on Particle Swarm Optimization combined with Quasi-Newton Method (PSO–QNM) and Artificial Gorilla Troops Optimization combined with Quasi-Newton Method (AGTO–QNM). In the proposed framework, PSO and AGTO are employed to perform global exploration of the model space, while the Quasi-Newton Method is subsequently incorporated as a local refinement strategy to improve convergence toward an optimized impedance solution. The inversion is formulated by minimizing an objective function based on the misfit between observed and synthetic seismic data, together with model regularization to obtain a

geologically plausible impedance model. The performance of the proposed hybrid approaches is evaluated using seismic data and compared with the corresponding standalone optimization algorithms. Their effectiveness is assessed using convergence behavior, correlation coefficient, seismic data misfit, and the agreement between inverted and well-log-derived impedance. The results demonstrate that incorporating QNM-based local refinement can improve the convergence and solution accuracy of both PSO and AGTO. The comparative analysis of PSO–QNM and AGTO–QNM provides insights into the effectiveness of combining global metaheuristic exploration with deterministic local optimization for seismic impedance inversion. The proposed hybrid frameworks offer robust and efficient approaches for high-resolution impedance estimation and improved subsurface reservoir characterization.

INTEGRATED STUDY TO CAPTURE THE CAP ROCK INTEGRITY AND CO_2 MIGRATION PATHWAYS IN CBM RESERVOIRS FOR CCUS FEASIBILITY

Debadrita Nag, Saurabh Datta Gupta
Department of Applied Geophysics, IIT (ISM) Dhanbad, India
25mt0141@iitism.ac.in

ABSTRACT

Gas-based energy exploration provides the scope of environment friendly resource. In view of potentiality of Indian sedimentary basin in CBM/ECBM, currently CBM exploration shows limited scope in production scenario. Carbon Capture Utilisation and Storage (CCUS) in Coal Bed Methane (CBM) reservoir has significant potential for reducing CO_2 emissions by permanently locking away CO_2 while enhancing methane recovery through ECBM. However, the feasibility and long term security of CO_2 storage depend on several geological and geophysical factors, including coal seam characteristics, caprock integrity, faults, fractures, formation water conditions and reservoir heterogeneity. Therefore, an integrated assessment is essential for evaluating the suitability of CBM reservoirs for secure CO_2 sequestration.

This study aims to assess caprock integrity and identify potential CO_2 migration pathways in CBM reservoirs for developing an integrated geological and geophysical framework. The geological investigation will focus on stratigraphy, coal seam geometry, thickness, continuity, heterogeneity and structural characteristics of the reservoir. Geoscientific data will be utilized for lithological identification and petrophysical characterization. Petrophysical parameters such as shale volume, porosity, density and permeability will be evaluated to assess the quality and continuity of potential caprock units. Structural interpretation will further examine faults, fractures and other discontinuities that may influence CO_2 movement and create potential leakage pathways.

The integration of all information will be used to identify zones of favourable containment and areas susceptible to CO_2 migration. Based on these integrated parameters, a CCUS suitability and leakage risk assessment framework will be developed for CBM reservoirs. The findings may contribute to improve site selection, safer implementation of CCUS-ECBM projects and to evaluate security of CO_2 storage in Indian CBM reservoirs.

UNIFIED ANOMALY EXPRESSIONS FOR VERTICAL CUM HORIZONTAL, AND TOTAL FIELD MAGNETIC ANOMALIES OF 2.75 DIMENSIONAL FAULT STRUCTURES CONFINED BY NON-PLANAR FAULT PLANES.

M. Deepak[1]*, B. Ramamma[2], V. Chakravarthi[3]
Center for Earth, Ocean and Atmospheric Sciences, University of Hyderabad, Hyderabad - 500046, India
*Presenting author: deepak.moturu@gmail.com

ABSTRACT

A generalized forward modeling equation to calculate the magnetic anomalies of a randomly magnetized finite-strike listric fault source is derived using Poisson's relation. This new equation combines analytic and numerical approaches to enable forward modeling of the anomalous source in any component. Polynomial functions are adopted to simulate the geometry of the curved fault plane between the displaced hanging wall and the footwall of the fault morphology. The utility of the derived equation is illustrated by a theoretical model of a limited-strike listric fault morphology, in which the anomalies in the vertical, horizontal, and total field components are computed. It is demonstrated that the magnitude of the anomalous field (in any component) does not remain the same but changes with the profile offset, although the anomalous source remains the same. The effect of structure dimensionality (2D versus 2.5D) on the magnitude of the anomalous field is also discussed.

GEOELECTRICAL INVESTIGATION OF THE TATTAPANI HOT SPRING REGION FOR GEOTHERMAL ENERGY EXPLORATION, CENTRAL INDIA

Dewashish Kumar[1#*], Ved Prakash Maurya[1#], Arun Kumar Ojha[1#], K. Lohith Kumar[1] and Labani Ray[1#]
[1]CSIR-National Geophysical Research Institute, Hyderabad -500007, India
[#]AcSIR – Academy of Scientific and Innovative Research, Ghaziabad, India
*Presenting author e-mail: dewashishkumar.ngri@csir.res.in

ABSTRACT

Tattapani represents one of the most prominent geothermal manifestations situated in the Balrampur district of Chhattisgarh, Central India. The main objective is to map and delineate the shallow anomalous conductive zones/low resistivity zones, geological structure(s) as well as to understand the near surface shallow geological aspects, conduit(s) and its linkage with the deeper source of the geothermal hot fluids in Tattapani area from state-of-the-art high resolution electrical resistivity tomography (ERT) technique. Twelve high resolution electrical resistivity tomography profile was carried out in and around the main Lord Shiva Temple, which is the main area of interest in Tattapani area, Chhattisgarh. Interesting and anomalous near-surface observations were seen during the data acquisition stage with both very low and very high resistivity variations in the study area. The interpretation of the resistivity tomography models result revealed the anomalous variation of resistivity from <10 Ohm.m to ~17,000 Ohm.m, which shows a large resistivity contrast between the highly conductive zone(s) and with the resistive host rocks within the geological setting of the study area. The range of resistivity anomaly variation is depicted and mapped from the near surface layers to the maximum up to 215 m depths within the study area. In addition, the resistivity model results also depicted very low conductive anomalies < 5 to 10 Ohm.m at few localized zones in and around the main Lord Shiva Temple in Tattapani. Interestingly, the resistivity model results delineated near surface fault structure, shearing zone as well as low resistivity conduit and thus depicted a large resistivity

contrast on either side of the fault and along the shear zone, which acts as a major conduit for hot water ingress from the deeper source depth to the near surface geological layers.

Keywords: Geothermal Energy, Electrical Resistivity Tomography, Tattapani Hot Spring, Fault/Fracture, Chhattisgarh, Central India

ILLUMINATING LITHOSPHERIC ANISOTROPY AND MANTLE DEFORMATION DYNAMICS BENEATH NORTHEAST INDIA USING RECEIVER FUNCTION HARMONICS

Dhiraj Kumar Singh[1,2*], Mohit Agrawal[1], Hitank Kasaundhan[1, 3]
[1]Department of Applied Geophysics, Indian Institute of Technology (ISM), Dhanbad, India
[2]Department of Earth Sciences, Indian Institute of Technology Bombay (IIT Bombay)
[3]Research School of Earth Sciences, Australian National University, Acton ACT 0200, Australia
*Presenting author: Dhiraj Kumar Singh Email: dhirajs0208@gmail.com

ABSTRACT

Characterized by intense seismotectonics and overlapping collision-subduction regimes, Northeast India offers critical insights into lithospheric strain and mantle flow. We characterize crustal and upper-mantle anisotropy by isolating back-azimuthal harmonics from teleseismic receiver functions at ten broadband seismic stations. The resulting models delineate sharp contrasts in deformation across the Eastern Himalayas, Assam Valley, Shillong Plateau, and Bengal Basin. Fast axes broadly correspond to the absolute motion of the Indian Plate, though complex deviations emerge along the seismically active Kopili Fault and the Indo-Burma subduction wedge. Crustal layering, dipping symmetry planes, and an E–W lattice-preferred orientation in the Eastern Himalayas illustrate the intensity of convergent strain, accompanied by southward Moho depression due to collision-driven thickening. Under the Shillong Plateau, an elevated Moho with tilt axes orthogonal to local compressive stresses reinforces an uplifted horst block geometry. In the Indo-Burma Ranges, the anisotropic signature reflects combined asthenospheric drag and transpressional crustal stacking, contrasting with the flexural subsidence and sediment loading in the Bengal Basin. These observations demonstrate that while first-order lithospheric fabric records the northward trajectory of the Indian Plate, regional deviations in the Tripura Fold Belt reveal strong mechanical coupling between mantle flow and localized structural boundaries.

Keywords: Receiver function, Anisotropy, Back-azimuthal harmonics, Northeast India

INTERSEISMIC PLATE COUPLING ALONG THE UTTARAKHAND HIMALAYA FROM GNSS AND ALOS-2 INSAR

Dibyashakti Panda[1,2], Mridul Yadav[1], Eric O. Lindsey[3], G Srinivasa Rao[1]
[1]Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai, India
[2]Now at the Department of Geology, School of Earth Sciences, Central University of Tamil Nadu, India
[3]Department of Earth & Planetary Sciences, University of New Mexico, Albuquerque, NM, USA
Presenting author: Dibyashakti Panda (dibyashakti@cutn.ac.in)

ABSTRACT

Differing interpretations of the strength of interseismic plate coupling along the Main Himalayan Thrust (MHT), particularly the possible existence of weak coupling zones, have led to widely varying

assessments of the associated seismic hazards along the megathrust with potential impacts for more than half a billion people. Here, we focus on the kinematic status of the MHT in the Uttarakhand Himalaya, the location of one of the proposed low-coupling regions. We use an updated compilation of Global Navigation Satellite System (GNSS) data, along with Interferometric Synthetic Aperture Radar (InSAR) satellite imagery, to estimate the slip deficit and characterize the width of the MHT that is accumulating elastic strain. GNSS-derived horizontal displacements indicate a slip deficit of ~18 mm/year, with an MHT that is locked up to a width of ~115 km. We use ALOS-2 InSAR imagery to quantify the interseismic vertical deformation in the same region and identify a peak uplift of 4–6 mm/year. We apply the Elastic Subducting Plate Model (ESPM) to characterize the fault slip responsible for this vertical deformation while avoiding the vertical motion artifacts introduced by backslip or deep dislocation models. Both the GNSS and InSAR measurements are consistent with a shallow MHT that is fully locked from the surface to a depth of ~20 km. Our results also indicate that the megathrust in the Uttarakhand Himalaya is highly coupled (>0.8), and the accumulated strain energy is equivalent to one Mw 8.1 megathrust earthquake every 100 years along this ~300 km section of the megathrust.

SEASONAL VARIATIONS IN SPECTRAL CONTENT OF SEISMIC AMBIENT NOISE IN UTTARAKHAND REGION

E Uma Devi*[1], Rajesh Rekapalli[1,2], Raviteja Kethavarapu[1,2],
Venkatesh Vempati[1], G Suresh[1] Sandeep Gupta[1,2]
CSIR – National Geophysical Research Institute, Hyderabad, India.
Academy of Scientific and innovative Research (AcSIR), Ghaziabad, Uttar Pradesh-201002, India.
Email: umaramakris@gmail.com

ABSTRACT

Seismic ambient noise variations in a region help to understand a broad range of sources, such as microseisms generated by ocean waves, environmental and meteorological signatures associated with seasonal changes, and anthropogenic signatures caused by human activities. Here we study the seismic ambient noise variations in the Uttarakhand region by computing the Probabilistic Power Spectral Density (PPSD) to understand seasonal variations using seismic waveforms recorded at eleven seismic broadband stations during the period 2021 – 2024. Benchmarking seasonal PPSD against the New Low Noise Model (NLNM) and New High Noise Model (NHNM) allows quantification of noise levels identify dominant spectral bands. The results show clear seasonal variations in the seismic noise characteristics across the stations. The monsoon season consistently produces the highest noise levels and greatest variability, particularly in the 4-20 s microseism band, likely driven by rainfall, surface runoff, river and hydrological processes and enhanced ocean-generated microseisms. The secondary microseisms (4-10 s) are prominent across several stations, while short-period noise varies more locally, reflecting local anthropogenic activities. Winters exhibit the lowest noise levels, while summer noise levels are between the monsoon maximum and winter minimum. During the seasonal transition from winter to summer, ambient seismic noise power in the 0.33–2 s band exhibited a pronounced elevation-dependent increase. High-altitude stations in the Greater Himalaya record a sharp, rapid escalation in power, which can be directly attributable to the onset of snowpack retreat and subsequent meltwater dynamics. In contrast, lower-altitude stations displayed a more gradual, human-activity-modulated

amplification. Together, these results show that seasonal changes in geomorphic and hydrological processes strongly influence the seismic ambient noise in the Uttarakhand region.

Keywords: Seasonal variations, Seismic ambient noise, Probabilistic Power Spectral Density (PPSD), Microseisms, Hydrological processes.

RADIOELEMENT DISTRIBUTION AND RADIOGENIC HEAT PRODUCTION IN MAJOR ROCK FORMATIONS OF THE UTTARAKHAND REGION, WESTERN HIMALAYA, INDIA

Eswara Rao Sidagam[1,2] *, Labani Ray[1,2], Ayan Dutta[1,2], Nagaraju Podugu[1], Nishu Chopra[1,2], Nidharshan B M[1]
[1]CSIR-National Geophysical Research Institute, Hyderabad 500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
*Presenting author: Eswara Rao Sidagam (eswar5063@gmail.com)

ABSTRACT

The Uttarakhand region of the Western Himalaya represents a significant geothermal province in India, characterized by numerous hot springs despite generally low surface temperatures. The occurrence of 42 geothermal hot springs, with discharge temperatures ranging from 40 to 94 °C, indicates the presence of considerable subsurface thermal energy. This thermal regime is potentially influenced by radiogenic heat production (A), together with the geothermal gradient, deep heat sources, fault-fracture systems, permeability, fluid circulation, and reservoir characteristics. Among these, the contribution of radiogenic heat production from the rocks associated with these geothermal systems is not yet sufficiently constrained. Here, we investigate the abundances of Th, U, and K and consequently radiogenic heat production in representative lithologies from the Higher Himalaya (HH), Lesser Himalaya (LH), and Sub Himalaya (SH). The results demonstrate systematic variations in radioelement abundances and heat production among the three tectonic domains, with generally higher values in the HH and LH than in the SH. Further, these values also vary with lithology, being relatively high in granitoids, gneisses, phyllites, and schists and comparatively low in quartzites, sedimentary rocks, and mafic lithologies. Radioelement ratios (Th/U and K/U) in these lithotectonic units indicate differences in source composition, metamorphic conditions, and radioelement redistribution. The estimated contribution of radiogenic heat to crustal heat flow increases from the SH through the LH to the HH, consistent with the greater abundance of felsic, heat-producing lithologies and massive crustal thickening in the higher tectonic domains. These results provide new constraints on the distribution of crustal heat production and contribute to improved assessments of the thermal structure, geodynamic evolution, and geothermal potential of the Western Himalaya.

Keywords: Radioelement abundance; Radiogenic heat production; Geochemical characterization; Geothermal energy; Western Himalaya; India

TWO-DIMENSIONAL MAGNETOTELLURIC INVERSION USING NEURAL SURROGATES AND IMPLICIT NEURAL REPRESENTATIONS

Fareeda Begum Shaik[1*], Roshan K Singh[1] , Pankaj K Mishra[2]
[1]Indian Institute of Petroleum and Energy, Visakhapatnam, India, [2]Geological Survey of Finland, Vuorimiehentie 5, Espoo, Finland, *Corresponding author: Fareeda Begum Shaik

ABSTRACT

Two-dimensional magnetotelluric (MT) inversion is computationally demanding because conventional numerical forward solvers such as the finite-difference method (FDM), finite-element method (FEM), and finite-volume method (FVM) iteratively calculate electromagnetic responses as the subsurface resistivity model is updated. This becomes especially challenging for large datasets, geologically complex problems, or repeated inversion experiments. We present an accelerated framework that combines an implicit neural representation (INR) of subsurface resistivity with a pretrained neural surrogate that serves as a differentiable surrogate for a conventional forward solver.

The INR represents the subsurface log-resistivity distribution as a continuous function of spatial coordinates. During inversion, this neural field is sampled on a computational grid, supplied to the surrogate, and surrogate learns the relationship between conductivity, frequency, and electromagnetic fields by enforcing the governing MT equations and boundary conditions during training, which is implemented by Fourier Neural Operator (FNO). The predicted fields are converted into surface impedance, apparent resistivity, and phase at receiver locations. Differences between observed and predicted responses are then backpropagated through a differentiable surrogate to update INR parameters. By replacing repeated solutions of the full electromagnetic system, the trained surrogate reduces the inversion time.

The INR combined with surrogate approach was evaluated using randomly selected synthetic resistivity models excluded from surrogate training. It was compared with INR combined with FDM using identical noisy observations, neural-network initialization, model parameterization, and optimization settings. Both methods recovered principal subsurface resistivity structures. Once trained, the surrogate-assisted inversion was approximately 20 times faster than the finite-difference-based inversion while maintaining broadly comparable recovery of major geological features.

These results demonstrate the potential of combining continuous neural parameterization with neural surrogate modelling for efficient two-dimensional MT inversion. Future work will extend the framework to field MT observations and assess its robustness under stochastic noise, ill-posed problems, greater geological complexity, and three-dimensional effects.

RESERVOIR CHARACTERIZATION OF THE SMEAHEIA CO_2 STORAGE SITE, NORTHERN NORTH SEA, USING JAYA OPTIMIZATION-BASED SEISMIC INVERSION

G. Hema*, S.P. Maurya
Department of Geophysics, Banaras Hindu University, Varanasi, India-221005
Presenting author: gopalhema96@gmail.com

ABSTRACT

Accurate characterization of reservoir properties is essential for evaluating subsurface formations for geological CO_2 storage. Seismic data provide broad spatial coverage of the subsurface; however, their

band-limited nature limits the direct estimation of quantitative reservoir properties. In this study, seismic inversion using JAYA optimization is applied to determine the distribution of acoustic impedance of the Smeaheia CO_2 storage site in the northern North Sea. The misfit between the field seismic and the modelled seismic response was minimized to optimize the acoustic impedance model using the JAYA algorithm. The inverted impedance model was validated against well-log-derived impedance at the well location, showing a correlation coefficient of 0.95 and an R^2 value of 0.89. The resulting impedance section delineates the principal reservoir intervals and reveals spatial variations in acoustic impedance within the Sognefjord and Fensfjord formations. The Sognefjord Formation exhibits impedance values of approximately 5500–6700 m/s·g/cc, while the Fensfjord Formation shows values of approximately 6400–8000 m/s·g/cc. The lower impedance zones are associated with the principal reservoir intervals and provide quantitative information on their subsurface properties. The results demonstrate the applicability of JAYA optimization-based seismic inversion to field seismic data for acoustic impedance estimation. Overall, this study highlights the potential of this approach for supporting the assessment and monitoring of geological CO_2 storage site.

THE SITE-SPECIFIC VARIATION OF H/V SPECTRA WITH DIFFERENT GEOLOGICAL CONDITIONS AND VICE VERSA — A CASE STUDY OVER DELHI.

H S Mandal and G Suresh
Scientist, National Center for Seismology, Ministry of Earth Sciences
Mausam Bhawan complex, Lodhi Road, New Delhi
Email: himangshu1970@gmail.com

ABSTRACT

A total of 544 sites, ground motion noise data of NCT Delhi are analysed using Nakamura techniques. The site-specific horizontal to vertical ratio(H/V) spectral characteristic for all 544 sites are correlated with local geological formations. Based on the observations, it is inferred that entire Delhi is characterized by four characteristics of spectral curves at depth and different geological conditions. The Type-I curve identifies the rock sites along the ridge axis with a spectral frequency of more than 5 Hz. Type-2 and Type-3 curves are characterized by a frequency between 2 and 4 Hz on the sites located just adjacent to the north-south oriented ridge axis inferred variable depth and complex geological deposited site. The spectra containing peaks at frequencies of greater than 3 Hz are identified the rock site, shallow and weathered rock site and intermediate rock site along the Delhi ridge and its adjacent part of the bridge. However, the major part of the area of Delhi found a spectral with peak of the frequencies of less than 1Hz lying in the Eastern part and Western part of Delhi with soil depth reaching up to 290m near the locality at Rohini site. Based on the spectral shapes, shear wave velocity, geology, the vulnerability of the area is mentioned for hard rock sites, soft rock sites, alluvium sites, Banger plains, Chhatarpur Basin, and Debar plains. Ridge ambience with exposing fractured and massive Quartzite, compressive strength (CS>20MPa). Locally weathered and reclaimed with soft soil, characterized by flat response curves of high fundamental frequency(>5Hz) and a low amplification ratio of less than 1.0 and very low vulnerability with average shortwave velocity >1250m/s. Shallow rock sites: alluvial and colluvial cover consisting of sporadic boulders with sandy matrix at the foothills, on high impedance contrast characterized by a well-defined response curve with frequency(>3Hz), moderate amplification and very low vulnerability and no liquefaction with average shear wave velocity

(>800m/s). Shallow soil sites: level ground with alluvium filled(sand-silt and clay) above the base rock (Quartzite) at a depth of (>30m) resulting in strong amplification fundamental mode of frequency around 1Hz with amplification 6.5 and average Shear wave velocity(~350-400m/s), Chhatarpur Basin: structurally controlled an oval shape basin (width by depth ratio 0.3), peak frequency of 1Hz strong basin effect with Shear wave velocity ranging from 300-750m/s, other geological formation like deep and very soft soil sites are along the active regime of Yamuna river with very low frequency(<0.6Hz) and amplification factor(>4.0), noted very high vulnerability and Liquefaction susceptibility with average Vs<200m/s. Banger plain represented the deep alluvium sites, paleo channels, meander scroll, oxbow lakes containing low frequency, high amplification and variable vulnerability, high liquefaction with Vs<250m/s. Debar plains area identified very deep soil strata(~300m) located along Najafgarh lake consisting of lacustrine sediments of silt-clay with kankar beds spectra that are low frequency(0.6-0.8Hz) with high amplification and moderate to high vulnerability. This information is very useful to get an idea from the researchers about how the shape of the H/V spectra changes in a complex geological formation with increasing soil depth and vice versa to understand the site-specific hazard estimation for Delhi or similar geological formations located outside the Delhi region.

Keywords: H/V spectra, Vs, Liquefaction, Vulnerability, Geology of NCT Delhi.

GEOPHYSICAL INSIGHTS FOR DAM SAFETY: THE NEED FOR AN INTEGRATED APPROACH

HVS Satyanarayana*, D. Mysaiah , P. Pavan Kishore
CSIR-National Geophysical Research Institute, Hyderabad-500007, India
*Corresponding author: hvsatya@ngri.res.in

ABSTRACT

Recent extreme flood events, sudden water releases and infrastructure failures have highlighted the vulnerability of dams and other critical water infrastructure to complex geological, hydrological and seismic hazards. These events underscore the need for comprehensive assessment of both known and hidden factors that may affect dam performance and downstream safety.

This paper emphasises the need for a multidisciplinary geophysical approach to dam-safety assessment, integrating MASW, Electrical Resistivity Tomography (ERT), Ground Penetrating Radar (GPR), Cross-Hole Seismic Testing (CHST) and seismic monitoring with geological and geotechnical investigations. The complementary nature of these methods enables improved understanding of foundation conditions, subsurface discontinuities, material properties and the seismic environment.

The paper discusses how such an approach can help identify potential anomalous or vulnerable zones, guide focused engineering investigations and strengthen the assessment of existing and ageing dams. It advocates integration of geophysical observations with geological, geotechnical and seismic information as an essential component of modern dam-safety practice, supporting risk reduction, informed decision-making and resilient infrastructure management.

Keywords: Dam safety; Engineering geophysics; MASW; ERT; GPR; CHST; Seismic monitoring; Geotechnical investigations.

ENIGMATIC EAST INDIAN SHIELD: EXPLICIT GRAVITY AND MAGNETIC SIGNATURES

J. V. Rama Rao[1*] , B. Ravi Kumar[2]
1: Formerly Geological Survey of India; 2: Geological Survey of India, Shillong
Presenting Author *rarajammi@ gmail.com

ABSTRACT

The East Indian Shield (EIS) is mainly defined by the Singhbhum Craton and the Chhotanagpur Granite Gneissic Complex (CGGC), and is bounded to the west by the Mahanadi Rift Zone and to the southeast by the Eastern Ghats Mobile Belt (EGMB). Contradictory opinions about the tectonic status of CGGC prevail in the tectonic frame work of Indian Shield. The Bastar Craton, another major cratonic nucleus of the Indian Shield, is generally considered part of the Central Indian Shield or the South Indian Block together with the Dharwar Craton. Significantly, EGMB was thrust on to both Bastar craton in west and Singhbhum craton in north. In this study, regional gravity and satellite-derived magnetic data are integrated to reassess the tectonic affinity and crustal architecture of the Bastar domain, which occupies a critical transitional position within the Indian Shield.

Qualitative and quantitative analyses of gravity and magnetic anomalies provide new constraints on the boundaries of crustal domains, variations in crustal architecture, and the geometry of the crust–mantle interface. The predominance of long-wavelength magnetic anomalies over the Dharwar and Bundelkhand cratons is interpreted to reflect deep-seated crustal magmatism, whereas the EIS is characterized by prevalence of relatively high-frequency magnetic anomalies, suggesting crustal modifications and more heterogeneous crustal source. P Depth solutions from gravity profiles across EIS and adjoining Eastern Dharwar Craton suggest variations in nature and depth persistence cratonic domains and those of major crustal-scale rift zones. Linear Bouguer gravity anomalies and depth estimates indicate that the narrow Pranhita–Godavari Rift (PGR) zone represents a peri-cratonic valley that extends to depths of ~30 km and constitutes a major crustal boundary within the southern Indian Shield. In contrast, the Mahanadi Rift Zone is a broad, shallow, intra-cratonic feature that appears to persist to depths of ~15 km. A prominent long-wavelength magnetic high over the Mahanadi Rift Zone suggests the presence of a mafic basement. Further, unlike PGR, the Mahanadi Rift Zone is not flanked by prominent granulite belts.

Gravity modelling across the EIS and adjacent terrains reveals three major crustal blocks, while the Bastar Craton itself appears to comprise three distinct sub-blocks. Considering the integrated gravity and magnetic signatures, crustal architecture, and tectonic relationships, we propose that the Bastar Craton is more appropriately regarded as an integral component of the East Indian Shield rather than the South Indian Block. This interpretation provides new insights into the tectonic evolution and crustal assembly of the Indian Shield. These studies provide evidence for the conjecture that Dharwar Craton, Southern Granulite Terrane and Madagascar continent are related to East African orogen, whereas Bastar, Singhbhum, Eastern Ghats Mobile Belt, Australia and East Antarctica are connected to Rodinia – Gondwana assemblage.

INTRINSIC DIVERGENCE OF TANER & KOEHLER SERIES USED IN TRAVELTIME APPROXIMATION: REMEDIES RESORTING TO PADÉ APPROXIMATION AND ASYMPTOTIC EXPANSION

Praveen Kunagu[1]* and Santi Kumar Ghosh[1]
[1]CSIR-National Geophysical Research Institute, Hyderabad, 500007
Presenting author email: praveen.ngri@csir.res.in

ABSTRACT

Essentially a power series connecting traveltime (t) and offset (x), Taner and Koehler series constitutes the basis of normal-move-out correction and velocity analysis for a horizontally layered earth where each layer has a uniform velocity. More than two decades ago, a paper demonstrated the divergence and degeneracy of the series, pointing out potential pitfalls in its unchecked implementation. (The root of divergence is traced to the absence of an extension of Snell's law in the complex domain). The caution had little repercussions and several truncated versions of the series continue to be in persistent use as before. In order to consolidate the issue of divergence, this paper presents a more lucid and persuasive mathematical demonstration and also reconfirms the divergence by computed examples for practically all offsets and for a diverse range of models, unlike earlier. To be specific, the corroboration corrects a foundational error, addressing a persistent gap in seismic theory. Also, for the first time, a mathematical proof for the asymptotic nature of the series is formulated. While many proposals exist for modeling the traveltime, none is unconditionally efficacious either for all offsets or for all models. Augmenting the established use of Padé approximation, we propose a mixed strategy consisting of the seventh order Padé approximation up to a selected intermediate offset point, and an asymptotic expansion about that point for offsets, still farther. The combined strategy is termed GK-hybrid. Padé approximation, arguably influenced by the explicit divergence of its parent series, i.e., the Taner and Kohler series, occasionally leads to pathologies, consisting of erratic jumps in t^2 and even its negative values at far offsets. The hybrid approach generally models t^2 efficiently, keeping the errors acceptably small while excluding erratic behavior of the Padé functions.

CRUSTAL ARCHITECTURE AND TECTONIC EVOLUTION OF THE DHARWAR CRATON: INSIGHTS FROM INTEGRATED GEOPHYSICAL DATA

Karishma Lagachu * and S. Lasitha
Department of Earth Sciences, Pondicherry University, Puducherry 605014, India
*Presenting author: karishmalaga2000@pondiuni.ac.in

ABSTRACT

The Dharwar Craton is a major Precambrian crustal domain of southern India with a complex history of crustal growth, deformation, and tectonic reworking. Understanding its deep crustal structure and lithospheric architecture is essential for deciphering the tectonic evolution of the southern Indian Shield. This study integrates regional gravity and aeromagnetic data to investigate the subsurface architecture, major crustal boundaries, and tectonically significant structures of the Dharwar Craton. The datasets are processed using reduction to the equator, upward continuation, analytical signal, and derivative-based techniques to enhance anomaly patterns and delineate shallow and deeper sources, lithological contacts, and structural trends. The processed gravity and magnetic anomalies reveal significant spatial variations and prominent linear gradients that correspond to contrasting subsurface domains. The

persistence of several magnetic anomalies and structural trends at different levels of upward continuation suggests that some of the identified features may extend to considerable crustal depths. Correlation of gravity gradients and magnetic lineaments with regional geological structures enables the identification of major crustal boundaries, shear zones, and other tectonically significant discontinuities. The integrated interpretation provides regional-scale constraints on the crustal architecture and structural continuity of the Dharwar Craton and demonstrates the effectiveness of gravity and magnetic methods in delineating concealed structures within the Precambrian crust. The results contribute to a better understanding of the tectonic framework and geological evolution of the Dharwar Craton and the southern Indian Shield.

NEPAL FLOODS-2026: A GEOSCIENTIFIC ANALYSIS

K. Seshadri* and P. Chandrasekhar
National Remote Sensing Centre (NRSC)/Indian Space Research Organization (ISRO), Hyderabad-500037, India.
*For communication: seshadri.nrsc@gmail.com

ABSTRACT

A mega ice–rock avalanche comprising of a large volume of glacier ice along with the bedrock debris detached from an elevation of approximately 5,200 m amsl in the vicinity of Langtang-Lirung in the Nepal Himalayas, close to the Nepal–China border, and fell down instantly into the Lendey Khola, a tributary of the Bhotekoshi River, on 26th August 2026 abruptly obstructing the river flow. This temporary blockage generated a destructive debris-flow surge that propagated downstream through the Bhotekoshi–Trishuli river valley corridor. The rapidly moving water, ice, mud, and rock mixture caused extensive destruction of settlements, roads, and bridges**,** besides the loss of more than a thousand lives. The immediate trigger of this disaster may appear as the recent one, but the actual origin lies in "depth" (i.e. the third dimension), which includes underlying lithological sequence, geological structures and plate tectonics, and surficial activities, namely climatic conditions and glacier formation. The lithology is mainly high-grade metamorphic rocks of greater Himalayan sequence, viz. gneisses, schists, quartzites and migmatites affected by intense deformation, foliation, faulting and fracturing resulting in high altitude slope instability. They are intruded with leucogranite cutting through the metamorphic rocks. The regional Himalayan tectonic structural framework in the area encompasses Main Central Thrust (MCT), Langtang Thrust (LT), South Tibetan Detachment System (STDS) with various innate structural fabric and discontinuities within the above structural features. Furthermore, the continuous convergence between lithospheric plates (Indian Plate vs Eurasian Plate) has produced intense crustal shortening, upliftment, thrust faulting and high relief. As a result the structural zones have become malleable within the high-grade Himalayan crystalline rocks producing instability of slopes, frequent tectonic deformation and earthquakes. Hence, seismicity is therefore an important component of regional slope and glacier hazard assessment keeping in view of past experience of the 2015 Gorkha earthquake generated ice–snow–rock avalanches in the Langtang region. Presently, the Langtang–Lirung collapse generated a seismic signal equivalent to approximately Mw 5.2-5.5. A second seismic record of approximately Mw4.2 was detected about three hours later. The seismic signal is therefore interpreted primarily as a consequence of the rapid mass movement rather than evidence of an earthquake-triggered failure. The glacier erosion due to structural and tectonic disturbances had generated cirques in the northern face of the mountain with steep slopes and sharp ridges. In doing so,

they continually modified the shape of the mountain. The degree of movement of glacier (advance or retreat) depends on the surplus or deficit of glacial deposition. In the present case, as a result of glacial retreat, the ice and rock faces disappeared. With the ice gone, the rock would have expanded slightly with water entering the joints and fractures within it, and over the time, these processes would have weakened the rock further. The Climate had recorded some of the highest temperature anomalies across this part of the region (Asia) before the occurrence of the disaster. The warmer conditions would have produced substantial melt water. The possibility raised by the evidence is that this melted water would have entered the fractures and weakened the rocks, which had become one of the causative factors of this calamity. The analysis reminds us, once again, that the Himalayan mountains are not still, as the geological processes that began millions of years ago still continue to shape the landscape of this region. The rocks store tectonic record and orogeny since the time the continents collided. A detailed lithological and glacial landform classification reveals the glacial interaction with weak rock masses. Interpretation of the InSar and GNSS data sets could reveal the information on the continuous spatial deformation and precise movements, respectively. Regional seismicity, structural discontinuities and earthquake-induced weakening should be considered as important long-term preconditioning factors for future. A study of the landforms created by the glaciers facilitates better understanding and prediction of this type of disasters by anticipating the forces at work and identifying vulnerable zones for better preparedness. Hence, it is recommended that the entire dynamic glacier landform conditions should be monitored in each and every watershed area, particularly in the highly populated and tourist valleys.

Keywords: Leucogranite, Cirques, Seismicity, Lithospheric boundaries, InSar, GNSS.

COSEISMIC AND POSTSEISMIC GRAVITY CHANGES OF THE 2025 MW 8.8 KAMCHATKA EARTHQUAKE FROM HIGH-TEMPORAL-RESOLUTION SATELLITE GRAVIMETRY

Kosuke Heki[1,2] & Zheng Shuo[3]
[1.]Hokkaido University, [2.]IIT Bombay, [3.]Hong Kong Polytechnic University
Kosuke Heki: kheki@ymail.ne.jp

ABSTRACT

We report coseismic and early postseismic gravity changes associated with the 29 July 2025 Mw 8.8 Kamchatka earthquake using weekly regional gravity field models inferred from GRACE-FO (Follow-On) line-of-sight gravity differences, together with conventional monthly spherical harmonics solutions. The observed coseismic gravity changes were consistent with those predicted, assuming a fault model and the realistic layered spherical earth, within the observational uncertainty. The postseismic gravity changes contain short- and long-term components with opposite polarities and different amounts. The short-term faint gravity changes have distribution similar to the coseismic step and last for a few months, whereas the long-term clear gravity increases occur around the ruptured fault and continue for years. They are considered to represent afterslip and viscoelastic relaxation at depth, respectively. Such gravity changes would complement observations of postseismic crustal movements and contribute to the clarification of underlying physical processes. These results also demonstrate that GRACE-FO, as the successor to GRACE, has a large potential of capturing subtle gravity signals associated with large earthquakes.

PERIODS AND 3D GEOMETRY OF COSEISMIC IONOSPHERIC DISTURBANCES OF TWO COMPACT EARTHQUAKES IN NORTHEAST JAPAN

Kosuke Heki[1,2] & Muhammad Usman[3]
[1.]Hokkaido University, Japan, [2.]IIT Bombay, [3.]Zayed University, Abu Dhabi, UAE
Kosuke Heki: kheki@ymail.ne.jp

ABSTRACT

We analyzed coseismic ionospheric disturbances of Mw7.3 and 7.4 earthquakes off the Pacific coast of Northeast Japan using a dense network of global navigation satellite system receivers. The N-shaped disturbance pulses of these earthquakes had periods of ~2 minutes, about four times as long as their moment release duration. Disturbance with periods of ≥4 minutes often found for Mw≥8 earthquakes are to be explained as the superposition of short-period N-waves excited at multiple regions with distributed arrival times. We also tracked the ascent and horizontal expansion of ionospheric electron density anomalies 10-12 minutes after earthquakes by simple pattern matching of the anomalies from multiple satellites. They were consistent with the simulated propagation of acoustic waves from uplifted surfaces.

DEEP LEARNING-ASSISTED TEM INVERSION FOR DELINEATING POTENTIAL SUBMARINE GROUNDWATER DISCHARGE PATHWAYS IN FRACTURED BASALTIC COASTAL ENVIRONMENTS

Kuldeep Sarkar, Shreya Maurya, Nimatullah, Anand Singh
Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, 400076, India
Email: kuldeepsarkar39@gmail.com

ABSTRACT

Submarine groundwater discharge (SGD) is an important component of coastal hydrological and biogeochemical systems, providing a pathway for the transport of freshwater and dissolved constituents from terrestrial aquifers to the ocean. However, identifying SGD pathways in basaltic coastal environments is challenging because of strong lithological heterogeneity, fractured volcanic structures, and complex saline–freshwater interactions. This study presents a deep learning-assisted transient electromagnetic (TEM) inversion framework for characterizing subsurface resistivity variations and identifying potential SGD pathways in a basalt-dominated coastal setting along the western coast of India.

A synthetic database of layered-earth models was generated using forward TEM modelling to represent a range of plausible coastal hydrogeological conditions. An encoder-decoder convolutional neural network incorporating pyramid dilated convolution modules was developed to directly estimate subsurface resistivity from TEM decay responses. The trained network showed stable convergence and excellent predictive performance, with low validation error and a coefficient of determination greater than 0.98. The approach was further applied to field TEM measurements acquired along multiple coastal profiles to construct quasi-three-dimensional resistivity models.

The resulting resistivity distribution revealed distinct subsurface domains associated with saline saturation, weathered and fractured basalt, and relatively compact basaltic units. Moderately resistive zones were spatially continuous and preferentially associated with structural features, suggesting

potential freshwater-bearing pathways and preferential groundwater flow toward the coastal zone. Integration with magnetic anomaly information further supports the interpretation of fracture-controlled groundwater movement within the basaltic sequence.

Although independent hydrogeological validation was not available, the results demonstrate the potential of deep learning-assisted TEM inversion for rapidly characterizing complex coastal groundwater systems and delineating potential SGD pathways. The study highlights the value of integrating artificial intelligence, electromagnetic geophysics, and structural information for investigating groundwater-seawater interactions in fractured basaltic environments.

Keywords: Submarine groundwater discharge; Deep learning; TEM inversion; Coastal groundwater; Fractured basalt; Resistivity imaging

EVIDENCE OF HALES-DISCONTINUITY, CRUSTAL HETEROGENEITY AND ANISOTROPY CHARACTERIZATION TOWARDS CENTRAL AND WESTERN DHARWAR CRATON, SOUTHERN INDIA

Laxmidhar Behera[a,*] and **Deepak Kumar**[a]
[a]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad – 500007, Telangana, India
*Corresponding Author: Laxmidhar Behera (E-mail: laxmidhar.ngri@csir.res.in)

ABSTRACT

We have obtained crust and upper-mantle P- and S-wave velocity models (V_P and V_S) along with Poisson's ratio (σ) and anisotropy estimate towards Central and Western Dharwar Craton (CDC and WDC) of southern India from the inversion of three-component (3-C) wide-angle seismic data. The models depict complex geology and tectonic settings with compositional distinctions having different shear-zones. Presence of magmatic underplating with significant Moho up-warping and seismic evidence of the Hales-discontinuity are deciphered in this region. The Hales-discontinuity is demarcated by sharp velocity jump (V_P and V_S) observed below the Moho at 74-88 km depth. This may be characterized by spinel-to-garnet peridotite-transition having depleted and intermediately-depleted peridotites with presence of 8-12 km thick low-velocity-zone formed in the upper-mantle due to mantle-metasomatism and refertilization. The estimated crustal and upper-mantle seismic anisotropy indicate relatively high average P- and S-wave anisotropic coefficients A_P (2.0-9.0%) and A_S (1.0-5.0%) in WDC as compared to corresponding low average values of A_P (0.2-3.5%) and A_S (0.1-2.65%) towards CDC of the Dharwar Craton. Anomalous high A_P (7.0-9.0%) and A_S (4.0-5.0%) values are obtained in the upper-crust below Chitradurga Shear Zone. This may indicate ubiquitous presence of mylonites and other mafic minerals forming prominent tectonic-divide/suture-zone having highly foliated shear-fabrics juxtaposed by CDC and WDC. The comprehensive tectonic model derived with suitable integration of seismic, other geophysical and heat-flow results favor plume-arc settings supported by concomitant mafic-to-felsic volcanic-activity (komatiite magmatism) and partial-melting caused by mantle-fluids and gases released during stretching of lithosphere and impact of deep-seated plume in this province.

Key-words*:* Dharwar Craton; Crust; Upper-mantle; Low-velocity-zone; Hales-discontinuity

EVALUATION OF HIGHLY OBLIQUE IMPACT CRATER NEAR LUOBUSA OPHIOLITE USING, NUMERICAL MODELS, ULTRA HIGH-PRESSURE MINERALS AND TEKTITES

Mahesh Patil
Science and Spirituality Research Institute, 804, Yash Aqua, Navrangpura, Ahmedabad- 380009 (India)
Corresponding:mup124@rediffmail.com

ABSTRACT

An elliptical formation, measuring roughly 100km by 48 Km is situated near Luobusa Ophiolite in Tibet (28°51'37"N 90°52'11"E To 28°35'46"N 91°47'04"E). This structure exhibits characteristics consistent with hydro code numerical models that simulate highly oblique impacts at less than 10^0 angle to horizontal surface. Oriented in northwest-South east direction, it features a circular formation on northwest side and scars extending towards Southeast. The closeness of this structure to the Luobusa ophiolite, which is notable for ultra-high-pressure findings like coesite with former stishovite along with other UHP finds-typically linked with impact craters further emphasize its significance. The NW-SE alignment of structure also correlates with Australasian strewn field which is a result of highly oblique impact in Indochina region.

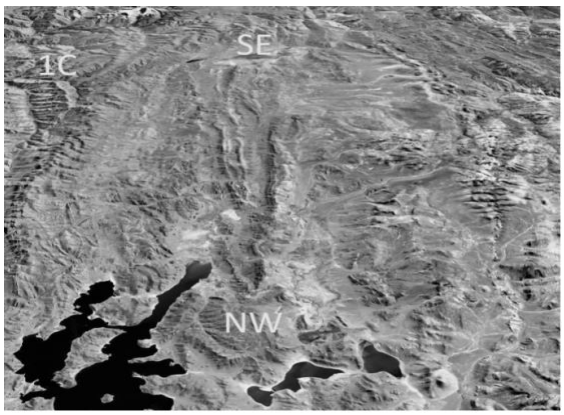


Figure 1: Satellite image of elongated structure.

INTEGRATED AIRBORNE ELECTROMAGNETIC AND MAGNETIC IMAGING OF SHALLOW SUBSURFACE ARCHITECTURE ACROSS THE TUNNEL ALIGNMENT, SLBC, TELANGANA

M. Prasanthi Lakshmi[1*], H.V. S. Satyanarayana[1], R.K. Kishore[1], Praveen Kunagu[1,2], D. Seshu[1], N. Srikanth[1], S. Parveen Begum[1], V. Pradeep Kumar[1]and Prakash Kumar[1]
[1]CSIR - National Geophysical Research Institute, Hyderabad – 500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad – 201002, India
[*]Presenting author. Email: prasantimp.ngri@csir.res.in

ABSTRACT

A comprehensive mapping of the subsurface along the Tunnel-I (44 km) of Srisailam Left Bank Canal (SLBC) scheme has gained importance to facilitate momentum of the tunneling works which were hindered due to the collapse occurred while major part of tunneling completed from either side. Challenging subsurface conditions like major fracture zones and other conduits that allow flow of groundwater are the potential threats in major infrastructure projects, especially in regions with high topographic relief and thick forests. In such situations, heliborne geophysical methods become cost and

time-effective and also provide uniform mapping subsurface geology and structure of the entire area of interest through Heliborne Magnetic and Time Domain Electromagnetic (TDEM) technology.

The inlet of the tunnel is located in the Srisailam sub-basin (predominantly occupied by Srisailam Quartzites as ridges) of the Proterozoic Cuddapah basin and extends into exposed granite-gneissic terrain. TDEM data revealed subsurface conductivity structure dominantly curvilinear paired conductivity trends within the quartzite, representing plunging folds with convex-to-west and convex-to-east fold domains separated by a structurally significant fault corridor. Highly fractured and jointed folded quartzites presume importance in allowing the free flow of water in the subsurface. The recorded Airborne Inductively Induced Polarization (AIIP) anomalies over outer limbs of quartzites reveal that the anomalies are fold-controlled, indicating the highly fractured and water saturated nature of the beds. The gently dipping quartzites holding high conductivity nature may appear vulnerable/incompetent during the tunnel excavations. Suggestions have been given on the location of more such zones where prior knowledge of the strata is highly useful for further safer tunnel operations and future management. The magnetic data revealed several geological contacts/fractures and or fault zones precisely. The structural domains and contact fracture mapped from the magnetic data also corroborate well with inferences drawn from TEM data.

SPATIAL AND TEMPORAL VARIATIONS IN SITE RESPONSE AND SHALLOW SHEAR-WAVE VELOCITY STRUCTURE IN THE PALGHAR EARTHQUAKE SWARM REGION, WESTERN INDIA

M. Srikanth,[1,2] V. Pavan Kumar[1,2], K. Sivaram[1,2,*] M. Shekar[1], Prakash Kumar [1,2]
1 CSIR-National Geophysical Research Institute, Uppal road, Hyderabad 500007
2. AcSIR-Academy of Scientific and Innovative Research, Ghaziabad, India
* Corresponding Author (email: srikanth.geo123@gmail.com.

ABSTRACT

We investigate the Palghar earthquake swarm region of western India, situated within the fractured Deccan Volcanic Province, for spatial and temporal changes in shallow subsurface properties and their influence on local site response. Using earthquake recordings from six broadband seismic stations, we integrate Earthquake Horizontal-to-Vertical Spectral Ratio (EHVSR), Site-to-Reference Spectral Ratio (SSR), and EHVSR inversion methods to characterize site resonance frequencies, amplification behavior, and shallow shear-wave velocity (V_S) structure. Observations are evaluated separately for pre-monsoon and monsoon/post-monsoon periods to identify temporal changes, while inter-station comparisons assess spatial variability. To ensure robustness, bootstrap resampling (95% confidence intervals) and source-effect analysis are used to quantify EHVSR estimates and the influence of earthquake source and wavefield characteristics. The results show distinct station-dependent resonance characteristics, with generally consistent fundamental frequencies but measurable seasonal variations in site characterisation and shallow (V_S). The SSR results broadly support the EHVSR-derived resonance frequencies at several sites. Inversion results reveal subtle temporal changes in shallow (V_S) and (V_P/V_S) ratios, particularly during the monsoon/post-monsoon period. We suggest that the observed spatial and seasonal variability to be associated with changes in near-surface conditions, such as monsoonal recharge and fluid circulation through fractured basaltic formations. These findings highlight the importance of EHVR and SSR to detect both spatial heterogeneity and seasonal changes

when characterizing site response and shallow subsurface conditions in active intraplate seismic regions.

Keywords : Palghar · Earthquake swarms · HVSR · Site-to-Reference Spectral Ratio (SSR) · Site response· V_S profile · Seismic hazard

CONTINUOUS GPS-BASED ASSESSMENT OF CRUSTAL DEFORMATION AND GRACE-BASED HYDROLOGICAL LOADING IN RELATION TO SEISMICITY IN NW HIMALAYA.

Muskan Nazir Dar, Bikram Singh Bali
Department of Geology, University of Kashmir, Hazratbal, Srinagar–190006, Jammu & Kashmir, India
E-mail: geomuskan603@gmail.com, baligeol@gmail.com

ABSTRACT

The Kashmir Himalaya represents a seismically active segment of the NW Himalayan convergent orogen, where India–Eurasia convergence drives persistent crustal deformation and recurrent earthquakes. Published continuous GPS observations provide an established tectonic framework for examining additional, time-dependent influences on seismicity. GPS observations processed with GAMIT/GLOBK in the ITRF14 and India-fixed reference frames distinguish regional plate motion from intraplate deformation. The ITRF14 velocity field exhibits coherent northeastward motion, whereas the India-fixed velocities reveal residual southwestward motions and spatially variable deformation across the Kashmir Valley.

Within this established tectonic setting, we independently examine whether surface-water redistribution influences earthquake occurrence. GRACE/GRACE-FO terrestrial water storage anomalies exhibit pronounced seasonal variability and a persistent long-term decline. Periods of hydrological depletion coincide with enhanced earthquake activity, indicating a temporal association between variations in surface mass and seismicity. Statistical analysis further supports a significant difference in earthquake occurrence between periods of lower and higher water storage.

These observations suggest that hydrological unloading may provide a secondary, time-dependent stress perturbation within an already tectonically loaded crust, potentially influencing earthquake timing on critically stressed structures. Rather than replacing tectonic forcing, hydrological variability may modulate the response of the crust to an existing tectonic stress field. The integrated GPS–GRACE–seismicity framework therefore connects long-term crustal deformation with transient surface mass redistribution and earthquake occurrence, offering complementary insights into earthquake modulation and time-dependent seismic hazard in the Kashmir Himalaya.

Keywords: Kashmir Himalaya, GPS geodesy, GRACE, hydrological loading, seismicity modulation, seismic hazard.

EARTHQUAKE SWARMS IN PENINSULAR INDIA: INSIGHTS INTO SPATIOTEMPORAL EVOLUTION AND TRIGGERING MECHANISMS

Naresh Bandari*, G Suresh, D Srinivas, M Shekar, Vijayaraghavan R and Prakash Kumar
CSIR-National Geophysical Research Institute, Hyderabad-07, India
Presenting author:nareshbandari@yahoo.com

Abstract

Peninsular India is generally considered a stable continental region; however, localized earthquake swarms have been observed in association with transient hydrological and anthropogenic processes. The CSIR-National Geophysical Research Institute (CSIR-NGRI) operates a regional seismic network across Peninsular India, which has enabled the identification and characterization of several swarm sequences. Following the onset of swarm activity, additional stations were deployed in selected areas for closer monitoring and to better constrain the spatial and temporal evolution of the sequences and their possible triggering mechanisms. In this study, we examine earthquake swarm sequences identified in different parts of Peninsular India in recent years, including Nellore (2016), Hyderabad (2017 and 2020), Palghar (2019), Pulichintala (2020), and the Gulbarga-Vijayapura region (2021). Analysis of the temporal evolution and spatial distribution of these seismic sequences indicates distinct relationships between swarm occurrence and external forcing mechanisms. The Hyderabad, Palghar, Nellore, and Gulbarga-Vijayapura sequences exhibit a strong temporal association with periods of enhanced rainfall, suggesting a significant role of hydrological loading, pore-pressure diffusion, and fluid migration in modulating crustal seismicity. In contrast, the Pulichintala sequence occurred in the vicinity of a major reservoir and displays characteristics consistent with reservoir induced seismicity, highlighting the influence of water level variations and reservoir loading on local stress conditions. The comparison of these sequences provides an opportunity to distinguish naturally modulated rainfall-related seismicity from anthropogenically influenced reservoir-triggered activity. Even within the stable continental interior, changes in hydrological conditions can influence the state of stress and pore-fluid pressure in the upper crust, potentially reactivating pre-existing fractures and faults and triggering localized swarm activity.

Keywords: Earthquake swarms; Peninsular India; Rainfall-induced seismicity; Reservoir-induced seismicity; Intraplate seismicity

FLUID-ASSISTED EARTHQUAKE SWARMS BENEATH THE DECCAN VOLCANIC PROVINCE: CONSTRAINTS FROM A MAGNETOTELLURIC STUDY

N.N. Chakravarthi*, G. Pavankumar, A. Manglik
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad – 500007, India
(*Presenting author; Email: chakrimarinegeop@yahoo.com)

ABSTRACT

The peninsular Indian shield, including the Deccan Volcanic Province (DVP), is generally considered a stable continental region. However, this region has experienced several significant intraplate earthquakes, including the Koyna and Latur earthquakes, as well as swarm-type seismic activity at Bhatsa, Silvassa, Navsari, Nashik, Valsad, Palghar, and more recently, Hingoli. Occurrence of earthquake swarms within and around the DVP during the past some decades highlights the need for a detailed understanding of the regional seismogenic processes and tectonic framework for improved seismic hazard assessment. We carried out magnetotelluric (MT) investigations along two traverses in the western part of the DVP, covering the Bhatsa and Palghar earthquake swarm regions. The results

indicate that the crust underlying the DVP consists of a mosaic of distinct structural blocks separated by faults. The three-dimensional (3D) geoelectric model reveals highly resistive, fragmented crustal blocks, interpreted as extensions of the Dharwar Craton beneath the DVP, dissected by pre- and post-eruptive fault systems such as the West Coast Fault, Panvel Flexure, and Kurudwadi Rift. The model also images shallow crustal conductive zones in the vicinity of the swarm regions, possibly reflecting infiltration of meteoric water into fractured crustal domains. Significantly, the hypocentres of the Palghar and Bhatsa earthquake swarms cluster within and around such enhanced conductive zones, suggesting possible role of fluids in facilitating swarm activity. We infer that intersections of local structural trends with the regional tectonic features may act as zones of stress concentration. In addition, water percolation along weak and fractured zones may modify the local stress state, thereby promoting seismic swarm activity within the DVP.

EVOLUTION OF AIRBORNE GEOPHYSICS AT CSIR-NGRI: FROM DAKOTA TO DRONE

HVS Satyanarayana, R Raj Kumar, N Srikanth*
CSIR- National Geophysical Research Institute, Hyderabad
*Presenting author. Email: srikanth.ngri@csir.res.in

ABSTRACT

Airborne geophysics has been an important component of the exploration-oriented research programme of CSIR-National Geophysical Research Institute (CSIR-NGRI) for about six decades. The journey began in 1965–66 with efforts to establish an indigenous airborne geophysical capability and the first experimental aeromagnetic survey in 1967 over the Kudremukh–Kotebare iron-ore province of Karnataka, using a proton-precession magnetometer carried on a Dakota aircraft. This marked the beginning of a sustained programme of airborne geophysical surveys, instrumentation development and technology advancement at NGRI.

Over the subsequent decades, the capability evolved through indigenous development and adoption of progressively advanced airborne magnetic and electromagnetic systems, together with improvements in navigation, positioning, data acquisition, processing and interpretation. The development and deployment of rubidium-vapour magnetometer, Transient Electromagnetic system represented an important phase in establishing airborne survey capability. With technological advances, fixed-wing regional surveys were complemented by high-resolution helicopter-borne investigations. The introduction of frequency-domain and transient electromagnetic systems, along with airborne magnetic and radiometric measurements, enabled integrated multiparameter surveys for mineral exploration, uranium exploration and geological characterization. Airborne geophysics was subsequently extended to groundwater investigations, including three-dimensional aquifer mapping, and to engineering and subsurface investigations.

A significant recent development has been the transition towards unmanned platforms under the CSIR Mission Mode project Drone-based Electromagnetic and Magnetic Systems (DREAM), undertaken in collaboration with partner CSIR laboratories. As the originally envisaged ~100-kg-payload UAV could not be procured, a 10-kg-payload UAV developed by CSIR-NAL was utilized for field demonstration towards the completion of the project. NGRI integrated a procured airborne magnetometer with the

UAV and successfully demonstrated high-resolution drone-borne magnetic surveying over the Yacharam mafic dyke, Telangana.

The evolution from Dakota-based experimental surveys to fixed-wing, heliborne and drone-based systems represents a transformation from regional anomaly detection to high-resolution and problem-oriented subsurface characterization. This paper reviews the evolution of airborne geophysics at CSIR-NGRI, highlighting technological advances, platform transitions and expanding applications that have shaped its present capabilities.

CRUSTAL STRUCTURE AND TECTONIC IMPLICATIONS OF THE SAURASHTRA REGION FROM MAGNETOTELLURIC STUDIES

P B V Subba Rao[1,3*] and P V Vijaya Kumar[2]
[1-] 204, Mayureshwar CHS, New Panvel (W), Navi Mumbai-410206, India
[2-]National Geophysical Research Institute, Hyderabad-500 007, India
[3-]Formerly Professor, Indian Institute of Geomagnetism, Panvel, Navi Mumbai-410218, India
Email: sraoiig@gmail.com

ABSTRACT

Three Magnetotelluric (MT) profiles were conducted across the Saurashtra Peninsula, a prominent horst structure largely covered by Deccan basaltic volcanic rocks. The three profiles, extending across the northern, central, and southern parts of Saurashtra, reveal a highly heterogeneous crust characterized by alternating resistive and conductive domains. The shallow subsurface structure clearly delineates the Deccan basaltic cover and the underlying sub-trappean Mesozoic sedimentary sequences, whose thickness generally increases westward, particularly along the central transect.

At greater depths, prominent resistive bodies are interpreted as relatively intact or recrystallized Precambrian basement, including possible extensions of volcanic plugs. These features likely represent uplifted, structurally preserved basement blocks that mafic intrusions later modified. In the upper crust, conductive anomalies spatially associated with dyke swarms, faults, and fractured zones suggest these structures served as preferential pathways for magma ascent and hydrothermal fluid circulation, facilitating localized alteration and mineral–fluid interactions. At greater depths, conductors near the crust–mantle transition are interpreted to reflect basaltic underplating and its associated thermo-chemical effects, including enhanced melt and fluid interaction, carbonate-rich fluid infiltration, and dehydration reactions. Collectively, the resistive and conductive domains indicate a crustal architecture in which inherited basement structures and tectonic discontinuities exerted strong control on magma emplacement, fluid migration, and subsequent crustal modification.

Three-dimensional modelling of the MT datasets can provide important constraints on the distribution and geometry of subsurface magmatic bodies beneath the Saurashtra Peninsula. These electrical resistivity structures may help delineate the underlying magmatic plumbing system and provide insights into the processes governing the storage, transport, and emplacement of Deccan magmas.

SOIL CHARACTERIZATION OF LANDSLIDE-PRONE REGIONS IN UTTARAKHAND, INDIA, USING SYNTHETIC AND FIELD (MASW) DATA

P. Sivasankar [*1], K. Swapna Sri[1, 2], and K. Satish Kumar[1]
[1.]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad, India
[2.]Academy of Scientific and Innovative Research, Ghaziabad-201002, India
*Corresponding Author: sivamarine007@gmail.com

ABSTRACT

A Multichannel analysis of surface waves (MASW) study is being carried out in parts of Uttarakhand to assess the liquefaction potential of soils near landslide-prone regions. In this study, we collected Active and Passive MASW datasets in Uttarkashi, Pithoragarh, Munsyari, Tehri Garhwal, and Nainital along a ~50 m stretch. A Python-based conceptual Landslide model is generated based on expected shear-wave velocities (Vs) for loose soil, saturated soil, and stiff rock/bedrock. It is inferred from the conceptual model that Layer 1 consists of loose soil with Vs<200 m/s, Layer 2 consists of saturated soil with (200 <Vs <300 m/s), and Layer 3 consists of stiff soil/ bedrock with Vs>600 m/s, sequentially from the surface to a depth of 50 m. The estimated Vs from the MASW study ranges from 100 m/s to <1500 m/s at all sites, from the surface to 50 m depth. Comparative studies between the synthetic and field results show that (i) Layer 1 is present up to a depth of 10 to 20 m, with Vs (100 m/s to 400 m/s) from the surface; (ii) Layer 2 is present from 20 m to 30 m, with Vs (>400 m/s to 1000 m/s), followed by Layer 3 with >1000 m/s velocities. (iii) The stiffness of the layers increases from surface to a depth of 50 m. (iv) The observed low Vs at deeper depths indicates that deposition of layer 1 material might be at deeper depths due to past landslide events/deep weathering. (v) Layer 2 acts as a barrier or interaction layer between layer 1 & 2, which might be located at the slip surface. (vi) Liquefied soils are observed between depths of 10 m and 15 m. This study used to understand landslide hazard assessment in conjunction with hydrogeological, geomorphological, and geospatial parameters in the studied regions.

Keywords: MASW, Liquefaction, Shear wave velocity, Landslide, and Uttarakhand.

CRUSTAL GEOELECTRIC ARCHITECTURE AND GEOTHERMAL FLUID PATHWAYS IN EASTERN LADAKH FROM MAGNETOTELLURIC IMAGING

G. Pavankumar[1,2]*, Ajay Manglik[1,2], Akashdeep Barman[1,2,] M. Demudu Babu[1], K. Raj Sunil[1,3], N.N. Chakravarthi[1], and M. Suresh[1,2]
[1.] CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad – 500 007, Telangana, India
[2.] Academy of Scientific & Innovative Research (AcSIR), Ghaziabad 201002, India3. Active Fault and Earthquake Hazard Center, Pukyong National University, Busan, Republic of Korea
(*Email: gayatripavan.ngri@csri.res.in)

ABSTRACT

The crustal geophysical framework of eastern Ladakh remains poorly understood despite it being an important geothermal province and also a repository of key signatures of the India–Eurasia subduction–collision system, limiting our understanding of its tectono-magmatic evolution, fluid pathways, and geothermal potential. To address this gap, broadband magnetotelluric (MT) investigations were carried out in eastern Ladakh, covering major lithotectonic domains, suture zones, and batholithic regions. The MT data were processed and modelled by using two-dimensional and three-dimensional inversion approaches to image the subsurface electrical resistivity structure. The resulting geoelectric models

reveal significant lateral and vertical resistivity variations across eastern Ladakh. Across the Indus Suture Zone (ISZ), the resistivity structure marks a transition from highly resistive Indian crust to moderately resistive crustal domains farther north. Several discrete crustal conductors are imaged between the ISZ and the Zanskar Thrust, including an upper-crustal conductor beneath the Tso Morari Crystalline complex and a mid-crustal conductivity anomaly beneath the Shyok Suture Zone–Karakoram region. These conductors may represent fluid-rich zones, altered zones, or fossil magmatic zones associated with earlier tectono-magmatic processes. The models further indicate that the Puga, Chumathang, and Gaik hot-spring systems are connected to a common shallow conductive body at about 5 km depth, suggesting structurally controlled geothermal fluid circulation. The Ladakh batholith also shows lateral thickness variation and is associated with a conductive channel beneath it, implying possible interaction between batholithic architecture and fluid/melt migration. Overall, our MT results reveal a multi-level conductive system in eastern Ladakh, linking shallow conductive zones with deeper crustal structures and major tectonic boundaries. These findings provide new insights on the crustal architecture, fluid pathways, and geothermal potential of the region.

CHARACTERIZATION OF CLASTIC RESERVOIR ROCK USING 3D TOMOGRAPHIC IMAGES: A DIGITAL ROCK PHYSICS FRAMEWORK

Ayush Chandra,[1,2], Piyush Sarkar[1*], Kumar Hemant Singh[3]
[1]Rajiv Gandhi Institute of Petroleum Technology, Amethi
[2]Oil and Natural Gas Corporation Limited
[3]Indian Institute of Technology, Bombay
Presenting author*: piyush.s@rgipt.ac.in

ABSTRACT

Understanding the pore architecture and connectivity of clastic reservoir rocks is important for assessment of their hydrocarbon storage and fluid-flow characteristics. In clastic reservoirs such as sandstone, the original pore network system is commonly modified by diagenetic processes and create isolated or poorly connected pores that contribute to total porosity but not effectively contribute to pore network for fluid flow. Conventional laboratory measurements provide valuable information on bulk petrophysical properties but limited information on the 3-D pore distribution, pore isolation, and connectivity of pores. Digital Rock Physics (DRP) combined with 3D tomographic imaging, provides a non-destructive approach for examining these micro-scale pore features. In this study, reconstructed tomographic images of sandstone sample were analyzed to estimate total, effective and isolated porosity and pore-network connectivity using a comprehensive digital rock physics framework. Image processing was used to separate the pore space from the solid matrix and identify its connected and isolated components. The computed total porosity is ~24%, while the effective porosity ~18% and ~3% of the total pore volume are reported as isolated pore, possibly reflecting diagenetic modification of the original pore structure. The image-derived porosity values agree well with laboratory results, supporting the reliability of the segmentation and analysis workflow. In this study, the coordination number was computed from extracted pore network using developed digital rock physics approach and further pore connectivity was quantified directly from coordination-number analysis. The calculated coordination number ranges from 5-7, indicating a well-developed and interconnected pore network. The quantitative and qualitative results also align closely with the pore geometry, distribution, and connectivity visible in the 3-D reconstructed images. These results validate the effectiveness of the used

DRP framework and support its application in assessing the fluid-flow potential of clastic reservoir rocks. Although image resolution may limit the identification of very small pores and narrow pore throats, the study shows that DRP can effectively distinguish connected & isolated porosity and pore network, providing an improved pore-scale characterization of clastic reservoirs.

Keywords: Digital Rock Physics (DRP), 3D Tomographic Imaging, Sandstone, Pore attributes, co-ordination number.

UPPER LITHOSPHERE STRUCTURE BENEATH THE NORTHWEST HIMALAYA, CENTRALIZING THE KASHMIR BASIN

Pousali Mukherjee, Raees C, Imtiyaz Ahmed Parvez
CSIR-National Institute of Data Science and Artificial Intelligence
Presenting author: Pousali Mukherjee (pousali.4pi@csir.res.in or pousali.iiserkol@gmail.com)

ABSTRACT

The Kashmir Basin occupies a distinctive tectonic setting within the Northwestern Himalaya, being bounded by the Pir Panjal and Zanskar ranges. The relatively lower convergence rate across the Kashmir Valley compared with the broader Northwestern Himalaya suggests that the region may accommodate deformation differently, reflecting variations in the underlying lithospheric structure. In this study, we investigate the upper lithospheric structure beneath the Northwestern Himalaya, with particular emphasis on the Kashmir Basin and its adjoining regions, using broadband seismic data from the CSIR-NIDSA network. Teleseismic events have been used to estimate P-wave receiver functions through iterative time-domain deconvolution, followed by stacking and inversion. Systematic variations in receiver function characteristics with backazimuth indicate significant lateral and azimuthal heterogeneity in the underlying crustal structure. The receiver function stacking and inversion results reveal Moho depths ranging from approximately 40 to 60 km across the study region. Comparison with previous geophysical studies suggests a general deepening of the Moho toward the northeast, although localized shallower Moho occurrences indicate substantial spatial variability in crustal thickness. In addition, low-velocity zones are observed at depth, which may be associated with zones of deformation and shearing within the crust. The observed variations in Moho geometry, crustal velocity structure, and receiver-function response provide evidence for significant structural heterogeneity beneath the Northwestern Himalaya. These results offer new constraints on the contrasting lithospheric architecture of the Kashmir Basin and the surrounding Himalayan regions and contribute to understanding how variations in crustal structure may influence the spatial distribution of deformation and convergence in the Northwestern Himalaya

INTEGRATED ASSESSMENT OF SEISMIC SITE EFFECTS, VELOCITY-DEPTH PROFILES, AND RESPONSE SPECTRUM IN THE CENTRAL INDO–GANGETIC PLAINS.

Prashant Vishwakarma[1]*, Nitin Sharma[1], and Prakash Kumar[1]
[1]CSIR–National Geophysical Research Institute (NGRI), Hyderabad – 500007, India
*Presenting Author: prashant.gpy@gmail.com

ABSTRACT

The assessment of seismic site effects in the Indo-Gangetic Plains (IGP) is important because of the presence of thick alluvial deposits underlying one of the world's most densely populated and rapidly developing regions. The IGP is located close to the seismically active Himalayan belt, which has hosted several destructive earthquakes in the past. Thick and heterogeneous sedimentary deposits can significantly modify seismic-wave propagation through impedance contrasts, resonance, and frequency-dependent amplification, potentially affecting the seismic risk assessment in the region. Therefore, in this study, we attempted to investigate earthquake-based horizontal-to-vertical spectral ratios (eHVSR) and acceleration response spectra across the Central Indo-Gangetic Plain by using the seismic records from the 2015 Nepal (Gorkha) earthquake Mw=7.8 and five of its aftershocks. The eHVSR results exhibit multiple prominent peaks at low frequencies, which are interpreted as signatures of the thick and multilayered sedimentary structure of the Indo-Gangetic Basin. The consistency of the predominant spectral peaks across multiple earthquake records indicates reliability and stability of the observed seismic site response. The observed predominant spectral periods are concentrated in the longer-period range (2-5 seconds), indicating the strong influence of the thick sedimentary succession on the dynamic response of the basin. Inversion of the observed eHVSR curves indicates relatively low shear-wave velocities (Vs) extending to shallow depths, consistent with observations in existing studies. The spectral response characteristics further demonstrate the frequency-dependent modification of ground motion across the sedimentary basin, with varying amplification factors ranging between 5 and 8 over the investigated period range. These results highlight the role of basin structure and local site conditions in controlling seismic-wave amplification and provide important constraints for seismic-hazard assessment, seismic microzonation, and the design of earthquake-resistant infrastructure across the Indo–Gangetic Plain.

Keywords: Seismic Hazard, Fundamental frequency, Indo-Gangetic Plains, Response Spectra, Himalaya.

MOHO DEPTH RETRIEVAL USING AMBIENT NOISE AUTOCORRELATIONS

Pratul Ranjan[1,2,*], Alan Augustine[1,3], Prakash Kumar[1,2]
[1] CSIR-National Geophysical Research Institute (NGRI), Hyderabad-500007, Telangana
[2] Academy of Scientific Innovation and Research (AcSIR), Ghaziabad-201002, Uttar Pradesh
[3] Cochin University of Science and Technology, Kochi-682001, Kerala
*Presenting author: pratulranjan.ngri@csir.res.in

ABSTRACT

The depth and geometry of the Mohorovičić discontinuity (Moho) are important for understanding crustal structure and the tectonic evolution of a region. Receiver-function analysis is one of the most commonly used methods to estimate Moho depth, based on identifying P-to-S converted phases generated at subsurface discontinuities. However, receiver-function studies depend on suitable teleseismic earthquakes with adequate magnitude and azimuthal coverage. Their interpretation can also be affected by source distribution, crustal anisotropy, and complex near-surface structure. These limitations can become particularly important in regions with sparse seismicity or limited earthquake recordings. In this study, we use ambient-noise autocorrelations as an alternative approach for

retrieving subsurface reflectivity and estimating Moho depth. By autocorrelating long-duration continuous seismic recordings, it is possible to extract coherent wavefield features associated with subsurface interfaces without relying on individual earthquake sources. The resulting autocorrelation functions can be interpreted as virtual zero-offset responses, providing information about major impedance contrasts within the crust. This makes the method particularly useful for dense seismic networks, where continuous recordings are available over long periods. We analyse ambient-noise autocorrelations to identify coherent crustal reflections and identify the Moho. The retrieved reflectivity is used to estimate crustal thickness, and the results are compared with independent constraints from conventional seismic observations. We further examine how the quality and stability of the Moho-related signal and our results demonstrate the potential of ambient-noise autocorrelations to recover crustal-scale reflectivity and provide estimates of Moho depth using earthquake-independent observations.

INTEGRATED ANALYSIS OF TEMPORAL AND SPATIAL SEISMIC VARIATIONS IN THE HIMALAYAS USING GUTENBERG–RICHTER PARAMETERS AND A CLUSTERING APPROACH

R. Annusha1 and N. Venkatanathan*[1]
SASTRA Deemed to be University, Thanjavur, India.
Presenting author: annumahaofcl.02@gmail.com

ABSTRACT

The Himalayan region is characterized by high population density and persistent seismic vulnerability associated with the ongoing convergence of the Indian and Eurasian plates. Significant earthquakes, including the 1975 Kinnaur (Mw 6.8), 1991 Uttarkashi (Mw 6.8), 1999 Chamoli (Mw 6.5), and 2005 Kashmir (Mw 7.6) earthquakes, highlight the importance of understanding the temporal and spatial evolution of regional seismicity for seismic hazard assessment. This study presents a retrospective analysis of seismicity across the Himalayan region (29.5°–35.0°N, 73.0°–81.5°E) during 1975–2025, integrating the Gutenberg–Richter (G–R) relationship with unsupervised machine-learning-based spatial clustering. The a-value and b-value are used to characterize variations in seismicity level and magnitude distribution, while clustering analysis examines the spatial organization of earthquake activity. The earthquake catalogue was first processed through magnitude homogenization and magnitude-ofcompleteness (Mc) assessment, followed by conditional, rule-based de-clustering to remove aftershock and swarm sequences. Temporal variations in G–R parameters were evaluated using an expanding fiveyear window with a weekly step. The analysis revealed a recurring pattern of increasing a-value accompanied by decreasing b-value preceding selected significant earthquakes (Mw ≥ 6.0). The corresponding pre-earthquake periods were further examined using rolling spatial clustering to identify changes in seismicity organization. The results revealed distinct spatial anomalies and variations in clustering characteristics during selected periods preceding significant earthquakes. The integrated G–R and clustering framework demonstrates systematic temporal and spatial changes in seismicity and highlights their potential relevance as precursory characteristics for retrospective seismicity analysis and seismic hazard assessment in the Himalayan region.

RESOLUTION ANALYSIS OF GRACE-DERIVED TERRESTRIAL WATER STORAGE USING THE BACKUS–GILBERT APPROACH

Raghav Singh[1], Nishant Singh[1], Swapnil Pandey[1] and Satya Prakash Maurya[1]
[1]Department of Geophysics, Banaras Hindu University, Varanasi, Uttar Pradesh, India
Presenting Author E-mail: raghavsingh@bhu.ac.in

ABSTRACT:

The Gravity Recovery and Climate Experiment (GRACE) satellite observations have been widely used to study changes in terrestrial water storage (TWS), particularly over large regions. Their application at smaller spatial scales, however, remains difficult because of the limited spatial resolution of the satellite gravity field. The present study examines this limitation for Sonbhadra district, Uttar Pradesh, using the Backus–Gilbert (BG) approach. Sonbhadra covers an area of about 6815.63 km² and has approximate dimensions of 103.82 × 114.41 km. CSR RL06 Level-2 GSM spherical-harmonic data are considered in the analysis, along with degree-dependent load Love numbers. BG averaging kernels are constructed at the centroid of Sonbhadra by minimizing their angular spread under a point-normalization constraint. Calculations were carried out for maximum spherical-harmonic degrees (L_{max}) between 10 and 96 to examine how the achievable resolution changes with spectral truncation. The estimated RMS resolution decreases from about 1995 km for L_{max}=10 **to** 965 km at L_{max}=20**,** 469 km at L_{max}=40 **and** 308 km at L_{max}=60. On extending the solution to degrees 80 and 96, the corresponding values decrease further to about 229 km and 190 km, respectively. At L_{max}=96, the half-response radius is approximately 172 km**.** The analysis also shows that only about 0.49%**,** 3.93% **and** 9.54% of the averaging-kernel energy lies within the Sonbhadra boundary for L_{max}=20, 60 and 96, respectively. Thus, although inclusion of higher spherical-harmonic degrees improves localization, the resulting footprint remains larger than the district itself. The results indicate that a GRACE-derived water-storage signal for Sonbhadra cannot be regarded as originating exclusively from within its administrative boundary and contains a considerable contribution from surrounding areas. The BG analysis provides a quantitative estimate of this spatial limitation and can assist in interpreting GRACE observations before their integration with regional groundwater and InSAR measurements.

Keywords: GRACE, Backus–Gilbert inversion, terrestrial water storage, spherical harmonics, spatial resolution, averaging kernel, groundwater, Sonbhadra.

TECTONIC AND NON-TECTONIC CRUSTAL DEFORMATION IN UTTARAKHAND.

Rajeev Kumar Yadav[1*]
[1]CSIR-National Geophysical Research Institute, Hyderabad, 500007.
[*]Presenting author: yadavrk.bhu@mail.com

ABSTRACT

Uttarakhand, located in the seismically active Northwest Himalaya, has experienced several devastating earthquakes in the past. A detailed investigation has been conducted into present-day crustal deformation using continuous GPS observations over the past two decades. The GPS time series reveal significant seasonal variations in horizontal and vertical displacements, of which approximately 40–60% can be explained by transient deformation derived from global hydrological models. After

removing seasonal variations, site velocities were used to estimate the regional plate convergence rate and the extent of locking of the Main Himalayan Thrust (MHT). The results indicate NNE-directed compression with a mean rate of −0.09 μstrain yr^{-1}, a convergence rate of ~18 mm yr^{-1}, and a locked frontal MHT width of ~100 km. Strong interseismic coupling indicates substantial strain accumulation across Uttarakhand. The combination of high strain accumulation and the prolonged absence of major to great earthquakes over the past ~200 years highlights the region's significant seismic potential, including the possibility of a future Mw ≥ 8 earthquake.

Keywords: Crustal deformation, Main Himalaya Thrust, Strain rate, Seismic hazard

SEISMIC NETWORK MONITORING FOR CASCADED HAZARD EARLY WARNING IN THE HIMALAYAS

***Rajesh Rekapalli[1,2], Sandeep Gupta[1,2] and N. Purnachandra Rao[2]**
[1] CSIR-NGRI, Hyderabad, Telangana-500007, India.
[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh- 201 002, India.
Corresponding author: Rajesh Rekapalli (rekapalli@gmail.com)

ABSTRACT

The Himalayan region, with its complex geological and tectonic settings, is highly vulnerable to cascaded hazards such as landslides, rockfalls, and avalanches. These events, often triggered by earthquakes, intense rainfall, or rapid snowmelt, pose severe risks to human life, infrastructure, and ecosystems. Traditional early warning systems (EWS) that rely on localized sensors often fail to capture the interconnected dynamics of these hazards. This study discusses a novel early warning framework that leverages seismic network monitoring to detect signals of landslides, rockfalls and associated mass movements. Particularly, secondary events like debris flows and floods associated with rockfall and landslide events cause more severe damage than landslide and rockfall events to downstream areas. The floods caused by (a) the Rontighad rockfall on 07 February 2021 in the Chamoli district, Uttarakhand, India and (b) the 26 August 2026 massive flash flood triggered by a glacier collapse near the Nepal–Tibet border are classic examples of such events. As seismic networks can capture rockfall or landslide signals precisely up to distances of hundreds of kilometers, timely detection of these signals enables the early warning of cascaded secondary hazards to minimize losses. In this work, key parameters of seismic network-based monitoring of landslides and rockfalls for early warning of associated mass flow events were discussed with methodological advances, success stories, and regional scalability, emphasizing seismic EWS's potential to mitigate risks in the Himalayas. This approach represents a significant step toward adaptive, real-time monitoring of cascaded hazards in fragile mountain environments.

Keywords: Seismic Monitoring, Himalayas, Early Warning Systems, Landslides, Rockfalls, Debris Flow, Flood.

COMPARISON OF CROSS-CORRELATION AND AMPLITUDE BASED LOCATION METHODS FOR IDENTIFYING LANDSLIDE SOURCE LOCATION

Kethavarapu Raviteja[*1, 2], Rajesh Rekapalli[1, 2], Mahesh Yezarla[1, 2], Sandeep Gupta[1, 2], V. Venkatesh[1]
[1.]CSIR-NGRI, Hyderabad, Telangana-500007, India.
[2.]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh- 201 002, India.
Email: ravitejakethavarapu2000@gmail.com

ABSTRACT

Seismic monitoring is increasingly used to monitor landslides in mountainous terrain, where traditional/in-situ observation is often difficult. Locating the source of a landslide from its seismic record, however, remains a challenging task. Missing seismic phases due to unclear onset and overlapping frequency content with earthquakes and background noise restrict the usage of standard phase-pick-based earthquake location methods. Researchers have been using amplitude- and cross-correlation-based methods for localization of landslide sources. Both categories rest on different assumptions and carry different limitations. Cross-correlation-based location requires reasonably coherent waveforms across the network. Its accuracy drops when signals lose coherence due to attenuation, scattering, or heterogeneous propagation paths, particularly at larger inter-station distances. Amplitude-based location depends on assumptions about how seismic energy decays with distance. It is sensitive to station-network geometry, site response, and local attenuation, all of which can bias the estimated source location. In both cases, the spatial distribution of stations around the source region plays a central role in how reliable the location estimate turns out to be. In this work, we present a comparative analysis using cross-correlation and amplitude-based location methods for large landslides. The study will provide a viable basis for choosing an appropriate location approach based on network configuration and site conditions in landslide early warning applications in mountainous terrain.

Keywords: Seismic monitoring, Landslides, Source location, Cross-correlation, Amplitude-based location, Early warning

INVESTIGATING THE RELATIONSHIP BETWEEN SITE-SPECIFIC K_0 AND HVSR-BASED SITE RESPONSE IN THE GARHWAL HIMALAYA, CENTRAL HIMALAYAN SEISMIC GAP

Renu Yadav and Dinesh Kumar
Department of Geophysics, Kurukshetra University Kurukshetra 136119 India
e-mails: renuyadav_geokuk@yahoo.com and dikumar@kuk.ac.in

ABSTRACT

Reliable characterization of local site effects and high-frequency attenuation is essential for seismic hazard assessment in the Himalaya, where complex geological conditions strongly influence earthquake ground motions. Although the spectral decay parameter κ and Horizontal-to-Vertical Spectral Ratio (HVSR) techniques are widely used for site characterization, their combined interpretation has received limited attention in the Himalayan region. This study investigates the relationship between site-specific κ_0 and HVSR-derived site response characteristics in the Garhwal segment of the Central Himalayan Seismic Gap using 432 three-component strong-motion records from 40 earthquakes (Mw 3.0-6.5). κ values were estimated using the Anderson-Hough approach, and

station-specific κ_0 values were derived through κ-distance regression, while site response was independently evaluated using the HVSR technique. Mean κ values were found to be 0.066 and 0.045 for horizontal and vertical components, respectively, with κ increasing systematically with hypocentral distance and exhibiting no significant magnitude dependence. Station-specific κ_0 values range from 0.03 at hard-rock sites to 0.097 at soft-soil sites, demonstrating the strong influence of near-surface geological conditions on high-frequency attenuation. HVSR analysis reveals predominant frequencies between 1.20 and 5.78 Hz and amplification factors ranging from 4.37 to 13.09. A clear correspondence is observed between κ_0 and site amplification characteristics, with stations exhibiting larger κ_0 values generally showing stronger amplification and lower resonance frequencies. The results suggest that κ_0 effectively captures attenuation-related site effects and may serve as a practical proxy for relative site response in regions where detailed geotechnical information is unavailable. The study provides new insights into the interplay between attenuation and amplification processes in the Garhwal Himalaya and offers valuable inputs for seismic hazard assessment, ground-motion modelling, and microzonation studies.

GEOPHYSICAL DATA FUSION AND MACHINE LEARNING FOR SUBSURFACE CHARACTERIZATION OF DECCAN TRAP TERRAIN

Ronak Dahiya[1,2]*, Sanjay Rana[1], Abul Aas[1], Ajay Mishra[1]
[1]PARSAN Overseas Pvt. Limited, New Delhi-110019, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
Presenting Author: mail2ronakdahiya@gmail.com

ABSTRACT

Understanding subsurface geology is important for engineering, environmental, and geological studies. In this work, Electrical Resistivity Tomography (ERT) and Seismic Refraction Tomography (SRT) data were integrated and analysed using a machine learning clustering approach to improve subsurface mapping in a Deccan Trap terrain. The ERT data showed resistivity values ranging from 12 to 9885 Ω.m, while the SRT data showed P-wave velocities ranging from 703 to 4854 m/s. Both datasets were interpolated onto a common grid and combined into a single database. A K-means clustering method was then applied to classify areas having similar geophysical properties. Borehole lithology data were used to compare and validate the clustering results.

The clustering analysis successfully separated different subsurface zones, including weathered material, basalt, sandstone, fractured zones, and compact rock formations. The results showed a good agreement with borehole information and helped reduce uncertainty in the interpretation. One of the important findings of the study is the identification of weak sandstone layers and Infratrappean (Lameta-type) formations beneath the basalt sequence. These units were clearly distinguished from the overlying basalt using the combined resistivity and seismic velocity information. The study shows that integrating ERT and SRT data with machine learning clustering is a simple and effective approach for subsurface mapping. The method helps in identifying different geological units more clearly and provides a better understanding of subsurface conditions in Deccan Trap terrains.

Keywords: Electrical Resistivity Tomography (ERT); Seismic Refraction Tomography (SRT); Machine Learning; K-means Clustering; Deccan Trap; Infratrappean Formation.

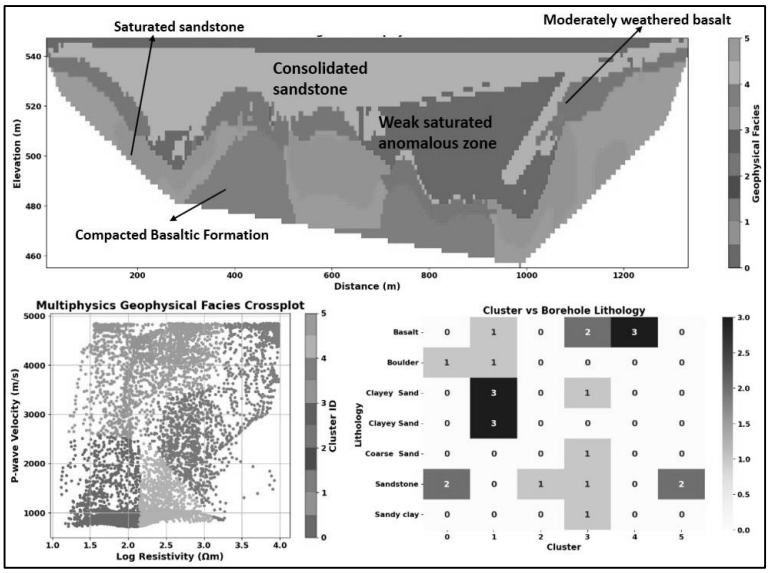


Figure 1: Integrated multiphysics geophysical facies model derived from Electrical Resistivity Tomography (ERT) and Seismic Refraction Tomography (SRT) data using K-means clustering

BOUGUER GRAVITY DATA ANALYSIS AND STRUCTURAL INTERPRETATION OF THE NUGGEHALLI SCHIST BELT: IMPLICATIONS FOR MINERAL EXPLORATION

S. Bangaru Babu, D. Deepthi and Shikha Jose
Geophysics Division, Geological Survey of India, Southern Region, Hyderabad, India- 500 068
E-mail: bangaru_geo@rediffmail.com

ABSTRACT

Regional gravity data covering an area of approximately 17,000 km² in parts of Chitradurga, Hassan, Tumkur and Mandya districts, Karnataka, India were analysed to investigate the subsurface structural framework and its relationship with mineralisation in the Nuggehalli Schist Belt (NSB). The NSB constitutes a prominent Archean supra-crustal belt within the Western Dharwar Craton and extends predominantly along NNW-SSE to NW-SE trends. It is enclosed by granitoid-gneissic rocks of the Peninsular Gneissic Complex and represents an important segment of the Archean greenstone terrain of the Dharwar Craton. The belt is dominated by metavolcanic and metasedimentary assemblages comprising amphibolites, metabasalts, banded iron formations (BIF), quartzites, schists and associated felsic volcanic rocks.

The regional gravity field delineates prominent NNW–SSE to NW–SE-trending anomalies extending from Huliyaru to Turuvekere, broadly consistent with the regional geological fabric and indicating significant structural control on the subsurface density distribution. The occurrence of positive gravity anomalies over the Nuggehalli Schist Belts is interpreted to reflect relatively high-density metavolcanic rocks, BIF and ultramafic–mafic complexes. A distinct NE-SW trending high gravity anomaly is spatially associated with exposed to near-surface ultramafic-mafic rocks of the NSB and may indicate their shallow subsurface continuation or structural uplift. The spatial association of gold occurrences in the Bukkapatna and Kadakola areas with these structural trends further suggests that the identified gravity lineaments may have influenced the mineralising processes.

The interpreted NE-SW trending cross-cutting geophysical lineaments appear to exert an important influence on the structural architecture of the region and intersect several favourable potential zones.

To assess the subsurface continuity and depth extent of the anomalous bodies, six representative gravity profiles were selected, comprising three profiles crossing known mineralised zones and three profiles across areas interpreted as concealed or potential mineralised zones. Spectral analysis and half-slope (Peter's half-slope) methods indicate that the principal density contrasts associated with the interpreted mineralised zones occur at depths of approximately 500-1100m. These zones coincide spatially with pronounced gravity-gradient maxima, suggesting sharp subsurface density contrasts and possible structural boundaries. The coincidence of gravity gradients, lithological contacts and mineral occurrences indicates that the identified deep-seated structures may have acted as conduits or pathways for mineralising fluids. The integrated gravity interpretation therefore delineates favourable prospective zones for further exploration of gold and chromite mineralisation, particularly along the intersections of the major NNW-SSE/NW-SE and NE-SW structural trends.

Key words: Nuggehalli Schist Belt, gravity anomalies and gravity gradient

CRUSTAL HEAT FLOW PARTITIONING AND 2D GEOTHERMAL MODELLING ALONG A PROFILE IN SOUTHWESTERN NIGERIA

[1*]Samuel Sedara, [2]Labani Ray, [3]Eswara Rao Sidagam, [4]Sasi Kumar Uddandam
[1,2,3,4]CSIR-National Geophysical Research Institute, Hyderabad, 500007, India
[2,3,4]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
[1]Department of Physics and Electronics, Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria
[*]samuel.sedara@aaua.edu.ng

ABSTRACT

In stable Precambrian terrains, surface heat flow (Q_s) reflects shallow crustal radiogenic heat production and deeper residual mantle heat flow (Q_m), whose partitioning remains poorly quantified in southwestern Nigeria. This study evaluates the partitioning of surface heat flow using a two-dimensional steady-state conductive thermal model along a 110 km W–E profile. The model is used to investigate crustal heat transfer, subsurface structure, thermal patterns, and the associated geothermal potential of the region.

A geological geometry for a 110 km × 20 km domain was constructed and solved numerically in COMSOL Multiphysics. The profile was partitioned at five stations (20 to 100 km) at 20 km intervals, assigned Q_s values of 60 and 70 mW/m², layer-specific thermophysical properties and radiogenic heat production for six lithological units (Crystalline Complex, Schist, Quartzite, Granite, Granitoid, Basement/Lower crust), and boundary conditions of 30 °C surface temperature with no lateral heat flow.

Crustal radiogenic contributions (Q_c) over the 20 km depth range were approximately 43–47 mW/m², with basal heat flow (Q_b) of 13–17 mW/m². Across the profile, temperature varied, with basal temperatures of 300–340 °C. Extending the crustal column to a 36 km Moho depth gave a Q_c range of 50–54 mW/m², producing a Q_m of 7–11 mW/m², confirming that only 60–70 mW/m² is physically viable at every station, with Moho temperatures of 400–450 °C, consistent with values in Precambrian regions.

The repeated model demonstrated temperature-field consistency within 2°C, whereas the near-horizontal isotherms with limited vertical disruption indicate largely sub-horizontal crustal layering. Of the Q_s scenarios tested, only 60–70 mW/m² produced consistent Q_m. The profile represents a locally radiogenically enriched domain within a lower regional background, with geothermal potential likely controlled more by structurally focused fluid pathways than by anomalously high regional heat flow, emphasizing the need for coupled

conductive-advective modelling. As the present model relies on literature-derived thermophysical properties, laboratory characterization of regional rock types is underway to improve robustness.

Keywords: Thermal modelling; Subsurface temperature; Conductive heat transfer; Geothermal potential; Nigeria

A DATA-DRIVEN FRAMEWORK FOR INTENSITY-BASED EARTHQUAKE EARLY WARNING IN THE UTTARAKHAND HIMALAYA

Sandeep[1]***, S. K. Pal**[2]
[1]Department of Geophysics, Banaras Hindu University, Varanasi
[2]Institute of Seismological Research, Gandhinagar, India
*****Presenting author: sandeepfgp@bhu.ac.in

ABSTRACT

The Indian Uttarakhand Earthquake Early Warning System (UEEWS) currently provides regional magnitude-based alerts, issuing similar warnings to locations surrounding an earthquake despite spatial variations in geological conditions, site amplification, and infrastructure vulnerability. This study develops a machine-learning framework that uses the initial characteristics of the incoming P-wave to rapidly estimate ground-motion parameters and seismic intensity, enabling more location-specific EEW. The Extreme Gradient Boosting (XGBoost) nonlinear regression algorithm is employed to predict P-wave arrival time (T_p), peak ground acceleration (PGA), peak ground velocity (PGV), and Modified Mercalli Intensity (MMI) for three structural classes (A, B, and C2). Unlike conventional EEW approaches based primarily on empirical magnitude-dependent relationships, the proposed framework directly estimates ground-motion parameters and intensity, thereby reducing dependence on earthquake magnitude as the principal predictor. The model is trained using 7,125 strong-motion records from earthquakes with M_w 2.9–7.0. During training, the PGA, PGV, and MMI models achieved R^2 values of 0.99 with low prediction errors. Independent validation using 1,734 records from 17 earthquakes (M_w 3.0–7.5) yielded R^2 values of 0.64 and 0.57 for PGA and PGV, respectively, demonstrating the model's ability to generalize to independent events. The predicted PGA and PGV are combined with regional parameters, including V_{s30}, vulnerability index (VI), and hypocentral distance (R), to estimate real-time seismic intensity. The framework further generates site-specific and interpolated PGA, PGV, and MMI maps, facilitating rapid identification of areas likely to experience severe shaking. The proposed approach provides a pathway toward spatially resolved EEW and can support rapid emergency response, disaster mitigation, and risk-informed decision-making across the Uttarakhand Himalaya.

SEISMIC SIGNATURE OF THE AUGUST 2026 NEPAL–TIBET GLACIER COLLAPSE: OBSERVATIONS FROM THE NATIONAL SEISMOLOGICAL NETWORK

Sanjay K Prajapati*, Ajay P Singh, G Suresh and R K Singh
National Centre for Seismology, Ministry of Earth Sciences, New Delhi
Presenting author: sanjaynecessary@gmail.com

ABSTRACT

On 26 August 2026, a massive ice–rock collapse along the Nepal–Tibet border near Rasuwagadhi mobilized nearly 200–500 million m^3 of material, descending ~1.2 km and triggering a devastating

debris flow and flash flood in the Bhote Koshi valley. Seismological agencies initially reported varying magnitudes (Mw 4.4 to 5.2), misinterpreting the event as a tectonic earthquake. This study presents a comprehensive seismic analysis of the failure and establishes diagnostic criteria to rapidly distinguish cryoseismic mass movements from fault-rupture earthquakes. Unlike impulsive tectonic ruptures, waveform analyses reveal a multi-pulse signal with a gradual onset, strong Rayleigh-wave energy, and sustained low-frequency vibrations (0.01–0.1 Hz). Spectrograms demonstrate progressive spectral broadening (0.5–8 Hz), capturing the continuous impact and fragmentation of the descending mass. Particle motion analysis confirms an elliptical retrograde pattern characteristic of shallow surface waves. Source modelling indicates a seismic moment (M0) of 1.1×1013 Nm, a low corner frequency (fc = 0.136 Hz), and a stress drop of just 0.07 MPa, nearly 77 times lower than that of a comparable tectonic earthquake. The energy conversion efficiency was exceptionally low (10-7 to 2 x 10-6), with radiated seismic energy (7.4 x 107 to 1.8 x 109 J) representing a minute fraction of the total gravitational potential energy (5.8 x 1015 to 1.45 x 1016 J). Waveform inversion resolved diffuse surface-wave dominated energy release without coherent rupture planes, further corroborating the mass-movement origin and aligning with global cryoseismic events such as the 2014 Oso landslide. Furthermore, Radiometric terrain correction (RTC) using gamma software shows a steep spectral decay rate over -30 to +30 dB, providing a distinct surface-wave fingerprint consistent with global mass-movement benchmarks. The Nepal–Tibet event thus exemplifies the cryoseismic class of mass-movement signals, distinct from tectonic earthquakes in both waveform morphology and energy partitioning. The findings underscore the critical role of dense broadband seismic networks in rapidly distinguishing cryoseismic signals from tectonic earthquakes in vulnerable Himalayan terrain.

ADVANCING GEOPHYSICAL PRACTICES FOR SAFE AND SUSTAINABLE INDIAN COAL MINING

Sanjit Kumar Pal[1*], R.M. Bhattacharjee[2], Rajwardhan Kumar[1], Amit Bera[1], Vivek Vikash[1], Umakant Das[1]
[1]Department of Applied Geophysics, IIT(ISM) Dhanbad
[2]Department of Mining Engineering, IIT(ISM) Dhanbad
Presenting author: Sanjit Kumar Pal; sanjitismagp@iitism.ac.in

ABSTRACT

The sustainable use of coal resources in India increasingly counts on advances in near-surface geophysical practices to mitigate subsurface geohazards and augment resource management in legacy coalfields. Coal mines, whether open-cast or underground, are susceptible to localised ground instability and water accumulation, both of which can pose significant risks to mine operations and personnel. Illegal mines voids threaten surface stability. Abandoned mine galleries are prone to collapse, and old mine workings beneath critical infrastructure, such as railway tracks, pose serious safety risks and threaten economic stability and the integrity of public infrastructure. Coal mine fires are a devastating geohazard in active Indian coal tracts that need to be detected and monitored at early stages using a combination of magnetic, thermal imaging, and advanced computational techniques. Conventional investigation techniques, including borehole-based investigations and discrete geotechnical measurements, provide valuable point-based information but have limited capability to continuously and non-invasively characterise hazardous zones. By transitioning to high-resolution, multi-parametric frameworks such as Gravity, Magnetic, Electrical Resistivity Tomography (ERT), Ground-Penetrating Radar (GPR), and Multichannel Analysis of Surface Waves (MASW), combined

with UAV remote sensing and artificial intelligence, the mining sector can non-invasively map subterranean environments and reduce geological uncertainty. This talk will cover a few case studies on integrated geophysical practices for concealed coal fire mapping, abandoned mine gallery mapping, and mapping hazards due to mining-induced subsurface cavities and waterlogged areas in the Raniganj and Jharia Coalfields. Successful case studies using integrated multiparametric geophysical imaging will promote more advanced practices in Indian Coal Mining.

CHARACTERIZATION OF PRESENT-DAY CRUSTAL DEFORMATION IN THE ANDAMAN–NICOBAR ISLANDS USING GNSS MEASUREMENTS

Sapna Ghavri, Ch. Patanjali Kumar, M. Vijaya Sunanda, Sudheer Joseph, Shiva Prasad, K. Rajesh, Balakrishnan Nair TM
Indian National Center For Ocean Information Servicies, Hyderabad
Presenting Author email: sapna.ngri@gmail.com

ABSTRACT

The 2004 Sumatra–Andaman megathrust earthquake ruptured approximately 1,400 km of the subduction zone and generated a devastating tsunami. To characterize ongoing crustal deformation and assess potential seismic source zones in the Andaman–Nicobar region, continuous GNSS observations from 30 stations established by INCOIS, Hyderabad, from 2013 to 2025 were analyzed. Data quality was assessed using TEQC software, and displacement–time series were generated using GAMIT-GLOBK software. The results reveal significant non-linear motions, which is 15-20 mm/yr in the horizontal component and 10 -15 mm/yr in vertical components, particularly at stations in the southern Andaman–Nicobar Islands, indicating ongoing post-seismic deformation associated with the 2004 megathrust earthquake. To characterize the post-seismic deformation, the inter seismic plate motion reported at Port Blair prior to the earthquake was assumed to be uniform across the stations and removed from the observations. A least-square approach was then used to estimate the characteristic decay timescale over a range of 0.1–1000 years. The estimated timescales range from 2 to 28 years. A layered viscoelastic deformation model was further applied using the 2004 earthquake source model of Chlieh et al. (2007), an upper-mantle viscosity of 10^{18} Pa-s, and a lithospheric elastic thickness of 60 km is used. The results demonstrate that significant post-seismic deformation continues to influence the present-day kinematics of the Andaman–Nicobar Islands, providing insights into the long-term relaxation behaviour of the subduction system. This study will further help in understanding the Seismogenic/Tsunamigenic hazard potential of the region.

CHARACTERIZATION OF SUBSURFACE SOIL PROFILE USING GPR AND BOREHOLE INTEGRATION IN ALLUVIAL TERRAIN

Satish Kumar Sinha[1], Krishna Kumar Yadav[1], Ashvini Kumar Yadav[1], and Alok Saini[2]
[1]Rajiv Gandhi Institute of Petroleum Technology, Jais, Amethi, Uttar Pradesh, India
[2] Remote Sensing Application Center, Lucknow, Uttar Pradesh, India
Presenting author: ssinha@rgipt.ac.in

ABSTRACT

A detailed understanding of near-surface alluvial architecture is important for engineering, groundwater, agricultural, and environmental applications. This study investigates the potential of borehole-calibrated, low-frequency Ground Penetrating Radar (GPR) for quantitative mapping of subsurface properties in the central Ganga Plain, India. Two fixed-offset GPR profiles were acquired

with a 16 MHz antenna near boreholes BH6 and BH7 at the RGIPT campus, Jais. Borehole logs and grain-size data reveal heterogeneous sand–silt successions with subordinate gravel and clay.

Borehole-constrained reflector depths were combined with GPR two-way travel times to obtain interval velocities, from which dielectric constant, soil water content (SWC), porosity, and void ratio were estimated. Porosity was calculated using three-phase solid–water–air conditions above the groundwater table and two-phase solid–water conditions below it. Vertical and normalized porosity gradients were additionally derived to emphasize stratigraphic transitions and compaction-related variations.

The velocity models show values of approximately 0.10–0.13 m ns^{-1} within the upper 5 m and 0.05–0.09 m ns^{-1} at greater depths. Corresponding dielectric, SWC, porosity, and void-ratio distributions delineate moisture-rich intervals at approximately 8–12 m and 23–26 m depth, characterized by reduced velocity and enhanced dielectric response. These zones are interpreted as relatively fine-grained, moisture-retaining sediments that may influence subsurface water storage and movement. Although both profiles display comparable vertical layering, greater lateral variability occurs near BH7, consistent with more heterogeneous depositional conditions.

The coherent relationships among velocity, dielectric response, SWC, and pore-space attributes support the use of Topp's relationship and the Complex Refractive Index Model for sandy–silty alluvium. The results show that borehole-constrained low-frequency GPR can provide spatially continuous information on stratigraphy, moisture distribution, pore-space variability, and relative sediment compactness.

CRUSTAL DEFORMATION STUDY OF EASTERN HIMALAYAN SYNTAXIS AND SURROUNDINGS FROM SWS ANALYSIS OF DIRECT S

Satyapriya Biswal[a], Debasis D Mohanty[a,b],
[a]Geosciences and Technology Division, Council of Scientific and Industrial Research (CSIR-NEIST), Jorhat, Assam, India
[b]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, New Delhi, India
Presenting author: satyapriyabiswal8763@gmail.com
Corresponding: debasis.neist@csir.res.in

ABSTRACT

The Eastern Himalayan Syntaxis (EHS) and its adjoining region represent a complex zone of active continental deformation, where regional convergence and inherited crustal structures produce pronounced spatial variations in strain. We investigate the crustal deformation mechanisms using shear-wave splitting (SWS) of direct-S phases recorded at 75 broadband stations, yielding 120 reliable splitting measurements. The resulting fast-polarization directions reveal a strongly heterogeneous but spatially organized crustal anisotropy patterns. In the western and central areas, fast directions are predominantly oriented NE–SW to ENE–WSW, broadly consistent with the regional Himalayan structural grain. Toward the eastern and northeastern regions, the orientations exhibit progressive rotation and greater scattering, including E–W, NW–SE, and locally N–S trends, indicating pronounced spatial partitioning of crustal strain. Comparison with previously reported teleseismic XKS splitting further demonstrates that direct-S orientations locally deviate from the broader lithospheric anisotropy pattern, while partial alignment occurs in regions where crustal and deeper deformation remain coupled. The variations in direct-S anisotropy suggest that crustal deformation is controlled by active faults, pre-

existing structures, and stress-related fracturing. This indicates that deformation across the EHS varies spatially and with depth, reflecting the complex nature of present-day Himalayan crustal deformation.

Keywords: Eastern Himalayan Syntaxis, Crustal Deformation, Shear Wave Splitting, Crustal Anisotropy

PORE PRESSURE MODELLING VIA INTERPRETABLE AI/ML USING DOWNHOLE RECORDS OF WELL U1519A, HIKURANGI MARGIN, NEW ZEALAND

[1]Saumen Maiti* and [1]Goutami Das
Department of Applied Geophysics, IIT(ISM) Dhanbad-826004(INDIA)
*Presenting/Corresponding Author's Email: saumen@iitism.ac.in

ABSTRACT

Pore pressure (pp) modelling plays an important role in understanding subsurface geomechanics, well-bore stability, drilling efficiency, and resource potential in any complex geological areas. Pore pressure modelling in the continental-slope setting area of Hikurangi margin is difficult as the evolved complex stress mechanism is driven by high sedimentation rate and slow slip seismic hazard activities, which limits the use of traditional methods for accurate pore-pressure prediction that usually neglects the geological process and related fluid generation history. The present study employs an interpretable deep learning framework for pore pressure prediction using five well log parameters (e.g., density, neutron porosity, velocity, resistivity, and sonic transit time), lithology, and the drilling parameter of rotation per minute of well U1519A (IODP Expedition 372/375). Autoregressive modelling concept is implemented to take into account the previous depth geological process for the prediction of future depth pore pressure. Comparative analysis suggests that interpretable CNN-LSTM model outperforms CNN and comparable to XGBoost based on various statistical performance measures (e.g., root-mean-square errors (RMSE) and coefficients of determination (R^2) $RMSE_{CNN-LSTM}$~0.009, ${R^2}_{CNN-LSTM}$~ 0.997). Interpretable framework analysis shows that sonic transit time, velocity and lithology dominate feature importance across CNN, CNN-LSTM, and XGBoost models, demonstrating their crucial role in accurate pore pressure prediction. This study shows the potential of interpretable AI/ML framework for modelling and interpretations of pore pressure at Site U1519 and could be the basis for detailed further geomodelling studies in this area.

Keywords: Pore pressure; Well Log; Interpretable deep learning; Hikurangi Zone; IODP;

2D MAPPING OF PERMEABILITY IN GAS HYDRATE-BEARING SEDIMENTS USING MLRT TOOL: A CASE STUDY FROM THE KRISHNA-GODAVARI BASIN

Seema Begum[1, 2, *], Ranjana Ghosh[1, 2], Maheswar Ojha[1, 2]
[1]CSIR-National Geophysical Research Institute, Hyderabad- 500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad- 201002, India
*Presenting author email: mominseema94@gmail.com

ABSTRACT

Estimating permeability is essential to understand the flow rates of gas and water in the gas hydrate reservoirs. In this study, we propose a technique to optimize the 2D permeability network in a gas hydrate reservoir from well log and seismic data utilizing multivariate geostatistics. The Krishna

Godavari (KG) Offshore Basin is ideal for our study as the pressure core, downhole logs and seismic data in the areas B, C and E from the NGHP-01 and 02 expeditions indicate presence of significant amount of gas hydrate. We formulate an empirical permeability model using the data of five wells of Area B from NGHP-02 expedition through iterative calibration that uses clay volume as a controlling parameter. Available core data validates the established model. The estimated permeability varies significantly across the wells as 0.026 - 18293.7 mD at hole NGHP-02-16A, 0.044 - 29138 mD at hole NGHP-02-17A, 0.026 - 16,543 mD at hole NGHP-02-23A, 1.405 - 12,956 mD at hole NGHP-02-20A and 0.002 - 17,148 mD at hole NGHP-02-24A. Next, we select an arbitrary seismic line from the 2D seismic data of NGHP-02 expedition that passes through all five wells to obtain the acoustic impedance (AI) section by inverting the seismic data using model-based inversion technique. Finally, we estimate the areal distribution of permeability using the derived permeability at five wells and inverted AI section by applying multivariate linear regression transform (MLRT) geostatistical tool. We find that the overall permeability is less than 4500 mD, while porosity varies from 40 to 75%. The results of this study will assist researchers and engineers in the petroleum industry to accurately predict permeability during the exploration phase. This will also aid in the accurate analysis of fluid flow behavior, reservoir characterization, and reduction of uncertainty related to a reservoir evaluation.

Keywords: Gas hydrate reservoir, Permeability, Seismic Inversion, Acoustic Impedance, Geostatistics, KG Basin

AEROMAGNETIC CHARACTERISATION OF THE SARNU-DANDALI AND MER-MUNDWARA ALKALINE COMPLEXES IN NORTHWEST INDIA: IMPLICATIONS FOR REE MINERALISATION

D. Seshu*, V. Pradeep Kumar, H.V.S. Satyanarayana, Prakash Kumar
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500007, Telangana, India
Corresponding author: *seshugeo.ngri@csir.res.in

ABSTRACT

Alkaline complexes are important exploration targets owing to their close association with carbonatites and economically significant rare earth element (REE) mineralisation. The SarnuDandali (SD) and Mer-Mundwara (MM) alkaline complexes of Rajasthan, northwestern India, are part of the Deccan Large Igneous Province related to the Réunion hotspot and comprise diverse alkaline lithologies, including syenites, nephelinites, phonolites, mafic-ultramafic rocks, and carbonatites. Despite their economic significance, the subsurface geometry and magnetic characteristics of these complexes remain poorly constrained, with previous studies largely limited to two-dimensional interpretations. This study integrates three-dimensional (3D) forward magnetic modelling and magnetic vector inversion (MVI) to investigate the spatial distribution of magnetisation using aeromagnetic data acquired by the Geological Survey of India (source: https://geodataindia.gov.in). The total magnetic intensity (TMI) anomaly data are characterised by a dominant magnetic low (-3000 nT), particularly over the MM complex, indicating a significant contribution from remanent magnetisation. Because conventional magnetic susceptibility inversion assumes purely induced magnetisation, the amplitude of the analytic signal (AAS) was first calculated to transform the complex dipolar anomaly into a source-centred response that is largely independent of magnetisation direction. The AAS was

subsequently used to guide MVI, enabling robust recovery of the three-dimensional magnetisation distribution. The inversion results delineate high magnetisation bodies beneath the principal magnetic lows that spatially coincide with AAS maxima, defining the geometry and depth extent of the alkaline intrusions. The recovered magnetisation model indicates that remanent magnetisation exerts a primary control on the observed magnetic response of the MM complex, whereas the SD complex exhibits comparatively simpler magnetic behaviour. These results demonstrate that integrating AAS with MVI effectively resolves remanence-dominated magnetic anomalies and provides improved imaging of subsurface alkaline carbonatite systems. The study highlights the potential of advanced magnetic inversion for delineating concealed alkaline intrusions and identifying prospective REE-bearing targets in complex geological environments, providing a valuable geophysical framework for mineral exploration in northwestern India and analogous alkaline provinces worldwide. Keywords: Aeromagnetic, Remanent Magnetisation, Magnetic Vector Inversion (MVI), REE, Alkaline Complex, NW India.

IMAGING CRUSTAL HETEROGENEITY ACROSS NORTH-EAST INDIA AND THE INDO-BURMA CONVERGENT MARGIN USING AMBIENT NOISE TOMOGRAPHY

Shantanu Pandey
Indian Institute of Geomagnetism
shantanu.p@iigm.res.in

ABSTRACT

North-East India lies at the junction of the Himalayan collision zone and the Indo-Burma convergent margin and is characterized by strong lateral variations in crustal structure associated with active deformation, basement blocks, and sedimentary basins. We present a regional three-dimensional shear-wave velocity (Vs) model of North-East India and adjoining Myanmar derived from ambient noise tomography complemented by Rayleigh-wave dispersion measurements from regional earthquakes. The combined data set improves spatial path coverage and constrains crustal velocity variations across the Eastern Himalaya, Shillong Plateau-Mikir Hills, Assam and Surma basins, Indo-Burma Ranges, and Central Myanmar Basin.

The model reveals pronounced lateral and vertical crustal heterogeneity. Low-Vs zones delineate major sedimentary basins, with the Surma Basin showing the thickest sedimentary succession, while the Upper Assam Basin contains a shallower low-velocity layer that changes markedly across the Kopili Fault. A prominent high-Vs anomaly (Vs ~3.4-3.8 km/s) is imaged beneath the Shillong Plateau at depths of ~5-20 km and is interpreted as a mafic–ultramafic intrusive body associated with crustal modification of the plateau.

Beneath the central Arunachal Himalaya, localized high-Vs bodies (Vs ≥4.0 km/s) occur at ~10-20 km depth and are interpreted as crustal stacking or duplex structures related to Himalayan shortening. Toward the Indo-Burma margin, broad low-to-moderate velocity zones characterize the accretionary domain and display significant along-strike variation, while deeper crustal velocity contrasts toward central Myanmar reflect the complex architecture of the convergent margin.

These results demonstrate the effectiveness of combined ambient-noise and earthquake surface-wave imaging for resolving crustal-scale structures across tectonically heterogeneous regions and provide new constraints on the interaction among Himalayan shortening, Shillong Plateau crustal modification, sedimentary basin development, and Indo-Burma convergence.

ADVANCING DIGITAL ROCK PHYSICS: LINKING SEGMENTATION TO ELASTIC MODULI

Shib Sankar Ganguli* and Prakash Kumar
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500007, India
Email: shibg.ngri@csir.res.in

ABSTRACT

Digital rock physics (DRP) is an advanced method that provides a framework for linking rock microstructures with their flow behaviour and physical properties. A considerable portion of sub-resolution pore space remains uncaptured in digital rock images, which limits the accuracy of numerical simulations used to predict the effective elastic properties of rock. However, DRP calculations often assume simplified microstructures and treat all solid minerals as a single mineral phase when estimating rock properties. In this work, we present a comparison of various rock segmentation approaches to establish a robust workflow for accurately determining rock elastic properties. We further examine the incorporation of multi-mineral phases, instead of a single mineral phase, to evaluate the impact of mineralogical variability and sub-resolution mineral and pore fractions on the accuracy of elastic property estimation. Our approach has been validated by reliable predictions of rock physical properties for the Bentheimer and Bera sandstones. This study highlights potential gaps in current DRP workflows and demonstrates new possibilities for improving the accuracy of rock elastic property estimations, offering insights relevant to a wide range of Earth science problems, including carbon geosequestration, geothermal energy, and hydrocarbon reservoir characterization.

SEMI-SUPERVISED DEEP LEARNING FRAMEWORK FOR HIGH-RESOLUTION SEISMIC IMPEDANCE INVERSION IN A CARBONATE RESERVOIR

Soutik Bhakta[1*], Ravi Kant[1], Sanjay Pandit[1], Rahul Singh[1], Shanu Biswas[1], Prof. Kumar Hemant Singh[1]
[1]Department of Earth Sciences, IIT Bombay, 400076
∗ Presenting author: email: 23d0452@iitb.ac.in

ABSTRACT

Accurate seismic impedance inversion is essential for reliable reservoir characterization. However, obtaining high-resolution impedance models remains challenging because the seismic wavelet is often unknown, and recorded seismic data lack low-frequency content. Deep learning, particularly convolutional neural networks (CNNs), can provide higher-resolution impedance estimates than conventional approaches. However, the locally constrained receptive fields of CNNs limit their ability to capture long-range correlations, while Transformer-based models can capture such correlations but generally require larger training datasets. Deeper networks may also suffer from training instability, which can be reduced using residual blocks based on depthwise-separable convolutions. This work proposes a hybrid semi-supervised framework that combines CNNs, depthwise-separable residual

blocks, and Transformer blocks for seismic impedance inversion. The inversion module uses seismic traces and a low-frequency impedance model to predict high-frequency impedance. A CNN-based forward module reconstructs the seismic traces and low-frequency impedance from the predicted impedance. The training objective combines supervised error from labeled data with a reconstruction loss from unlabeled traces, allowing the framework to learn from both labeled and unlabeled data when well-log information is limited. A component-wise analysis demonstrates that the individual architectural components contribute to the overall inversion performance.

The proposed framework is applied to the D1 field of the Deep Continental Shelf block of the Mumbai Offshore Basin, a carbonate reservoir on the western Indian shelf. Of the ten available wells, eight are used for training, one for validation, and well D1-C1 is completely held out as a blind test. At the blind well, the proposed method improves the goodness of fit from 0.7047 to 0.8055 and reduces the normalized mean square error from 0.00738 to 0.00486 compared with a model-based inversion performed on the same seismic line. The inverted section also resolves thin impedance layers that are merged into single units in the model-based result, with these laterally continuous layers providing a good match to the D1-C1 impedance log. The results demonstrate that the proposed semi-supervised CNN-Transformer framework can improve the resolution and accuracy of seismic impedance inversion while effectively utilizing limited well-log information.

Keywords: seismic impedance inversion; semi-supervised learning; CNN-Transformer network; carbonate reservoir; Mumbai Offshore Basin.

COMPOSITIONAL ASSESSMENT AND CRUSTAL HETEROGENEITIES DECIPHERED ALONG HARDI-SAMATPUR 3-C WIDE-ANGLE SEISMIC PROFILE OF SOUTH REWA BASIN, CENTRAL INDIA

Sudeshna Moharana[1,2*] and Laxmidhar Behera[1,2]
[1]CSIR-National Geophysical Research Institute (CSIR-NGRI), Uppal Road, Hyderabad – 500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Uttar Pradesh, Ghaziabad 201002, India
*Corresponding Author: sudeshna.ngri19a@acsir.res.in

ABSTRACT

To decipher crustal compositional nature and underlying heterogeneity along the N-S trending Hardi-Samatpur 3-C seismic profile, shot in the south Rewa basin of Central India, we have used modelling and inversion of 3-C wide-angle seismic data. The 2-D crustal V_P and V_S models are derived from the radial (R) component seismic data by employing ray-trace inversion technique. The V_P and V_S models shows both lateral and vertical velocity variations along the profile till Moho depth. Using the derived velocity models, we have computed V_P/V_S and Poisson's ratio (σ) to infer compositional structure. The V_P/V_S along the profile, ranges from 1.63 to 1.84 and σ, from 0.20 to 0.29. The estimated V_P/V_S of 1.630-1.70, with corresponding σ (0.20-0.23) indicates Gondwana sedimentary rocks. Similarly, the moderate values of V_P/V_S (1.70-1.74) and σ (0.22-0.24), characterized the granitic-gneissic basement. The relatively high V_P/V_S of 1.79 and σ (0.274) present in the mid-crust form a low-velocity-zone (LVZ) at a depth of 13-18 km, may indictate fluid entrapment during the Gondwana rifting period. The lower-crust is characterized by V_P/V_S of 1.76-1.79 with σ (0.26-0.28) indicate presence of mafic rocks. At the base of the lower-crust, still higher V_P/V_S of 1.81-1.84 with σ (0.28-0.29) would indicate

presence of magmatic underplating related to Late-Cretaceous mantle plume activity. The Moho is detected at a depth of 37-44 km. Further, the deep-seated faults present along the profile, such as Narmada-Son-South faults (NSSF), Bahmin-Chilpa fault (BCF) and Balarampoor-Tattapani fault (BTF) are characterized by sharp changes in the compositions as deciphered from the V_P/V_S and σ plots. The present study provides an important insight about the rock composition and crustal heterogeneities beneath the South Gondwana Rewa basin.

Key-words: 3-C seismic data; V_P/V_S; Poisson's ratio (σ); Crustal composition; Underplating; Moho

PROGRESSIVE FABRIC DEVELOPMENT IN CRUSTAL SCALE SHEAR ZONE: INSIGHTS FROM INTEGRATED AMS, PGR, AND SPO ANALYSES

Swagata Singha[1*], Tridib Kumar Mondal[2], Susanta Kumar Samanta[1] and Subhabrata Das[1]
[1]Jadavpur University, Kolkata, India, *swagatas2701@gmail.com (Presenting and corresponding author), susantak.samanta@jadavpuruniversity.in, subhabratadas162@gmail.com
[2]Indian Statistical Institute, Kolkata, India, tridibkumarmondal@gmail.com

ABSTRACT

Shear zones represent domains of intense deformation, where the resulting fabrics preserve fundamental information on crustal deformation processes. The present study examines the development and spatial variation of deformational fabrics within the northeastern segment of the Singhbhum Shear Zone (SSZ), eastern India, using an integrated approach of Anisotropy of Magnetic Susceptibility (AMS), Point-Girdle-Random (PGR) fabric analysis, and Shape Preferred Orientation (SPO). A total of 120 oriented block samples were collected from seven distinct lithologies across the SSZ, yielding 674 oriented AMS specimens. AMS results reveal a consistent NW-SE-striking magnetic foliation and a predominantly NE-trending magnetic lineation, both broadly aligned with field-measured shear fabrics across various lithologies. Mean magnetic susceptibility (K_m) ranges from negative to strongly positive values, reflecting mixed diamagnetic-paramagnetic mineralogy. The nonlinear relationship between K_m and the degree of anisotropy (P_j) indicates dominant strain control on magnetic anisotropy. The predominance of oblate ellipsoids indicates that deformation is largely governed by flattening strains, while locally developed prolate fabrics mark zones of enhanced stretching. Magnetic fabrics are synchronous with the regional deformation, demonstrated by their alignment with shear-zone geometry and down-dip lineations.

PGR plots of magnetic lineation demonstrate systematic variation in magnetic fabric types, from weak or isotropic fabrics in lower-strain interior domains to well-developed tectonic and shear-related fabrics proximal to the shear zone. These patterns indicate progressive strain localisation and lithology-dependent fabric evolution within the SSZ. SPO analysis of 10 oriented thin sections, analysing over 18,000 mineral grains, reveals variable angular relationships between mineral long axes and magnetic lineations, with stronger alignment and higher SPO intensity recorded near the shear zone. Together, the AMS-PGR-SPO dataset highlights that progressive deformation and lithology-controlled mineral fabrics jointly govern strain partitioning in ductile shear zones, providing a comprehensive framework for integrating magnetic and mineral fabrics in complex shear systems.

EVALUATING POINT SOURCE AND FINITE FAULT STOCHASTIC SIMULATIONS FOR THE 2017 MW 5.6 GUPTKASHI EARTHQUAKE.

Tanishka Jadhav[1*], Nitin Sharma[1], and Prakash Kumar[1]
[1] CSIR-National Geophysical Research Institute, Hyderabad, Telangana-500007, India
*Presenting Author: tanishkajadhav910@gmail.com

ABSTRACT

Stochastic ground-motion simulation is a useful approach for estimating earthquake ground motions, particularly in cases where strong-motion observations are limited. In this study, we compare the performance of two stochastic simulation approaches, the Stochastic Method SIMulation (SMSIM) and the Extended Finite-Fault Simulation (EXSIM), for the 6th February 2017 Mw 5.6 Guptkashi Uttarakhand region. The earthquake occurred in a seismically active part of the Northwest Himalaya, between the source regions of the 1991 Mw 6.8 Uttarkashi and 1999 Mw 6.6 Chamoli earthquakes. SMSIM was used to simulate the event using a point-source assumption based on Brune's ω^{-2} source model, whereas EXSIM was used to account for the finite size and spatial complexity of the earthquake rupture. Site-specific amplification functions obtained from horizontal-to-vertical spectral ratio (HVSR) analysis were incorporated into the simulations. Ground motions were simulated over the frequency range of 0.1–10 Hz and compared with recorded data in terms of peak ground acceleration (PGA), Fourier amplitude spectra (FAS), and response spectra. The sensitivity of the simulations w.r.t stress drop ($\Delta\sigma$) and the near-surface attenuation parameter (κ) was also examined, and the optimum parameter combination was determined by using an iterative grid search method. Despite their different source assumptions, both techniques produce similar ground motions characteristics. The results also show that incorporating site-specific amplification improves the agreement between simulated and recorded motions. The comparative analysis highlights the sensitivity of simulated ground motions to source and attenuation parameters and provides useful constraints on regional ground-motion characteristics. The findings demonstrate the applicability of stochastic simulation methods for improving seismic-hazard assessment in data-sparse regions.

Keywords: Stochastic Ground Motion, Site Effect, Simulation, Strong motion data, Himalaya, Earthquake Hazard.

ANOMALOUS RADIOELEMENTAL ABUNDANCE AND RADIOGENIC HEAT PRODUCTION IN THE HYDERABAD GRANITIC COMPLEX, EASTERN DHARWAR CRATON

Sasi Kumar Uddandam*[,1,2], Labani Ray[1,2], Pragyan Mohapatra[1], Nishu Chopra[1,2], Eswara Rao Sidagam[1,2], Neeraj Benny[1]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
*Presenting author email: uddandamsasikumar838@gmail.com

ABSTRACT

Radiogenic heat production in continental crust is a fundamental parameter controlling crustal thermal structure and is controlled by the abundance and distribution of the heat-producing radioelements Th, U, and K, which are influenced by lithological, geochemical, and mineralogical processes. In this study, we analysed the radioelemental abundances and radiogenic heat production (A) of the Hyderabad Granitic Complex (HGC) in the Eastern Dharwar Craton, southern India. Radioelement abundances are

measured using gamma-ray spectrometry for the samples, which broadly capture the lithological variability across the HGC. The main rock types we studied are granites, alkali granites, granodiorites, and syenodiorites. The calculated radiogenic heat production varies considerably among the analysed samples, reflecting heterogeneous enrichment of Th, U and K within their respective lithologies.

The results reveal a systematic decrease in radioelement abundance and radiogenic heat production from alkali granite through granite, and granodiorite to syenodiorite, broadly corresponding to the progressive transition from felsic to intermediate composition. This systematic variation indicates the strong influence of lithological and compositional differences on the distribution of radioelements within the HGC. However, considerable variability within individual lithological groups indicates that mineralogical and textural factors also exert important controls. Geochemical and petrographic observations further provide constraints on the chemical composition, mineralogy and textural characteristics governing radioelement distributions. Furthermore, the high Th and U abundances are primarily reflect the presence of Th & U bearing accessory minerals such as zircon, apatite, monazite and thorite, whereas K abundances show comparatively narrow range and are mainly associated with mica group minerals. Thus, geochemical and petrographic evidences collectively support the observed radioelemental patterns and the resulting radiogenic heat production. The study provides new constraints on the distribution of radioelements and radiogenic heat production in the Hyderabad Granitic Complex, contributing to a better understanding of the thermal characteristics of the region and its crustal evolution.

SITE CHARACTERIZATION AND SEISMIC HAZARD ANALYSIS OF CITIES IN THE INDO-GANGETIC PLAIN USING MICROTREMOR AND MASW MEASUREMENTS

Uma Shankar
Department of Geophysics, Institute of Science, Banaras Hindu University, Varanasi-221005
Presenting author: umashankar@bhu.ac.in

ABSTRACT

The Indo-Gangetic Plain is characterized by thick, heterogeneous Quaternary sediments that can significantly modify seismic ground motion and amplify earthquake-induced shaking. Rapid urbanization and the high population density of cities in this region make reliable site characterization and seismic hazard assessment essential for earthquake-resilient urban development. In this study an integrated geophysical approach using microtremor measurements and Multichannel Analysis of Surface Waves (MASW) to characterize near-surface geological conditions and evaluate local seismic hazard in major selected cities of Uttar Pradesh in the Indo-Gangetic Plain. Microtremor observations are analyzed using the Horizontal-to-Vertical Spectral Ratio (HVSR) technique to estimate the fundamental frequency of the soil-sediment column and identify areas susceptible to resonance and ground-motion amplification. MASW surveys is used to derive shear-wave velocity profiles and estimate parameters such as V_{S30} for seismic site classification. The results from both techniques are integrated with geological, geomorphological, and geotechnical information derived from Standard Penetration Test (SPT) to delineate spatial variations in subsurface conditions. These site-specific parameters subsequently be incorporated into seismic hazard analysis to assess the influence of local site effects on expected ground shaking. The study will provide seismic microzonation-oriented maps

highlighting variations in site response, fundamental frequency, shear-wave velocity, and potential amplification across the investigated urban areas. The integrated methodology is expected to improve understanding of the complex sedimentary response of the Indo-Gangetic Plain and provide a scientifically robust basis for urban seismic risk reduction, earthquake-resistant design, and land-use planning in cities.

SEISMIC SOURCE INVERSION FOR EARTHQUAKES AND LANDSLIDES IN CENTRAL HIMALAYAS

Vipul Silwal[1], Pankaj Lahon[1], Rinku Mahanta[2], M.L. Sharma[3], Himanshu Mittal[4]
[1]Department of Earth Sciences, Indian Institute of Technology Roorkee, India
[2]National Centre for Polar and Ocean Research, Goa, India
[3]Department of Earthquake Engineering, Indian Institute of Technology Roorkee, India
[4]National Center of Seismology, New Delhi, India
Corresponding Author: vipul.silwal@es.iitr.ac.in

ABSTRACT

The seismic moment tensor (MT) is a fundamental parameter in seismology that characterizes the source mechanism of an earthquake and its associated radiation pattern. The Central Himalaya has experienced several significant earthquakes and large mass-movement events, including the 26 August 2026 event in the Langtang region. Although earthquakes and mass movements differ fundamentally in their source processes, both generate seismic waves that can be used to investigate their sources. This study employs waveform-based inversion methods to characterize seismic sources associated with both tectonic earthquakes and non-tectonic mass movements, such as landslides.

We analyze aftershocks of the 2015 Gorkha earthquake recorded by the NAMASTE broadband seismic network. Double-couple (DC) and full moment tensor (FMT) inversions are performed using body- and surface-wave data. Synthetic waveforms generated from Green's functions based on a 1-D regional velocity model for Nepal are compared with the observed waveforms. The DC and FMT solutions constrain the earthquake source mechanisms, while additional grid searches are performed to estimate the optimal source magnitude and focal depth. The resulting solutions provide insights into earthquake source characteristics and the seismotectonic characteristics of the region.

We also investigate a large mass-movement event in the Langtang region on 26 August 2026 using broadband seismic observations. The mass movement is represented using a single-force point-source approximation. Point-force inversion is performed by comparing observed waveforms with synthetic waveforms generated using Green's functions based on the ak135 1-D global velocity model. The resulting solution provides estimates of the effective force and its orientation, which are used to characterize the source process and constrain the dynamics of the mass movement.

Overall, this study demonstrates the application of waveform-based source inversion to both tectonic and non-tectonic seismic sources and highlights its potential for investigating earthquake source mechanisms and slope-failure processes in the high-mountain environment of the Nepal Himalaya.

THICKNESS DISTRIBUTION ACROSS THE DECCAN VOLCANIC PROVINICE AND ITS IMPLICATIONS

Shilpa Patil Pillai[1], Gauri Dole[2], Madhu Rajput[3], Devdutt Upasani[3], and Vivek S. Kale[4*]
[1] Department of Earth & Climate Science, Indian Institute of Science Education & Research (IISER Pune), Pune 411008, INDIA.
[2] Department of Environmental Science, Savitribai Phule Pune University, Pune 411007, INDIA.
[3] Department of Geology, Fergusson College, Pune 411004, INDIA.
[4] Advanced Center for Water Resources Development and Management (ACWADAM), Pune 411038, INDIA.
* Corresponding & presenting author: *dr.vivekale@gmail.com*

ABSTRACT

A revised compilation of the thickness distribution across the on-land exposures of the Deccan Volcanic Province integrates geophysical interpretations, field data, and structural extrapolations. In light of uncertainties that subsurface continuity of the lava piles, we have plotted two separate contour maps. One uses above-ground thicknesses that are derived from field studies integrated with highest and lowest elevations of exposures, while the other is a plot of the maximum possible thickness data integrating geophysical subsurface extrapolations.

This compilation provides a perspective of the pre-eruptive topography of the Indian craton on which the lava piles erupted. The thickness distribution endorses the interpretation of the Deccan Volcanic Province as an assemblage of subprovinces, each of which had an independent eruptive duration and style. This data reinforces the presence of several deep-seated crustal weakness zones that were reactivated during and following the volcanic activity. It also helps better quantify the eruptive history of Deccan volcanism, in space and time across the province. In addition, this data provides a direct baseline for determining the post-eruptive erosional volumes and rates that carved out the present-day landscape in the province. There is a possibility that thickness data provides the fundamental input to develop a robust estimation of carbon sequestration in the Deccan basalts.

GROUNDWATER QUALITY PREDICTION USING HYBRID MACHINE LEARNING APPROACH – A CASE STUDY FROM KANYAKUMARI DISTRICT, TAMIL NADU, INDIA

Dr.Y.Srinivas and Annie Jose
Centre for Geotechnology, Manonmaniam Sundaranar University, Tirunelveli
Presenting author: drysv@yahoo.co.in

ABSTRACT

The hybrid machine learning framework was developed for predicting the Drinking Water Quality Index (DWQI) using 10 years of groundwater quality and rainfall data from Kanyakumari District, Tamil Nadu. The study utilized groundwater quality and rainfall data observations gathered from 65 sampling stations between 2013 and 2022. The groundwater quality dataset consists of physicochemical parameters such as pH, electrical conductivity, total dissolved solids, concentration of sodium, potassium, calcium, magnesium, total hardness, sulfate, chloride, bicarbonate, carbonate, fluoride, nitrate in groundwater. The proposed approach uses Random Forest, k-Nearest Neighbor (kNN) Regressor, and Support Vector Regressor (SVR) as base regression models, with an Artificial Neural Network (ANN) serving as the meta-regressor. An ARIMA component was also used to depict temporal variation in DWQI. The model was employed in using groundwater measurements from 2013

to 2021, with the 2022 observations serving as a temporal validation dataset. To improve the prediction of relatively high DWQI observations, a SMOTER-based synthetic sampling method was included in the modeling framework. The proposed framework's performance was assessed using MSE, MAE, RMSE, and coefficient of determination (R^2).The results show that the hybrid framework can predict DWQI with low prediction error and a high level of agreement between observed and predicted values. The addition of SMOTER helps to rectify the uneven distribution of DWQI observations. The proposed approach can thus be utilized as a support tool for groundwater quality monitoring, future DWQI prediction, reduces the dependence on conventional assessment and assists in water resource management decisions.

Key Words: Groundwater quality prediction, Machine Learning, DWQI, Regressors, Kanyakumari District.

AUTOMATIC DETECTION AND DISCRIMINATION OF SEISMIC EVENTS USING SVM AND RF MACHINE LEARNING MODELS

Mahesh Yezarla[1, 2], Rajesh Rekapalli[1, 2], Sandeep Gupta[1, 2], Kethavarapu Raviteja[1, 2]
[1] CSIR-NGRI, Hyderabad, Telangana-500007, India.
[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh- 201 002, India.
Corresponding author: Mahesh Yezarla (mj.geo2017@gmail.com)

ABSTRACT

Landslides are one of the major natural hazards that cause loss of life and damage to property. Predicting landslides remains difficult because these events are controlled by many triggering factors, such as rainfall and earthquakes, which are often random in space and time. However, landslide monitoring and early warning are essential, as early detection helps greatly to reduce the losses due to destructive cascading events like debris flows, floods, etc. Recent advancements in the detection of landslides and associated cascaded events using seismic networks help to overcome the spatio-temporal resolution issues associated with satellites and in-situ monitoring approaches. We test the robustness of seismic waveform spectral attributes for the detection of landslide seismic signals using Support Vector Machine (SVM) and Random Forest (RF) algorithm-based framework. The RF and SVM classifiers were trained and tested using 912 seismic signals of 28 well-documented landslides around the world, 1065 seismic signals of 28 small-magnitude earthquakes, which are at equal distance from the recording station as the landslides and 1065 noise signals recorded just before/after the landslide signals. The ternary RF classifier based on spectral features achieved ~98% accuracy in distinguishing landslides from earthquakes and background noise. The model has shown robust performance in detecting 50 earthquakes and 8 earthquake-triggered landslides following the April 2, 2024 Mw 7.4 Taiwan earthquake on 48 hours of continuous seismic data from a single station. Finally, our study concludes that spectral feature-based ML techniques as a robust tool for real-time seismic landslide monitoring for the early warning of associated cascaded events.

Key words: Seismic monitoring, Landslides, Power Spectral Density (PSD), Random Forest, SVM

MARINE GEOSCIENCES

RETRIEVAL OF GLOBAL VERTICAL GRAVITY GRADIENT (VGG) FROM SURFACE WATER OCEAN TOPOGRAPHY (SWOT) DATA: NEW INSIGHTS INTO THE OCEAN FLOOR TECTONICS

Krishna D.V.P.[ab*], Sreejith, K.M.[b], Rao, G.S.[a], Radhakrishna, M.[a]
Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai, India
[b] Geosciences Division, Space Applications Centre, Ahmedabad, India
*Presenting/Corresponding author's email: dvamsiiist@gmail.com

ABSTRACT

Seafloor mapping from ship-based soundings has limitations in the spatial coverage due to the cost and time involved. Retrieval of marine gravity using ocean topography measurements from satellite altimetry enables global mapping of the tectonic features on seafloor. Satellite altimeter-derived gravity maps are extremely helpful in exploring the ocean basins covered with thick sediments and in the regions uncharted by ships. However, the resolution of gravity field obtained using 1D measurements from the conventional nadir altimeters are about 12 km over ocean basins and further reduces significantly near the coastal regions. In this context, recently launched wide-swath satellite altimeter, Surface Water and Ocean Topography (SWOT) mission offers substantial advancement in the perspective of radar remote sensing of global water surfaces, even in shallow waters. We use the sea surface measurements computed from 50 cycles (~3 years) of SWOT Science Phase data to construct a global map of Vertical Gravity Gradient (VGG). We observe that SWOT-derived VGG enhances fine-scale tectonic features such as fracture zones and abyssal hills on the seafloor fabric that were difficult to detect from the nadir altimeter-derived VGG maps. A sharper look at the seafloor enabled by SWOT allows to detect and resolve previously uncharted seamounts of smaller dimensions (<1 km). A focused analysis of the Indian Ocean region reveals that SWOT-derived VGG maps reveals the intricate tectonic fabric of the lithosphere including the Indian ocean mid-oceanic ridge systems, aseismic ridges and continental margins.

MAGNETOFOSSIL RECORD OF PALEOENVIRONMENTAL CHANGES IN THE ARABIAN SEA SINCE LATE EOCENE

Firoz Badesab[1,2], Nitin Kadam[1], Virsen Gaikwad[1], Omkar Sagavekar[1,2]
[1] CSIR-National Institute of Oceanography, Dona Paula-403004, Goa, India
[2]Academy of Scientific and Innovative Research (AcSIR) Ghaziabad-201002, India
Presenting Author: Dr. Firoz Badesab (firoz@nio.res.in)

ABSTRACT

Magnetotactic bacteria (MTB), group of microorganisms that synthesize tiny (nanometer-sized) magnetite and/or greigite particles and their genesis and preservation is closely linked to paleoenvironmental conditions. These nanoparticles preserved in marine sediments are termed as "magnetofossils" and they largely contribute to the magnetic signal of host sediment. Magnetofossils are potential recorder of environmental changes and their abundance and diversity data in marine sedimentary system can be utilized to reconstruct the paleoenvironmental conditions. In this study, we established a high-resolution magnetofossil record to reconstruct paleoenvironmental changes in the Arabian Sea [AS] since Late Eocene. Electron microscopy observations coupled with crystallography data indicate the presence of abundant magnetofossil in the sediments representing different time

periods and provide confirmation based on their distinct morphologies and magnetite crystal structure. First order reversal curves of the selected intervals exhibit a central ridge feature, typical signature of non-interacting single domain [SD] magnetofossils. A trend of increase in magnetofossil length and abundance from middle Miocene – middle Oligocene – Late Eocene observed at this site can be attributed to decline in bottom water oxygenation and subsequent rise in nutrient supply (bioavailable iron), which might have triggered the MTB bloom in the Arabian Sea.

GEOPHYSICAL INVESTIGATION OF THE INDIA-ELAN BANK-EAST ANTARCTICA CONJUGATE MARGINS: CRUSTAL ARCHITECTURE AND BREAKUP KINEMATICS

Janne X J*, S. Lasitha
Department of Earth Sciences, Pondicherry University, Puducherry 605014, India
*Presenting author: xjjanne@pondiuni.ac.in

ABSTRACT

The breakup of East Gondwana during the Early Cretaceous period led to the separation of India from East Antarctica and played a major role in the evolution of the Indian Ocean. East India-Elan Bank-East Antarctica region preserves the important geological and geophysical evidence of this continental fragmentation. Although several studies have been done in this region with geological, geochronological and geophysical data, uncertainties still remain regarding their crustal architecture of conjugate margins, the pre-breakup position of Elan Bank, the nature of continent-ocean transition zones and the kinematic processes involved in continental separation. These uncertainities is due to the limited data coverage in some sectors including East India and adjacent offshore regions. Therefore, a re-evaluation using integrated and recently available geophysical datasets is necessary to improve our understanding of the India-Antarctica breakup history.

The present study aims to investigate the East India-Elan Bank-East Antarctica conjugate margins using a combination of gravity, magnetic, Bathymetry, seismic and geological datasets. Regional gravity data from AntGG and global gravity grids, magnetic anomaly from ADMAP, EMAG2, and NCPOR datasets, bathymetric information and published geological and seismic profiles are utilized to examine crustal structure and tectonic characteristics across the conjugate margins. Particular attention is given to identifying crustal domains, major structural features, margin segmentation and geophysical signatures associated with continental breakup.

This study is expected to give new insights into the crustal architecture and breakup kinematics of the East India-Elan Bank-East Antarctica sysem. The results may help to find the nature of separation, crustal thickness variation, Continent to Ocean transition zones and provide additional geophysical evidence for the timing and mechanism of separation. The findings will contribute to ongoing efforts in Gondwana reconstruction and enhance our understanding of the tectonic evolution of the Indian Ocean region.

MESSAGES FROM THE SUBDUCTING SLAB: WHAT ANDAMAN MUD VOLCANOES REVEAL ABOUT FOREARC PROCESSES

Jyotiranjan S. Ray
Physical Research Laboratory, Navrangpura, Ahmedabad 380 009
jsray@prl.res.in

ABSTRACT

Mud volcanoes at convergent margins provide rare access to materials mobilized from depth and therefore offer a direct window into the physical and chemical processes operating within subduction-zone forearcs. The mud volcanoes of the Andaman accretionary prism occur above a faulted plate interface where the Indian plate subducts beneath the Burma microplate. Their continuous discharge of mud breccia, water, and gases provides an unusual opportunity to characterize materials released from the downgoing slab as it progressively transforms.

Integrated mineralogical, elemental, and isotopic studies indicate that the expelled materials originate from deep within the accretionary prism. Low-salinity waters, together with their δD–$\delta^{18}O$ and Sr isotopic compositions, record mixing between sediment pore water and fluids released during clay-mineral dehydration, whereas carbon isotopes of methane, ethane, and CO_2 indicate predominantly thermogenic hydrocarbon generation. Geothermometric constraints place fluid–mud generation within the forearc décollement system. The clay-rich mud breccia is interpreted to originate from tectonic mélanges at the base of the accretionary prism and to ascend rapidly through fault networks. Major–trace-element and Sr–Nd–Pb isotopic compositions further demonstrate contributions from both altered oceanic crust and terrigenous sediment, with altered oceanic crust constituting the dominant (>80%) component.

These observations establish Andaman mud volcanoes as natural probes of slab dehydration, sediment–oceanic-crust interaction, fluid migration, and material recycling before the slab enters the deeper mantle. Their documented response to major earthquakes further highlights the coupling between plate-boundary deformation and forearc fluid release. Thus, mud-volcano products provide a valuable geochemical archive that links shallow forearc processes to deeper subduction-zone mass transfer and arc magmatism.

THE NINETYEAST RIDGE: THREE DECADES OF INDIAN RESEARCH ON CRUSTAL STRUCTURE AND TECTONICS

K.S. Krishna
H. No. 1-95, Chinaogirala, Krishna (Dt), Andhra Pradesh - 521 245, India
(E-mail: nio.krishna@gmail.com)

ABSTRACT

The Ninetyeast Ridge (NER), with an average width of 200 km, extends for more than 5000 km in the N-S direction, stretching from 18°N to 34°S. Its northern 800-km portion (between 10°N and 18°N) is completely buried under Bengal Fan sediments, whereas its southern end at ~34°S latitude connects to the E-W-oriented Broken Ridge.

In the late 1980s, India and Russia launched two game-changing bilateral programs, ILTP and TIOG, in the Indian Ocean. This marked a major milestone for Indian institutions, paving the way for more

rigorous deep-water studies across the Central Indian Basin and the NER. The studies on the NER have greatly advanced our understanding of its seafloor morphology, crustal architecture, and tectonic evolution. The research on the NER investigates the mantle plume and spreading centers interactions. The disordered magnetic lineations in the vicinity of the NER have prompted to hypothesize that repeated ridge jumps towards the south may have generated extra oceanic crust beneath the NER and adjacent regions. Furthermore, approximately two km of steep downward faulting was observed on the east flank of the NER between 11°S and 21°S latitudes, resulting from the movements of oceanic blocks back and forth caused by the ridge jumps. From the Neogene onwards, the NER became part of the diffuse plate boundary of the Indian Ocean, leading to fracturing of the NER with numerous normal and reverse faults.

These findings from the NER generated substantial international interest, underscoring the need to collect fresh marine geophysical datasets and basement rock samples. To address this, an international expedition brought together scientists and students representing 12 institutions across six countries: the United States, India, Russia, South Africa, the United Kingdom, and Canada. The magnetic pattern in the vicinity of the NER, particularly between 86°E FZ and 92°E FZ, is not in sequential order, suggesting the occurrence of multiple ridge jumps for transferring blocks of oceanic crust between the Antarctic plate and the Indian plate. From 77 to 43 Ma the NER lengthened at a rate of 118 km/Myr, twice that of the 48–58 km/Myr accretion rate of adjacent oceanic crust. This difference can be explained by southward jumps of the Wharton spreading ridge toward the hot spot, which transferred portions of crust from the Antarctic plate to the Indian plate, thereby lengthening the NER. Magnetic anomalies document a small number of large spreading ridge jumps in the ocean crust immediately to the west of the NER, especially two leaving two observable fossil spreading ridges aged 65 and 42 Ma. In contrast, complex magnetic anomaly progressions and morphology imply that smaller spreading ridge jumps occurred at more frequent intervals beneath the NER. A comparison of the NER dates and magnetic anomaly ages implies that the hot spot first emplaced NER volcanoes on the Indian plate at a distance from the Wharton Ridge. However, as the northward-drifting spreading ridge approached the hot spot, the two interacted, keeping later NER volcanism near the spreading ridge crest by spreading center jumps.

Recently, an international team of researchers from China, Australia, Sweden, and the US proposed a model that the NER was generated by a moving Kerguelen hotspot. Using $^{40}Ar/^{39}Ar$ dating and isotopic geochemistry of the ridge rocks, these researchers inferred four stages of non-linear volcanism with rates varying from 47 to 302 mm yr^{-1}, and postulated that plume-ridge interactions led to hotspot migration during the northward motion of the Indian plate. Considering various geological and geophysical parameters, including paleolatitude data of the Kerguelen volcanic products, it is believed that the Kerguelen mantle plume remained quite stable beneath the Indian and Antarctic plates. The absolute Indian plate motion was the process that prompted the spreading centres to reside closer to the Kerguelen mantle plume either by northward or southward ridge jumps. Consequently, the NER was constructed from a combination of volcanic blocks: those formed on the Indian plate, those transferred from the Antarctic plate, and those created on the Indian plate that were later transferred to the Antarctic plate and back again to the Indian plate.

MANTLE PLUME–RIDGE INTERACTION AND THE FORMATION OF RIDGEWARD-DIPPING REFLECTORS AT SLOW-SPREADING RIDGES

M. Ismaiel[1]
[1] Earth and Climate Science, Indian Institute of Science Education and Research - Pune, India
Presenting author: m.ismaiel@iiserpune.ac.in

ABSTRACT

Mantle plume–mid-ocean ridge interaction can profoundly modify melt supply and crustal accretion, producing anomalously thick and volcanically complex oceanic crust. However, the mechanisms by which enhanced plume-derived magmatism influences volcanic architecture at slow-spreading ridges remain poorly understood. Here, seismic reflection data from the Bay of Bengal reveal thick, wedge-shaped volcanic packages within the upper oceanic crust, where total crustal thickness reaches 8–15 km. Their distinctive ridgeward-dipping geometries define three evolutionary stages: (i) arcuate, diverging thick wedges with seaward migration, (ii) high-curvature wedges with limited pinch-out, and (iii) thin wedges transitioning into flat-lying lava flows. We interpret these geometries as a progressive change from focused, high-volume volcanism during initial plume–ridge interaction to widespread lava emplacement during subsequent crustal accretion. Paleobathymetric depths exceeding 1.5 km and estimated mantle potential temperatures of ≥1400 °C further support submarine emplacement under anomalously high thermal and magmatic conditions. We propose that near-axis plume influence enhanced melt production and disrupted steady-state seafloor spreading, generating SDR-like volcanic wedges within an oceanic setting. As plume influence diminished, magmatism and crustal accretion progressively returned toward normal mid-ocean-ridge conditions. These observations provide new insights into how transient plume–ridge interaction can reshape oceanic crustal architecture and generate SDR-like volcanic sequences beyond continental rifted margins.

SEISMIC EVIDENCE FOR FLEXED MOHO BENEATH SEMAIL OPHIOLITE, OMAN MOUNTAIN

Muhammed Rishal[1], **Mohammad Ismaiel**[1]
[1]Department of Earth and Climate Science, Indian Institute of Science Education and Research Pune, Pune
Presenting Author mail id: rizuuzir130@gmail.com

ABSTRACT

The Semail ophiolite in Oman is one of the world's best-preserved ophiolite complexes, offering a unique window into continental obduction processes shaped by pre-existing tectonic inheritance. This study investigates the crustal structure and Moho topography beneath the central Oman Mountains by combining P-wave receiver function (PRF) analysis with 2-D forward gravity modelling. Broadband seismic data from 12 stations spanning the Semail ophiolite belt, the Ghaba sedimentary basin, and the Saih Hatat Dome (SHD) were analyzed using H-κ stacking to estimate Moho depth and crustal Vp/Vs ratios.

Results reveal significant lateral variation in Moho depth: ~39 km beneath the sedimentary basin, deepening to ~46 km beneath the ophiolite belt, then shallowing sharply to ~30 km beneath the SHD over a distance of only ~15 km. Gravity modelling along a 192-km transect, constrained by these seismic results and surface geology, confirms flexural bending of the lithosphere driven by the ~5-km-

thick ophiolite load. Forward flexural modelling (effective elastic thickness, Te = 20–25 km) predicts a maximum lithospheric deflection of ~4.4 km, a foredeep basin ~2 km deep, and a forebulge of ~155 m located ~160 km from the load centre, closely matching observed Moho geometry.

The thin crust beneath the SHD is attributed to Permian rifting and lithospheric thinning rather than ophiolite loading alone. High Vp/Vs ratios (1.75–1.87) support the presence of Permian mafic intrusions in the lower crust. Compared to the northern Oman-UAE mountain belt, the southern Arabian lithosphere is mechanically weaker (Te ≈ 25 km vs. ≈40 km), likely reflecting pre-obduction magmatic and rifting-related weakening. These findings provide new constraints on crustal architecture in southern Oman and highlight how inherited lithospheric heterogeneity governs flexural response and obduction dynamics along the Arabian margin.

DIAGENETIC CONTROLS ON MAGNETIC MINERAL ASSEMBLAGES IN THE BAY OF BENGAL SEDIMENTS

Nitin Kadam[1, *], Somraj Misra[1], Jahnavi Punekar[1]
Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai
*Presenting Author: Nitin Kadam (nitinkadam7798@gmail.com)

ABSTRACT

Magnetic mineral assemblages in marine sediments are sensitive recorders of past climate, environmental conditions, and geological processes. In monsoon-dominated settings such as the Bay of Bengal, magnetic proxies are widely used to reconstruct monsoon-driven productivity and redox variability. However, post-depositional diagenesis can variably overprint primary magnetic signals. In this study, we used a suite of advanced magnetic techniques to characterize magnetic mineral assemblages in a long sediment core section (core length: 242 m) collected from the Mahanadi Basin (Bay of Bengal) to assess the effects of progressive diagenetic alteration. Magnetic mineral concentration inferred from the hysteresis loop parameter (saturation magnetization) suggests high magnetic mineral concentrations above the present-day sulfate-methane transition zone (SMTZ), which lies at ~30 m in the sediment column. Below this depth the concentration of magnetic minerals reduces drastically. Domain state diagnostic first-order reversal curve (FORC) diagrams reveal the occurrence fine grained single-domain magnetic particles above SMTZ associated with the presence of biogenic magnetic minerals (magnetofossils). The dominant presence of biogenic end member is further corroborated with low and high temperature magnetic measurements. In sulfidic zone, the greigite diagnostic closed concentric contours in a few FORC diagrams suggests its formation during lower hydrogen sulfide fluxes and higher pore water iron concentrations (enhanced iron reduction) leading to the arrestation of pyritization during sulfidic diagenesis. The low temperature magnetic transition at 37 K for deeper sediment intervals points to the Néel temperature of siderite, which is likely formed during the anaerobic oxidation of methane (AOM) at paleo-SMTZ. Our findings demonstrate that magnetic mineral preservation and alteration are directly governed by the extent of sulfidic diagenesis, methane flux intensity, and AOM. Furthermore, anomalous pore-water iron concentrations and fine-grained magnetic particle formation in the sulfidic zone highlight a complex coupling between microbial organic matter consumption and magnetic mineral diagenesis.

PROBING OFFSHORE DEEP EARTH DYNAMICS OVER TRISTAN DA CUNHA, SOUTH ATLANTIC OCEAN, WITH MARINE MAGNETOTELLURICS: PERSPECTIVES FOR INDIA

Singh, R.K.[1*], K. Baba[2], Y. Usui[2], M. Jegen[3], A. Morschhauser[4] and W.H. Geissler[5]
1. Indian Institute of Petroleum and Energy, Visakhapatnam
2. Earthquake Research Institute, The University of Tokyo
3. GEOMAR Helmholtz Centre for Ocean Research, Germany
4. GFZ Potsdam, Germany
5. Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Germany
*Presenting Author Email Id: roshan_rms.es@iipe.ac.in

ABSTRACT

Marine magnetotellurics (MT) is a geophysical technique that measures natural variations in the Earth's magnetic and electric fields to map the electrical conductivity structure beneath the seafloor. This method provides complementary insights to seismic studies by detecting resistive and conductive features at various depths, enhancing our understanding of deep Earth dynamics in offshore environments. This study focuses on recent marine MT investigations conducted over the Tristan da Cunha (TDC) volcanic island in the South Atlantic Ocean and explores their implications for similar studies in India's offshore regions. TDC has long been considered a site for deep mantle upwelling based on geochemical and petrological evidence. Marine MT and seismological surveys had been carried out to investigate the upper mantle structure beneath TDC. The 3-D MT inversion reveals a prominent NE–SW-trending conductive structur**e** beneath the Tristan da Cunha hotspot region. A vertically elongated conductive anomaly is observed southwest of Nightingale Island, extending into the upper mantle, with its geometry and increasing conductivity with depth being consistent with a plume-like structure**.** Therefore, marine MT provides an effective approach for imaging subsurface structures from shallow sediments to deep mantle, with significant potential for India's offshore regions. Its application can complement exploration of major offshore basins and national initiatives such as the Deep Ocean Mission and Samudra Manthan, advancing understanding of offshore geology, mantle processes, and resource potential.

LATE QUATERNARY TECTONIC AND CLIMATIC RECONSTRUCTION FROM PALAEOLAKE SEDIMENTS OF INDUS RIVER VALLEY, LADAKH, NW HIMALAYA

Pratikshya Behera, Manan Singh, B. V. Lakshmi, K. Deenadayalan, A. P. Dimri
Indian Institute of Geomagnetism (IIG), Navi Mumbai, India.
Presenting Author: pratikshya.barsha@gmail.com

ABSTRACT

The evolution of Himalayan landscapes involves a complex interplay between active tectonics and climate variability. The Trans-Himalayan province of Ladakh has an arid-semi-arid continental climate that is affected by fluctuations in the Indian Summer Monsoon (ISM) and mid-latitude westerlies. Its palaeolacustrine - deposits are thus important archives to understand earlier environmental and tectonic changes. The present study focuses on the Khalsi palaeolake system along the Indus River, Ladakh, which developed following temporary blockage of the Indus River associated with the Lamayuru dam-burst event during deglaciation. The lacustrine sequence preserves evidence of depositional and environmental changes from the post-Last Glacial Maximum (LGM) to ~5 ka. An integrated environmental magnetic and anisotropy of magnetic susceptibility (AMS) approach was employed to

investigate the climatic variability, sedimentary processes, and tectonic modification of the basin. Rock magnetic parameters and inter-parametric ratios, including χ_{lf}, χ_{ARM}, SIRM, χ_{fd}%, ARM/SIRM, χ_{ARM}/χ_{lf}, S-ratio, and HIRM, were used to characterize magnetic mineral concentration, grain size, and mineralogy. The results indicate that magnetite and titanomagnetite are the principal magnetic carriers, whereas paramagnetic minerals and hematite contribute significantly to the magnetic susceptibility fabric. The AMS data show the magnetic fabrics are generally from prolate to oblate, with a girdle-shaped distribution of maximum and intermediate susceptibility axes, which exhibit relatively weak clustering. The distribution of K_{max}, K_{int} and K_{min} axes show that the fine-grained deposits possess mainly horizontal and imbricated magnetic fabrics. These fabrics are indicative of deposition by suspension settling and current action. However, the main fabric may have been altered by post-depositional compression and sediment deformation. The combined magnetic and AMS signatures thus provide new insights into the relationship between sedimentation, climatic variability, and tectonic deformation in the NW Himalaya, indicating paleolake sediments' potential as archives of Late Quaternary environmental and tectonic evolution.

SOURCES OF DISSOLVED INORGANIC CARBON TO THE WESTERN BAY OF BENGAL AND THEIR CONTRIBUTION TO OCEAN ACIDIFICATION USING ISOTOPIC COMPOSITION OF DISSOLVED INORGANIC CARBON

R. Sreevidhya[1*], V. V. S. S. Sarma[1,2], Aditi Sharma[1,2]
[1] CSIR-National Institute of Oceanography, Regional Centre, Visakhapatnam 530045, India
[2] Academy of Scientific and Innovative Research, Ghaziabad, India
*Presenting author (sreevidhyasarathy@gmail.com)

ABSTRACT

Land-ocean interactions drive biogeochemical changes in coastal waters. Discharge of acidic freshwaters and atmospheric deposition into the coastal waters of the BoB induces acidification, leading to alterations in the coastal ecosystem. Using concentrations and stable isotopic composition of carbon in dissolved inorganic carbon (DIC), the DIC contribution to the coastal waters through riverine input and in situ biogeochemical processes was computed along a transect in the western Bay of Bengal (BoB). DIC in coastal waters was mainly influenced by organic matter decomposition, supported by strong heterotrophy in the coastal BoB. Organic matter decomposition contributed 32 to 45% of DIC added to the coastal waters, followed by river discharge (11-32%), whereas air-sea CO_2 flux (20-30%), primary production (up to 12%) and carbonate production (up to 10%) removed it from the upper ocean. The surface ocean pH was enhanced through air-sea exchange, primary production, and carbon dissolution by 0.6, 0.3 and 0.2, respectively, whereas decline in pH by decomposition of organic matter and river discharge by -1.6 and 0.07, respectively. Though river discharge did not contribute significantly to the pH change however, decomposition of organic matter brought by the rivers contributed significantly to the decline in pH. The net impact on pH due to external sources and internal process comes to decline in pH by 0.6. This study suggested that decomposition of organic matter is the dominant process in changing DIC in the western Bay of Bengal, leading to a decline in pH. Neither regional nor global model include the riverine organic matter fluxes and associated changes in DIC and pH, the model simulations differ significantly from that of measured. The changes in intensity of monsoon due to climate change alters the river discharge and associated organic matter transport to the

coastal Bay of Bengal that may have cascading effect on the DIC budget and ocean acidification in the future.

Keywords: Dissolved inorganic carbon, river discharge, organic matter decomposition, ocean acidification, Bay of Bengal

FUTURE DIRECTIONS OF BIOGEOCHEMISTRY RESEARCH IN THE INDIAN OCEAN

VVSS Sarma
CSIR-National Institute of Oceanography, Regional Centre, Visakhapatnam
Email: sarmav.nio@csir.res.in

ABSTRACT

Earth is entering an era in which human activities have become a dominant force, profoundly altering all kinds of materials across the Earth's surface. Thus, understanding these natural and altered interconnected processes demands a new paradigm that integrates geology, hydrology, biogeochemistry, ecology, microbiology, atmospheric science, environmental engineering, and data science. The northern Indian Ocean is the best region to study these interactions. Monsoon is the main driving force to bring the precipitation over India, and peninsular rivers are mainly fed by rainfall. These rivers carry significant amounts of nutrients, organic matter and microbes to the adjacent coastal ocean and subsequent microbial decomposition of terrestrial organic matter in the coastal waters supports heterotrophic activity, fishery production and generates ocean acidification. The exchange of anthropogenically impacted groundwater generates harmful algal blooms and declines/supports fishery production. The absence of long-term trends in phytoplankton biomass and primary production in the northern Indian Ocean, and the weak rate of warming, were attributed to a thick layer of aerosols in the lower atmosphere. Deposition of atmospheric pollutants supports biological production and enhances ocean acidification. Surface runoff stratifies the upper ocean, resulting in the formation of thick and strong oxygen minimum zones (dead zones). Seasonally reversing currents due to the monsoon, formation of eddies due to the morphology of the basin, and freshwater discharge lead to cross-shelf exchange of organic matter that strengthens the intensity of oxygen minimum zones. The warming of the atmosphere due to an increase in CO_2 levels leads to melting of Himalayan glaciers that enhances river discharge, leading to an increase in the oceanic capacity to absorb atmospheric CO_2. Unfortunately, these interactions have not been well studied and are not part of any numerical models, resulting in poor simulation of biogeochemical processes and projections due to climate change.

ATMOSPHERIC, PLANETARY & SPACE SCIENCES

SPATIAL DISTRIBUTION OF GEOMAGNETIC IMPULSES FROM THE INDIAN SECTOR DURING 2014-2025 BASED ON SWARM SATELLITE MISSION

Archana R.K1 and Kusumita Arora2,3*
Space Physics Laboratory, VSSC, ISRO, Trivandrum, India1
CSIR-NGRI, Hyderabad, India2
Indo-German Science & Technology Centre, New Delhi3*
Corresponding author: archanark.geo@gmail.com

ABSTRACT

The sudden changes in geomagnetic secular variations are known as geomagnetic impulses, believed to be generated by rapid changes in the dynamo process in the earth's outer core. The mechanisms of generation and spatial-temporal distribution of geomagnetic impulses are not fully understood yet. Previous studies on spatial and temporal evolution of geomagnetic impulses are mostly constrained to the locations of geomagnetic observatories, hence information on these are limited. Over India, the spacing of magnetic observatories is better in the peninsular region and studies have been conducted here on the nature of secular variations of the field and the trends of changes of the dip Equator. Corresponding changes to the north, especially the Himalayan region remains to be studied in detail. The present study provides the first systematic satellite-based spatial and temporal distribution of geomagnetic impulses in the Indian sector. We used level one vector magnetometer data of east-west component (Y) from Swarm A and C satellites during 2014-2025 years. Swarm passes along the Indian sector during 17:00LT-30:00LT of quiet days, when ionospheric contributions are minimal has been considered for the analysis. Further, contribution from crustal and external field components has been removed using CHAOS model and monthly means Y values have been computed for each 2°x2° grids. Obtained secular variations (SV) are validated using ground observatory data and IGRF model. The identification of the geomagnetic impulses followed detection criteria based on a secular acceleration threshold, and spatial coherence between neighbouring grid cells. The SV trends over the last decade shows uniform trend over peninsular India, while trend changes along active boundaries along southeast and northeast region; the occurrence and amplitudes of geomagnetic impulses also shows differences, illustrating the regional differences in the surface expression of rapidly varying outer core dynamo generated signals.

Key word: Geomagnetic impulses, Secular variations, surface expression

IONOSPHERIC RESPONSE OVER INDIAN SECTOR TO A GREAT GEOMAGNETIC STORM:INSIGHTS FROM MULTI-INSTRUMENT OBSERVATIONS AND PHYSICS-BASED SIMULATIONS

Arya Ashok1,2, K. M. Ambili1, and R. K. Choudhary1
1Space Physics Laboratory, Vikram Sarabhai Space Centre, Indian Space Research Organization, Trivandrum, India
2Department of Physics, University of Kerala, Trivandrum, India

The G5 geomagnetic storm of 10–11 May 2024 induced severe global ionosphere–thermosphere perturbations. This study investigates the Indian equatorial and low-latitude ionospheric response using multi-instrument observations (GNSS, Digisonde, magnetometers) and a physicsbased model to isolate prompt penetration electric field (PPEF) and thermospheric meridional wind contributions. Observations reveal a differential response. During the nighttime main phase, a westward PPEF drove

plasma downward, reducing Vertical Total Electron Content (VTEC) by 60%. Conversely, the daytime recovery phase showed a complete suppression of the Equatorial Ionization Anomaly (EIA) contrasting with typical storm-time super fountain effects. The dip equator (Trivandrum) experienced a 100% VTEC enhancement with wave-like undulations, while the anomaly crest (Bhopal) depleted by 60%. To disentangle the drivers responsible for such features, we coupled an in-house developed regional ionospheric model with TIEGCM/AMIE storm-time winds. This novel regional first-principles framework computes the ion/electron density by solving the coupled time dependent continuity and momentum equations of multiple ions accounting for photochemistry and plasma transport along and across the geomagnetic field. Simulations confirm that the long duration highly fluctuating PPEFs and the rapid storm-time meridional wind reversals governed the fine scale wave-like undulations observed in the VTEC over the dip equator. This study underscores the necessity of coupled electrodynamic–thermospheric frameworks during such extreme space weather events over a regional scale.

IMPACT OF SECULAR VARIATION OF THE DIP EQUATOR ON EEJ ESTIMATION

Ayushi Srivastava[1], Murlidhar Mudgal[1], Rajesh Kumar Barad[2]
1. Indian Institute of Geomagnetism, Navi Mumbai, Maharashtra, India
2. Institut de Physique du Globe de Paris, Paris, France
Presenting author: ayushisrivashtava@gmail.com

ABSTRACT

The Earth's main magnetic field changes progressively with time as a consequence of dynamical processes occurring in the outer core known as secular variation. This secular variation modifies the spatial distribution and strength of the geomagnetic field and, consequently, the magnetic inclination and dip latitude at a given location. The resulting movement of the dip equator can alter the background electrodynamic environment of the equatorial ionosphere and may thereby affect the equatorial electrojet (EEJ), an ionospheric current system at low latitudes. While variations in solar activity and geomagnetic latitude are known to contribute to changes in EEJ strength, the role of the long-term displacement of the dip equator over the Indian sector has received comparatively limited observational attention. Here, we examine the evolution of the EEJ over the Indian sector using quiet-day geomagnetic measurements from Tirunelveli (8.6°N, 77.8°E) for the period 1996–2025. During this interval, the dip equator is found to move progressively southward at approximately 0.062° yr^{-1}, equivalent to about 6.9 km yr^{-1}. Over the same period, the EEJ shows a gradual reduction in intensity and an inverse relationship with dip latitude, with a correlation coefficient of approximately −0.49. After removing the contribution associated with solar activity, this relationship becomes substantially stronger ($R \approx -0.71$), indicating a pronounced association between dip-latitude evolution and the long-term EEJ variation. A comparison of the earlier and later parts of the record further shows a reduction of ~ 12–14 nT in the daytime EEJ intensity during 2016–2025 relative to 1996–2005, particularly around local noon. The combined results demonstrate that the progressive geomagnetic field evolution and the associated displacement of the dip equator are important factors in the observed long-term changes in EEJ strength over the Indian sector. This study emphasizes that secular geomagnetic variations should be considered when interpreting long-term changes in equatorial ionospheric currents and their electrodynamic environment.

GEOMAGNETIC STORM PHASE DEPENDENCE OF EMIC-ASSOCIATED ENERGETIC PARTICLE PRECIPITATION: A STATISTICAL STUDY DURING THE VAN ALLEN PROBES ERA

S. Deepak*(1), B. Remya(1), L. Capannolo(2), Amrutha(1), S. V. Singh
(1) Indian Institute of Geomagnetism, Navi Mumbai, India.
(2) Boston University, USA.
e-mail*: deepakresearch2023@gmail.com

ABSTRACT

Electromagnetic ion cyclotron (EMIC) waves play a crucial role in the dynamics of Earth's inner magnetosphere by scattering energetic ring current protons and relativistic radiation belt electrons into the atmosphere through resonant wave–particle interactions. Understanding the storm-phase dependence of EMIC wave generation and the associated energetic particle precipitation is essential for quantifying particle losses and improving space weather models.

A comprehensive statistical investigation of EMIC wave-driven energetic particle precipitation during the Van Allen Probes era is conducted using magnetic field line conjunction analysis between the Van Allen Probes and National Oceanic and Atmospheric Administration low-Earth-orbiting satellites to identify conjugate observations of in situ EMIC waves and the corresponding proton and relativistic electron precipitation. Superposed epoch analysis is carried out to examine the evolution of solar wind parameters, geomagnetic activity, and plasmaspheric density measured by the Van Allen Probes during the main and recovery phases of geomagnetic storms. The analysis further investigates storm-phase variations in the occurrence, duration, magnetic local-time distribution, radial extent, and wave-band characteristics of EMIC wave activity, as well as plasmaspheric structural changes that provide favourable conditions for wave growth and particle scattering.

The energy input associated with EMIC wave-driven proton and relativistic electron precipitation is also estimated to quantify its contribution to ring current decay and radiation belt losses throughout storm evolution. The results are expected to provide a comprehensive observational assessment of the storm-phase dependence of EMIC wave activity, identify the magnetospheric conditions favourable for EMIC wave generation, and improve

LONGITUDINAL CHARACTERISTICS OF SOLAR TIDES FROM LOW-LATITUDE GROUND MAGNETIC OBSERVATIONS

Divyanshu Dwivedi* , N. Phani Chandrasekhar
Geomagnetic Observatories, CSIR-National Geophysical Research Institute, India
Correspondence*:ddwivedi.ngri@csir.res.in

ABSTRACT

The longitudinal variability of geomagnetic solar tides provides valuable insights into ionospheric electrodynamics and the influence of solar forcing on the Earth's magnetic field. In this study, hourly geomagnetic H-component data from the low-latitude observatories Guam (GUA), Hyderabad (HYB), and Alibag (ABG) were analysed for the period 1986–1996, covering Solar Cycle 22. After correcting the data using the revised Dst index, harmonic analysis was employed to derive the principal solar tidal components (S1-S4) and investigate their temporal and spatial variability. The extracted tidal amplitudes were examined with respect to different phases of the solar cycle and grouped into Lloyd's

seasonal classifications to evaluate seasonal behaviour. The results reveal a systematic decrease in solar tidal amplitudes from the eastern to the western longitude sector, with GUA exhibiting the largest amplitudes and ABG the smallest. Lower-order tidal components show a strong association with solar activity, whereas higher-order tides display greater longitudinal variability. Correlation analysis further indicates a reduction in coherence with increasing longitudinal separation, suggesting the influence of non-migrating tidal processes and regional ionospheric dynamics. Spectral analysis identifies dominant periodicities associated with solar rotation together with secondary harmonics. These findings improve the understanding of longitudinal modulation of geomagnetic solar tides and their response to varying solar conditions.

Keywords: Solar tide, Geomagnetism, Longitudinal variability, Solar cycle, Harmonic analysis

AN INVESTIGATION OF THE GLOBAL RESPONSES OF THE THERMAL FIELD OF THE MLT REGION TO THE 'SEVERE' GEOMAGNETIC STORM OF 10-11 OCTOBER 2024

Govind Narayanan K[1], Navin Parihar [1], Chinmaya Nayak[1], Alok Taori[2], Anand Kumar Singh[3], Shailendra Saini[3], Prasant K. Tiwari[1], and Ashok Priyadarshan Dimri[1]
(1) Indian Institute of Geomagnetism, Navi Mumbai, 410218, India
(2) National Remote Sensing Centre, ISRO, Hyderabad, 500037, India
(3) National Centre for Polar and Ocean Research, Goa, 403804, India
Presenting author: govindnk2022@gmail.com

ABSTRACT

Geomagnetic storms can influence the thermal field of the mesosphere-lower thermosphere (MLT) region in the Polar Region - Auroral Oval (PRAO) via Joule and particle heating. Present study reports the global responses of the MLT region thermal field to the 'G4' class geomagnetic storm of 10-11 October 2024 utilizing Sounding of the Atmosphere using Broadband Emission Radiometry/Thermosphere Ionosphere Mesosphere Energetics Dynamics (SABER/TIMED) measurements. We observed that both heating and cooling can occur during the storm-time and the temperature changes were primarily confined to the altitude range 90-110 km. A maximum temperature enhancement of ~40 K was seen around 75-90° N (at ~108 km) on 11 October. An increase in temperature exceeding 30 K was noted in 60-75° N, and can be attributed to the equatorward expansion of the PRAO. Interestingly, near simultaneous temperature enhancement was observed at ~110 km around midnight in the equatorial region and PRAO during the storm progression, and both their scales were similar. Beginning 12 October, cooling occurred at lower heights (~105 km) around mid-afternoon near equator, and persisted beyond 14 October. We use Weimer-2005 Model simulations to study the extent of Joule heating (JH) towards lower latitudes. During 10-11 October, the JH was found to extend down to ~50° latitudes with a maximum increase exceeding 150 mW/m^2. The study revealed that the observed thermal changes in the MLT are significantly dependent on various background factors such as season, solar radiation, local time, latitude, longitude, thermospheric winds, tides, gravity waves, SPE-induced changes, or the combination of these effects.

MULTI-SPACECRAFT STUDY OF ICME-ICME INTERACTIONS, ICME-IN-SHEATH AND ASSOCIATED GLE #77 DURING 11-12TH NOV 2025

Harsh Bhati[1], Mani K Chettri[2], Hemam Dinesh Singh[1]
[1]Netaji Subhas University of Technology, Delhi, India
[2]Sikkim University, Gangtok, Sikkim, India
Presenting author: harshbhatimultiverse@gmail.com

ABSTRACT

We examine the propagation, interaction, and turbulence properties of a multi-CME sequence erupted between 9–11 November 2025, using multi-spacecraft in situ observations from Aditya-L1 (MAG, ASPEX), WIND (SWE), MMS (FGM), and Solar Orbiter (MAG, EPD; positioned at 0.83 AU, 13.5° inclination), supplemented by ground-based neutron monitor data. X1.7 and X1.2 flares on 9–10 November (07:36 and 09:48 UT) produced CMEs with speeds of 625 and 1644 km/s, respectively; the faster ejecta overtook the preceding one, forming a complex merged structure whose shock arrived at L1 at ~23:48 UT on 11 November, driving an intense geomagnetic storm (Dst_min = −217 nT). Quasi-perpendicular shock parameters were derived from peak ion flux enhancements (Aditya-L1/ASPEX, Solar Orbiter/EPD) and triaxial magnetic field discontinuities (Aditya-L1/MAG, Solar Orbiter/MAG), followed by a turbulent sheath. Velocity, density, temperature, energetic-ion, and IMF signatures indicate clear ICME-ICME interaction. A subsequent X5.1 flare (10:04 UT, AR 14274) generated a 1845 km/s CME whose leading edge overtook the trailing magnetic cloud of the 10 November ejecta, producing an ICME-in-sheath configuration with compressed, turbulent plasma and anomalous fluctuations observed between 10:00-12:00 UT on 12 November. MMS-derived PSD analysis yields a kinetic-scale spectral index of ≈−2.602, intermediate between KAW and whistler-type turbulence, indicating enhanced dissipation. Neutron monitor data confirm GLE #77, exhibiting a rare double-peak, anisotropic profile. ENLIL simulations corroborate the merged-ejecta formation and subsequent interaction with the preconditioned heliosphere, elucidating shock-driven particle acceleration mechanisms relevant to SEP generation.

IONOSPHERIC SEISMOLOGY AND VOLCANOLOGY: OBSERVING EARTHQUAKES, VOLCANOES AND TSUNAMIS FROM SPACE

Mala S. Bagiya
IIG, Navi Mumbai
mala.bagiya@iigm.res.in

ABSTRACT

Large earthquakes, explosive volcanic eruptions and tsunamis generate atmospheric acoustic and gravity waves through dynamic coupling between the solid Earth and the atmosphere[1-3,6].

Upon arriving the ionosphere, these atmospheric wave disturbances manifest as co-seismic, co-volcanic, or co-tsunami ionospheric perturbations depending on their source. Global Navigation Satellite System (GNSS)-based ionospheric remote sensing measurements have enabled detailed investigations of these disturbances[2,3-5]. These disturbances have increasingly been used to derive information about the seismic source[2,3,5-7]. Ionospheric seismology and volcanology, emerging interdisciplinary research fields, refer to the investigation of earthquakes, volcanoes and tsunamis -

through the analysis of their ionospheric manifestations. The presentation will discuss the current status and future perspectives of these fields.

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STORM-PHASE EVOLUTION OF LOW-LATITUDE PC5 GEOMAGNETIC PULSATIONS AND THEIR RELATIONSHIP WITH SOLAR-WIND DRIVERS DURING SEVERE STORMS OF SOLAR CYCLE 25

Manjula Lingala and Sergey Y. Khomutov
CSIR-NGRI and FEB RAS IKIR
Corresponding author: manjula.ngri@csir.res.in

ABSTRACT

Pc5 geomagnetic pulsations are an important manifestation of solar wind–magnetosphere coupling; This study uses 1-s geomagnetic field measurements from the HYB observatory to examine Pc5 activity during six severe geomagnetic storms of Solar Cycle 25. Pc5-active intervals were identified within 1.7–6.7 mHz using time–frequency analysis and classified into pre-storm, main, and recovery phases. In total, 148 intervals were evaluated using RMS amplitude, band-integrated power, dominant frequency, duration, and spectral quality factor (Q factor).

Pc5 activity consistently intensified during the storm main phase. Median RMS amplitude and band power increased from the pre-storm to main phase in all five storms permitting direct comparison, and Pc5 intervals generally became longer. In all four storms with resolved dominant-frequency estimates during both phases, dominant frequencies shifted toward lower values in the main phase. Q-factor variations were less consistent because fewer intervals yielded reliably resolved spectral peaks.

To examine associated external conditions, every Pc5 interval was matched with simultaneous 1-min IMF Bz, solar-wind speed (Vsw), dynamic pressure (Pdyn), and SYM-H measurements. Storm-phase analysis revealed strong positive associations of RMS amplitude and band power with both Pdyn and Vsw. Pc5 duration was also strongly associated with Pdyn, whereas dominant frequency was negatively associated with Pdyn. Negative correlations of RMS amplitude and band power with SYM-H further indicated enhanced Pc5 activity under stronger geomagnetic disturbance.

These results demonstrate that severe storms produce stronger, more powerful, and longer-lasting low-latitude Pc5 pulsations during the main phase, accompanied by lower dominant frequencies. Their close associations with Pdyn and Vsw emphasize the importance of enhanced solar-wind forcing. Nevertheless, correlations alone cannot establish a unique generation mechanism; event-resolved analyses are needed to distinguish pressure-driven, cavity/waveguide, and field-line resonant responses under varying magnetospheric conditions during storm phases.

Keywords: Pc5 pulsations; Geomagnetic storms; Low-latitude ULF waves; Solar-wind dynamic pressure; Storm-phase evolution; Solar-wind–magnetosphere coupling.

EFFECT OF GEOMAGNETIC STORM OF 01 JANUARY 2025 ON NOCTURNAL EQUATORIAL/LOW LATITUDE THERMOSPHERE-IONOSPHERE SYSTEM

Manu T1, 2, C. Vineeth1, R. K. Choudhary1, T. K.Pant1
1. Space Physics Laboratory, VSSC, ISRO, Trivandrum, India
2. Department of Physics, University of Kerala, Trivandrum, India
Email: manu.t0111@gmail.com

ABSTRACT

The present study deals with the response of Equatorial/Low-latitude Thermosphere-Ionosphere system during the geomagnetic storm of 01 January 2025 primarily using three atomic oxygen airglow emissions from Trivandrum (8.47°N, 76.92°E geographic, 1.9°N dip latitude). The data from collocated Fluxgate Magnetometer and Digisonde data have also been used. Additionally, the GPS-TEC data from multiple stations across different latitude region over Indian sector are also used. The Prompt Penetration Electric Field Model (Manoj and Maus, 2012) has been used for estimating the low latitude disturbance electric fields during the storm. The geomagnetic storm of 1 January 2025 was a G4 class geomagnetic storm with a Dst minimum of -212 nT. This storm exhibited the characteristics of a positive ionospheric storm with large modulations in both the ionospheric peak electron density (NmF2) over equator and TEC over equatorial and low latitudes region. The analysis of the data from multiple instruments revealed that equatorial and low latitude ionosphere experienced drastic modulations due to the penetrated electric fields. A threefold increase in the intensity of 630 nm nightglow emission was observed on the recovery phase of this storm. In addition, all the three emissions showed a sudden depletion at around the midnight on the storm day. The strong eastward disturbance electric field also led to a night-time reactivation of plasma fountain, which modulated the plasma distribution over the low-latitude stations in the Indian sector. This study discusses about these aspects in detail.

CLIMATE VULNERABILITY OF SORGHUM PRODUCTION ACROSS INDIA'S AGROCLIMATIC ZONES UNDER FUTURE CLIMATE SCENARIOS

Mrinalini Srivastava[1*], R.K Mall[1]
[1] DST – Mahamana Centre of Excellence in Climate Change Research, Institute of Environment & Sustainable development, Banaras Hindu University, Varanasi, India.
[*]Corresponding email- mrisri18@gmail.com , rkmall@bhu.ac.in

ABSTRACT

Sorghum (*Sorghum bicolor* L. Moench) is a climate-resilient cereal that plays a critical role in food and nutritional security across the semi-arid agroclimatic zones of India. However, rising temperatures and

changing precipitation patterns are expected to alter crop productivity and water availability, posing significant challenges to sustainable sorghum production. This study assessed the impacts of future climate change on sorghum productivity, water use efficiency (WUE), growing degree days (GDD), rainfall, and heat–water stress across India's major sorghum-growing agroclimatic zones using the DSSAT CERES-Sorghum model. Simulations were driven by bias-corrected CMIP6 climate projections under SSP2-4.5 and SSP5-8.5 for the mid-century (2040–2069) and late-century (2070–2099) relative to the 1980–2009 baseline. Spatial analysis revealed widespread reductions in grain yield, with localized losses reaching 30–36%, particularly under SSP5-8.5 during the late-century period. Water use efficiency declined across most sorghum-growing regions, with local reductions of up to 31%, indicating reduced crop productivity per unit of water consumed. Mean accumulated GDD increased from 1953 °C-days during the baseline period to 2108–2160 °C-days under SSP2-4.5 and 2151–2304 °C-days under SSP5-8.5, reflecting enhanced thermal accumulation and accelerated crop development. Future rainfall remained predominantly monsoonal but exhibited greater spatial variability and more concentrated precipitation events, especially under SSP5-8.5. The spatial distribution of climate stress further indicated an expansion of heat and combined heat–water stress across several agroclimatic zones, highlighting emerging climate-risk hotspots. Overall, the results demonstrate increasing vulnerability of sorghum production to future climate change and provide a spatially explicit scientific basis for prioritizing climate-resilient adaptation strategies and improving sustainable sorghum production across diverse agroclimatic regions of India.

Keywords: CERES Model, CMIP6, Elevated temperature, CO_2, Climate Change

IMPACT OF THE SEPTEMBER 2017 CME ON THE MARTIAN PLASMA ENVIRONMENT

V. S. P. Pranjali*(1) , Chinmaya Nayak(1) , Suraj Gupta(1) , Satyavir Singh(1) , and A. P. Dimri(1)
(1) Indian Institute of Geomagnetism, Navi Mumbai, India
Email: pranjali.p11@gmail.com

ABSTRACT

Enhanced solar wind dynamic pressure and interplanetary magnetic fields driven by Coronal Mass Ejections (CMEs) strongly affect the Martian induced magnetosphere and ionosphere. The study investigates the shifts in the boundaries of the Martian Plasma Environment during the September 13, 2017 CME event using in situ observations by MAVEN (Mars Atmosphere and Volatile EvolutioN). The CME-driven increase in solar wind dynamic pressure compressed the magnetosphere and pushed the magnetic pile-up boundary inward by approximately 17–18%. The consequent enhancement in the magnetic pressure was observed. The ionosphere also showed a severe response, with electron density decreasing by approximately 80–100% above 300 km altitude. Electron temperature increased by ~150% during the inbound pass and by ~350% at 400–450 km during the outbound pass. These observations demonstrate the significant impact of extreme CME-driven solar wind disturbances on the Martian ionosphere.

SUBSURFACE IMAGING OF MARS FROM INSIGHT SEIS

Prathmesh Tari[1*], Mala S. Bagiya[1], Rabin Das[1], Priyeshu Srivastava[1] , Melanie Drileau[2], Philippe Lognonné[2], A.P. Dimri[1]
[1]Indian Institute of Geomagnetism, sec.-18, Near Kalamboli Highway, New Panvel, Navi Mumbai – 410218
[2] InstitutSup´erieurdel'A´eronautiqueetdel'EspaceISAE-SUPAERO, Toulouse, France
Presenting Author : prathmeshtari@gmail.com

ABSTRACT

Although Mars is presently considered tectonically inactive, its geological features provide evidence of past and potentially ongoing seismic activity. The Seismic Experiment for Interior Structure (SEIS) instrument aboard NASA's InSight mission, comprising Very Broadband (VBB) and Short Period (SP) sensors in the UVW orientation, recorded 1,319 seismic events (Lognonne et al, 2023). Of these, 26 high signal-to-noise ratio events were selected for P-receiver function (P-RF) analysis, of which 15 were identified as containing glitches and were excluded from further analysis.

In this study, we investigate the crustal structure beneath the InSight SEIS station using the P-receiver function approach. The three-component UVW seismic data were first rotated into the ZRT coordinate system (vertical, radial, and transverse components). The relatively low magnitudes of marsquakes and the presence of substantial background noise make the extraction of reliable seismic phases challenging. Consequently, previous investigations of the Martian crust using receiver functions have adopted different filtering, preprocessing, and receiver-function methodologies, reflecting the challenges associated with the limited quality and quantity of Martian seismic data(Shi et al 2023, Dai and Sun 2023). Time-domain iterative deconvolution with a Gaussian filter width of 2 was then applied to minimize source and propagation-path effects, thereby isolating the receiver-side response and enhancing the identification of P-to-S converted phases. To further improve waveform quality and consistency, Principal Component Analysis (PCA) was employed for noise reduction. In addition, apparent shear-wave velocity and Rayleigh-wave ellipticity were derived and jointly inverted with the P-RFs to provide stronger constraints on the subsurface velocity structure. The combined analysis provides new insights into the upper-crustal structure beneath the InSight landing site on Mars, with detailed results of the joint inversion presented in this study.

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THE HEMISPHERIC ASYMMETRY IN THE IMPACT OF DISTURBANCE ELECTRIC FIELD IN THE INDIAN SECTOR: - A STATISTICAL ANALYSIS BASED ON GEOMAGNETIC STORMS OF DST<-50 OCCURRED DURING 2012-2016

R. K Archana1, Lekshmi O Nair2, C. Vineeth1, T. K. Pant1, Lijo Jose2
Space Physics Laboratory, VSSC, ISRO, Trivandrum, India1
S. B. College Changanasseri, Kottayam, India2
Corresponding author: archanark.geo@gmail.com

ABSTRACT

Magnetic signatures associated with disturbance electric field have been examined in the Indian sector for 98 geomagnetic storms of Dst <-50nT occurred during 2012-2016 period. The study examined magnetic signatures from nine geomagnetic observatories covering both the hemispheres in the Indian sector. The analyses have been extended to other latitudes for the events where westward electric disturbance identified at equator. Study reveals that the southern hemisphere (SH)of the Indian sector shows the formation of anti-Sq loop for 35% of the events while northern hemisphere (NH)is only 24%, clearly depicting the hemispheric differences in the response of the ionospheric current of both the hemispheres. The analysis of O/N2data over this sector revealed a hemispheric asymmetry with higher variations in SH than NH. The observed hemispheric asymmetry could be attributed to the orientation of geomagnetic fields and relative positions of the geomagnetic poles, where the polar heating occurs during the geomagnetic storms. The southern geomagnetic pole is located at 65°S and 135°E, while northern pole is at 85°N and 240°E. This could be an indicator that the proximity of geomagnetic poles plays a role in modifying disturbance electric field over equatorial ionosphere in the Indian sector.

Keywords: Geomagnetic storms, Disturbance dynamo, EEJ, CEJ

GRAVITY CONSTRAINTS ON CRUSTAL THINNING AND STRUCTURAL HETEROGENEITY IN THE HUMBOLDTIANUM AND MENDEL–RYDBERG LUNAR IMPACT BASINS

Rahul Biswas[1]*, U. Sreenandana[2], Arghya Kusham Dey[1], Prakash Kumar[1];
[1] CSIR–National Geophysical Research Institute (CSIR-NGRI), Hyderabad, Telangana, India;
[2] PG Department of Geology, Bishop Kurialacherry College for Women, Amalagiri, Kottayam, Kerala, India, affiliated to Mahatma Gandhi University
Presenting Author e-mail ID: rbiswas92.ngri@csir.res.in

ABSTRACT

Gravity and topographic characteristics of the Humboldtianum and Mendel–Rydberg lunar impact basins are investigated to evaluate relative crustal thinning and basin-scale structural heterogeneity. Co-registered Lunar Orbiter Laser Altimeter (LOLA) topography and GRAIL GRGM900C gravity are processed through the same basin-centred workflow to obtain free-air, Bouguer and residual gravity fields, radial power spectra, and a gravity-derived equivalent crustal-thickness proxy. Humboldtianum shows a spatially coherent and strongly positive Bouguer anomaly of +605 ± 32 mGal in the central region, whereas Mendel–Rydberg exhibits a lower and more spatially variable Bouguer response of +375 ± 51 mGal. The residual-gravity field of Mendel–Rydberg shows approximately 2.1–2.5 times greater variability than Humboldtianum. Radial power spectra independently confirm this contrast, with substantially stronger high-wavenumber gravity power at Mendel–Rydberg, indicating enhanced short-wavelength structural heterogeneity.

The gravity-derived crustal-thickness proxy indicates thinner crust beneath Humboldtianum than beneath Mendel–Rydberg. Comparison with independent crustal-thickness estimates preserves the same relative ordering, although the proxy overestimates absolute crustal thickness by factors of approximately 1.3–2.3. The inferred thickness is 10.1 km at Humboldtianum compared with an independent range of 4.4–8.4 km, and 18.9 km at Mendel–Rydberg compared with 13.1–16.4 km. Density-contrast sensitivity tests show that no single density contrast reconciles both basins simultaneously. Von Kármán spectral analysis of the basin topography, using the angular-wavenumber convention $k = 2\pi/\lambda$, yields similar model-dependent correlation lengths of approximately 20–21 km for the two basins (equivalent to spectral transition wavelengths of roughly 125–135 km), despite their contrasting gravity behaviour.

The results indicate that Humboldtianum is characterized by comparatively coherent crustal thinning, whereas Mendel–Rydberg preserves greater short-wavelength gravity heterogeneity. The similar topographic correlation scales but contrasting gravity spectra suggest that differences between the two basins are expressed more strongly in their subsurface-sensitive gravity fields than in the characteristic spatial scale of surface relief. These results demonstrate the value of combining gravity, topography and spectral analysis for comparative characterization of lunar impact basins.

Keywords: Lunar impact basins; GRAIL; LOLA; crustal thinning; structural heterogeneity; residual gravity; von Kármán analysis; Humboldtianum; Mendel–Rydberg

USING SHORT PATH VLF WAVE INTERFEROMETER TO CHARACTERIZE THE PROPERTIES OF THE EQUATORIAL D-REGION OF THE IONOSPHERE

Reuben Samson Yaqub1,2, Mridula N.1 , Nazeer M.1 , Koushik N.1 , Manu T.1,2, Vineeth C.1 , Tarun Kumar Pant1
1 Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, Kerala- 695022 2Department of Physics, University of Kerala, Thiruvananthapuram, Kerala- 695034
Presenting author: reubenyaqub@gmail.com

ABSTRACT

The D-region of the Ionosphere, spanning 60 km to 95 km in altitude, presents challenges in continuous in-situ probing. The Earth's surface and the D-region also form a waveguide for the propagation of Very Low Frequency (VLF) waves over long distances. Any changes in the D-region parameters are reflected in the propagation characteristics of VLF waves and thus they can be used for continuous D-region observations. The D-region is influenced by forcings from both lower and upper altitudes. The forcings from below, via wave activity, can change D-region temperatures and lead to cooling. The downwelling from higher altitudes can cause temperature increases, which are often observed during Geomagnetic storms. Thus, having an idea of the D-region temperature provides insight into how this region is coupled to other regions of the atmosphere. In this study, VLF waves over a short propagation path were used to investigate variations in the D-region neutral temperature and density during local sunrise and sunset. The interference between the skywave and the ground wave component of the VLF signal, which manifested as a bump in amplitude versus time observations, was used to study temperature variations. A clear seasonal picture in the skywave strength was observed, which was consistent with the seasonal variation of mesopause temperature. For the days with lower temperatures, morning counter electrojet signatures were seen in the local magnetometer observations, which pointed

to forcings from below. The period of the May 2024 Geomagnetic storm was also studied using this technique and cases of heating in the D-region were observed which were consistent with satellite-derived temperature observations.

MIRROR-MODE WAVES AND ASSOCIATED ENERGETICS IN EARTH'S MAGNETOSHEATH REGION

Sachit Upadhyay[1], Amar Kakad[1], Shubhangi Lagad[1], Sahil Pandey[1], Dhirajkumar Shende[1]
[1]Indian Institute of Geomagnetism, Navi Mumbai, India
Presenting author: upadhyaysachit@gmail.com

ABSTRACT

Mirror Mode (MM) waves are non-propagating compressive structures characterized by anti-correlated fluctuations in magnetic field strength and plasma density. They typically develop in regions with high plasma beta ($\beta > 1$) and ion temperature anisotropy ($T_\perp/T_\parallel > 1$). These conditions are common across boundary layer regions, including planetary magnetosheaths, interplanetary coronal mass ejection (ICME) sheaths, and solar wind interaction regions. Sheaths in particular are compressive and turbulent, creating an environment that favours plasma instabilities and the prolonged growth of MM structures. Using *in situ* spacecraft observations, the present study provides a generalized approach to detecting and characterizing MM waves using Minimum Variance Analysis (MVA) of the magnetic field, validated alongside plasma parameter relations and their interactions with the ambient plasma environment, highlighting their role in particle energetics around the magnetosheath.

GLOBAL TEMPERATURE CHANGE MODELLING VIA NONLINEAR BAYESIAN NEURAL NETWORK AND INTERPRETABLE AI/ML

[1]Saumen Maiti*
[1]Department of Applied Geophysics, IIT(ISM) Dhanbad-826004
*Presenting Author's Email: saumen@iitism.ac.in; saumen.maiti@gmail.com

ABSTRACT

Modelling of global temperature modelling assumes a special significance for climate change and other earth-atmospheric-ocean modeling studies. However, it is difficult to model the global scale temperature change using climate variables as there is intricate coupling, interplaying and interaction among the earth-atmospheric-ocean/climate-subsystems resulting in complex (non-linear) relationships between climate variables and global temperature change. A Bayesian neural network model optimized by Hybrid Monte Carlo (HMC) and interpretable AI/ML with Random Forest Regression (RFR) model with SHapley Additive exPlanations(SHAP) analysis were used to model the global temperature change over past 166 years 1856-2023 records. Model studies show that the AI/ML and Bayesian neural model can able to model the global temperature change with coefficient of determination (R^2~0.98) between observed and predicted temperature change when the model makes use of natural+ anthropogenic+ other climate series as inputs. In addition, Bayesian neural model detects the key role of anthropogenic forcing (e.g., RFANTH (~85%)) on global temperature anomaly in the last 50-60 years while interpretable AI/ML with RFR-SHAP analysis provides precise role of influence of inputs (e.g., solar, volcanic, greenhouse gas, black carbon and atmospheric sulphates) on target temperature modeling

with Force, Beeswarm, Waterfall, Feature Clustering, Violin and Partial Dependence Plot-based analysis.

IDENTIFICATION OF ASYMMETRIES IN AURORAL ACTIVITY BETWEEN NORTHERN AND SOUTHERN HEMISPHERES

Shailja Saxena[1], Geeta Vichare[1]
[1]Indian Institute of Geomagnetism, Navi Mumbai, India
Presenting author: shailja.saxena@iigm.res.in

ABSTRACT

Space weather phenomena are the primary cause of disturbances in the Earth's magnetosphere and ionosphere system. These disturbances are recorded by ground-based magnetometers and quantified using geomagnetic indices. The auroral zone magnetic activity is measured using the Auroral Electrojet index (AE). It is calculated using data from 10 - 13 magnetometer stations located around the auroral oval in the northern hemisphere. To improve the spatial coverage, the SuperMAG collaboration has developed the SuperMAG electrojet index (SME). It is derived using the data from approximately 110 magnetometer stations located between geomagnetic latitudes $+40^0$ and $+80^0$. SME shares the same methodology as AE. Even though SuperMAG utilizes a large number of stations, it has poor coverage in the southern hemisphere. In this work, we studied the substorm signatures as H-component variations at the Antarctic stations. Then, we compared these observations with the indices computed based on the magnetic field measurements in the northern hemisphere. The data at magnetic conjugate points in the northern and southern hemispheres is analyzed. We have attempted to identify the asymmetries between both the hemispheres and discussed the North-South asymmetries during auroral activity.

OBSERVATION OF GLOBAL PC5 PULSATIONS DURING MAIN PHASE OF 10 MAY 2024 GEOMAGNETIC STORM

Shreya Mishra1 , Jayashree Bulusu1 , Kazuhiro Yamamoto2 , Archana Radhakrishnan3 , and A.P Dimri1,4
1 Indian Institute of Geomagnetism, Mumbai, India, 410218
2 Institute for Space-Earth Environmental Research (ISEE), Nagoya University
3Space Physics Laboratory, Vikram Sarabhai Space Centre, ISRO, Thiruvananthapuram 695021, India
4School of Environmental Science, Jawaharlal Nehru University, New Delhi, India, 110067
shreya.m@iigm.res.in

ABSTRACT

The Earth's magnetosphere experienced the largest geomagnetic storm of Solar Cycle 25 on 10 May 2024, with the Sym-H index decreasing below 500 nT. In this study, we investigate the impact of this storm on long-duration Pc5 pulsations. For this purpose, we used data from 42 ground-based magnetic observatories from INTERMAGNET during the main phase of the storm. The investigation was conducted during the interval between the two ICMEs (17:30–21:30 UT on 10 May) to characterize the magnetospheric and Pc5 responses associated with the first ICME. Three intervals of global Pc5 pulsations (2–7 mHz) were identified from the ground-based magnetic signatures. A Pc5 power index was estimated to investigate the global distribution of Pc5 wave power. The local-time and latitudinal variations were investigated individually for all three events. The latitudinal profiles show an enhancement of Pc5 wave power near the equator in the noon sector, which may be associated with the

contribution of ionospheric currents. Gradient analysis reveals signatures of field line resonance (FLR) structures in the American sector. Polarization characteristics indicate linear polarization, with a degree of polarization equal to 1. To investigate the wave generation mechanism, the azimuthal wave number (m) was estimated, with m ~ 10 suggesting an externally driven mechanism. Possible external drivers, including solar-wind speed and dynamic pressure from DSCOVR, were examined by comparing their variations with the ground magnetic-field measurements. The observed good correlation suggests that the Pc5 pulsations were likely driven by external solar-wind conditions.

Keywords: Pc5 Pulsation, 10 May geomagnetic storm, Solar wind parameter, Field line resonance (FLR), Magnetometer data

FROM SUNSPOTS TO GEOMAGNETIC ACTIVITY: STATISTICAL AND MACHINE LEARNING ANALYSIS OF LONG-TERM SPACE WEATHER VARIABILITY

Shreyas Khobragade
Vidyalankar Institute of Technology, University of Mumbai
Presenting author: shreyaskhobragade1002@gmail.com

ABSTRACT

Space weather arises from the interaction of variable solar activity with the near-Earth environment and can produce geomagnetic disturbances that affect technological systems and space-based infrastructure. This study investigates long-term relationships between solar activity and geomagnetic activity using monthly observations spanning 1948–2024. Monthly mean Sunspot Number and 10.7 cm solar radio flux (F10.7) were used as indicators of solar activity, while the Planetary Kp index was used to characterize geomagnetic activity. The datasets were integrated into a temporally consistent monthly dataset comprising 922 observations.

Exploratory, statistical, and time-series analyses were performed to characterize long-term variability and relationships among the selected indicators. Sunspot Number and F10.7 exhibited a very strong positive correlation ($r = 0.976$), reflecting their common variation over the approximately 11-year solar cycle. Both solar indicators showed statistically significant positive associations with Kp, with correlations of $r = 0.407$ for Sunspot Number and $r = 0.379$ for F10.7. A linear regression using Sunspot Number explained 16.6% of the variance in Kp, while a model incorporating both solar indicators explained 17.2%. Lag-correlation analysis identified the strongest statistical association between Sunspot Number and Kp at a lag of approximately 16 months ($r \approx 0.50$), indicating temporal structure in the monthly observations without implying a direct physical response delay.

Unsupervised machine-learning analyses complemented the statistical results. Principal Component Analysis showed that the first two components retained approximately 99.2% of the total variance, while K-Means clustering identified three naturally occurring groups of monthly observations. These results demonstrate that combining statistical, time-series, and unsupervised machine-learning approaches can characterize long-term solar–geomagnetic relationships and identify patterns within multidimensional space-weather observations. The study provides a reproducible data-driven framework for investigating Sun–Earth coupling using openly available historical observations.

IMPACTS OF INITIAL SEEDS ON THE EVOLUTION AND MORPHOLOGY OF SIMULATED EQUATORIAL PLASMA BUBBLES

Shubham J. Mehta[1], Gopi K. Seemala[1], Sudhansu S. Rayaguru[1], Sanket J. Dore[1]
[1]Indian Institute of Geomagnetism, Navi Mumbai, 410218
Presenting author: mehtashubham1512@gmail.com

ABSTRACT

Equatorial Plasma Bubbles (EPBs) are critical ionospheric irregularities that severely degrade satellite communication and global navigation satellite systems (GNSS) signals. While the underlying physics of EPB development is well established as a nonlinear extension of the generalized Rayleigh-Taylor (RT) instability, identifying the precise atmospheric mechanisms that act as initial seeds remains a significant challenge in modeling. This study investigates the sensitivity of EPB growth, morphology, and evolutionary dynamics to different initial seeding conditions within a self-consistent, numerical RT model. We isolate and evaluate three distinct classes of initial perturbations under identical background ionospheric conditions: structural background plasma density depletions, vertical neutral wind velocity disturbances representing localized gravity wave interactions, and random ambient density fluctuations representing low-level background noise.

The primary focus of this investigation is to determine whether distinct seeding mechanisms leave characteristic signatures on the macroscopic development of the resulting plasma plume. The simulated EPBs are quantitatively compared using high-fidelity spatial diagnostics, including bubble onset timing, vertical rise rate, maximum apex altitude, and structural asymmetry across the geomagnetic field lines. Preliminary results demonstrate that while different seed types can successfully converge into macroscopic density depletions, their temporal trajectories and morphological features vary substantially. The objective is to identify the initial trigger mechanism, ultimately providing a vital bridge toward validating observational event triggers using satellite and ground-based instruments. Triggering the simulation with a localized neutral wind seed quickly shoots a distinct, high-altitude plume upwards with a sharp vertical acceleration curve, whereas starting with random noise delays the initial kickoff, eventually creating a wider scattered field of fragmented, multi-scale plasma plumes instead of a single coherent bubble. By charting these completely different growth patterns, we try to showcase a distinct visual catalog of bubble structures.

VARIATIONS OF EQUATORIAL ELECTROJET DURING GEOMAGNETIC STORM CONDITIONS

Sneha Vengurlekar* and Geeta Vichare
Indian Institute of Geomagnetism, Navi Mumbai, 410218, India
Presenting author: Snehaveg87@gmail.com

ABSTRACT

In the present study, multi-station ground magnetometer observations are utilised to investigate storm-time variations in the equatorial electrojet (EEJ) across three longitudinal sectors during the geomagnetic storm events of 10-11 May 2024, 10-11 October 2024, and 24-25 March 2024. EEJ index for each sector is calculated from the difference between the H-component measurements at an equatorial station and a corresponding off-equatorial station in the Indian (~75°E), Peruvian (~75°W), and Brazilian (~45°W) sectors. The Indian and Peruvian sectors represent opposite day-night

configurations, whereas the Peruvian and Brazilian sectors experience similar sunlit or dark local-time conditions for a relatively longer duration (~20 hours). Initial observations indicate that, under positive interplanetary electric field conditions, the EEJ exhibits positive responses on the dayside and negative responses on the nightside. Accordingly, strong positive correlations are observed between the Peru and Brazil sectors, with correlation coefficients ranging from +0.8 to +1.0, while the India and Peru sectors show strong anti-correlations, ranging from -0.5 to -0.9. However, approximately 10-12 hours after storm onset, these correlation patterns temporarily reverse, with a negative correlation between Peru and Brazil (-0.7), and a positive correlation between India and Peru (+0.4 to +0.7) is seen. To investigate the origin of these polarity changes, the EEJ response to seven isolated sudden-impulse events is examined. All seven events exhibit anti-correlations between the opposite-hemisphere sectors, suggesting that the observed polarity reversals during storms may be associated with the disturbance dynamo electric field effects. A detailed analysis will be presented and discussed.

MINE: A MACHINE LEARNING BASED MARTIAN IONOSPHERIC ELECTRON DENSITY(NE) PREDICTION MODEL

Suraj Gupta 1 , Chinmaya Nayak 1 , Erdal Yiğit 2 , David Andrews 3 , Stephan Buchert 3 , V. S. P. Pranjali 1 , S. Tulasi Ram 1 , Gopi K. Seemala 1 , Satyavir Singh 1 , A. P. Dimri 1

1. Indian Institute of Geomagnetism, NaviMumbai, India

2.Space Weather Lab, Department of Physics and Astronomy, George Mason University Fairfax, Virginia, USA

3.Swedish Institute of Space Physics, Uppsala, Sweden

Presenting author: surajg1781@gmail.com

ABSTRACT

The electron density (ne) is possibly the most important parameter historically used to study and characterize planetary ionospheres. This paper discusses the development of a machine learning (ML) based Martian Ionospheric electron density (ne) model (MIne). Radio occultation-derived ne-profiles from multiple missions (MAVEN (Mars Atmosphere and Volatile EvolutioN), Mars Global Surveyor (MGS), Mars Express (MEX), and MEX Trace Gas Orbiter (TGO)) have been used as inputs for the model development. Further, we have analyzed the prediction performance of five different ML regression models, namely, (i) Decision Tree (DT), (ii) Random Forest (RF), (iii) Gradient Boosting (GB), (iv) HistGradientBoostitng (HistGB), and (v) Xtreme Gradient Boosting (XGBoost) for the electron density of the Martian ionosphere. Each model considered six independent input parameters, namely, Solar Zenith Angle (SZA), Solar Longitude (Ls), Latitude, Longitude, Altitude, and Sunspot Number (SSN), with electron density (ne) as the predicted output parameter. Among the methods considered, Gradient Boosting (GB) regression performed best on standard metrics. Hence, the final model is based on GB regression. Furthermore, the outputs of the MIne model were compared with test profiles, which were kept separate from the training profiles. The results showed that the MIne model performed well across the main ionospheric altitude region for all missions' test profiles except MEX. The current MIne model is the first step towards developing a machine-learning/deep-learning-based Martian ionospheric model by integrating all available measurements from various satellite missions. The current version of the model has been made publicly available for use by the scientific community.

MULTI-YEAR VARIABILITY OF LOW-LATITUDE MESOSPHERIC WINDS AND TEMPERATURES

Vasundhara Barde[1]*, Jayashree Bulusu[1], Ashish Jadhav[2], S. Sathishkumar[3], S. Gurubaran[3] and A. P.Dimri[4, 5]
1 Colaba Geomagnetic Research Laboratory, Indian Institute of Geomagnetism, Mumbai 40005, India
2 Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Pune, India, 411 008
3 Equatorial Geophysical Research Laboratory, Indian Institute of Geomagnetism, Tirunelveli 627011, India
4 Indian Institute of Geomagnetism, New Panvel, Mumbai 410218, India
5 School of Environmental Science, Jawaharlal Nehru University, New Delhi 110067, India
*corresponding email: vasundhara.barde@iigm.res.in

ABSTRACT

The mean horizontal winds and thermal structure of the low-latitude mesosphere and lower thermosphere (MLT) are investigated in relation to long-term solar variability using medium-frequency (MF) radar observations from two Indian stations, Tirunelveli (8.7°N, 77.8°E; 1993-2025) and Kolhapur (16.7°N, 74.2°E; 2015-2025). The meridional wind observations reveal a transition in the prevailing circulation, with southward flow becoming more dominant after 2003, whereas northward winds prevailed before this period. A similar transition is observed in the background zonal mean wind around 2007, with westward winds becoming more prominent after 2007 and eastward winds dominating prior to this period. The wind structure altitude wise also exhibits distinct differences between the ascending and descending phases of solar cycles-22 to 25, with the annual oscillation (AO) amplitude generally decreasing during the ascending phase and increasing during the descending phase of solar cycles 22 to 24. However, this relationship is not evident during the ascending phase of solar cycle 25, when an unexpected enhancement in AO amplitude is observed at both radar stations. Analysis of SABER temperature observations for 2002 to 2024 further indicates that the upper MLT region (>95 km) is warmer during the ascending phases of the solar cycles, accompanied by a pronounced vertical expansion of the mesopause region compared with the descending phases. In addition, a strong inverse relationship between solar activity and diurnal tidal amplitudes is observed at both locations. These findings demonstrate the complex and nonlinear response of the low-latitude MLT to solar forcing and emphasize the role of solar cycle variability in modulating the background dynamical and thermal state of the middle atmosphere.

Key Words: MF (medium frequency) radar, mesosphere and lower thermosphere (MLT) regions, mesospheric winds, SABER data, ascending/descending phase of solar cycle.

YOUNG RESEARCHER PROGRAM

ROLE OF NUTRIENTS AVAILABILITY IN MODULATING OCEAN ACIDIFICATION EFFECTS ON PHYTOPLANKTON

Aditi Sharma[1,2*] and V. V. S. S. Sarma[1, 2]
[1]CSIR-National Institute of Oceanography, 176 Lawsons Bay Colony, Visakhapatnam, India
[2]Academy of Scientific and Innovative Research, Ghaziabad, India
[*]Presenting author (aditi.nio24a@acsir.res.in)

ABSTRACT

Ocean acidification (OA) is an ongoing global challenge caused by rising CO_2 emissions. The highest rate of OA is reported in the coastal region of South and Southeast Asia because ~30% of the global population resides there and resulting in rapid industrialization. Microcosm and mesocosm experiments conducted to examine the impact of OA on plankton often overlook the role of nutrients. The phytoplankton in tropical regions are severely nutrient limited that is projected to expand further in future due to global warming. It is hypothesized that nutrient limitation may overshadows the biological impacts under low pH conditions. To test this, we conducted a microcosm experiment in the northeastern Indian Ocean by lowering pH under nutrient-replete and deplete conditions.

The incubated waters were dominated by cyanobacteria, and green algae and decreased under OA in nutrient-deplete conditions whereas increase in biomass by 391% from that of control was observed in the nutrient-replete conditions. The nutrient-rich acidic environment favored diatoms, which utilized the energy saved from downregulated CCMs to dominate. On the other hand, severe decline in heterotrophic bacterial abundance was noticed under nutrient-deplete OA conditions, whereas sustained bacterial abundance was observed in the nutrient-replete OA conditions likely supported by dissolved organic matter from diatom bloom. Ultimately, these findings show that phytoplankton response may severely constrained by ambient nutrient availability under OA. This study further suggests that the impact of OA on phytoplankton in the tropical regions, where oligotrophy prevails, need to be reconsidered. This study highlights the need for future multi-stressor experiments to understand the role of OA on altering the phytoplankton community structure.

Keywords: Acidification, CCM, Phytoplankton, Oligotrophic, Bay of Bengal

FRACTURES WITHIN MAFIC DYKES AND HOST GRANITES: CAN THEY BE KINEMATICALLY RELATED?

Gourav Das*, Anubhab Dey, Tridib Kumar Mondal
Geological Studies Unit, Indian Statistical Institute, Kolkata, India, *gouravdas352@gmail.com

(Presenting and corresponding author), anubhab.kv@gmail.com, tridibkumarmondal@gmail.com

ABSTRACT

The Neoarchean Closepet granite (Eastern Dharwar Craton, South India) was emplaced syntectonically along a crustal-scale dextral shear zone. During subsequent cooling, small-scale strike-slip to oblique-slip faults developed within the pluton. These faults are kinematically related to regional shearing, as their orientations and sense of movement vary systematically with their proximity to the pluton boundary or shear zones. Fault-slip analysis reveals that a strike-slip stress regime, driven by a regional E-W horizontal far-field compressive stress, was responsible for the generation of the faults. It is also

observed that due to the arcuate nature of the pluton, contrasting sinistral and dextral shear senses are observed in the northern and southern part of the pluton, respectively. Furthermore, these faults are often cross-cut by meter-scale mafic dykes of a later generation, which are themselves replete with fractures of different origins and orientations, hereafter referred to as intra-dyke fractures. Interestingly, a major population of the intra-dyke fractures is of a tectonic origin. Kinematic analysis reveals that the regional shear may have partitioned along the dyke margins and systematically generated both tensile and shear fractures within the dyke body. Based on this, we provide a conceptual model in which the orientation of the solidified dyke relative to the regional stress field governs the geometry and kinematics of intra-dyke fractures. This combined approach provides a robust framework for understanding post-emplacement evolution of regional shear within a virtually isotropic pluton and how it is affected by the presence of mechanical anisotropies such as the dykes.

HOW MISSINGNESS MECHANISMS AND IMPUTATION METHODS SHAPE FAIRNESS, EXPLAINABILITY AND STABILITY

Himanshi Bansal , Dharam Prakash , Harsh Kasyap
Department of Computer Science, Indian Institute of Technology, BHU, Varanasi-221005
Email Id: himanshibansal.rs.cse25@itbhu.ac.in

ABSTRACT

Missing data is a common challenge faced by machine learning models, which is addressed by different imputation methods. However, these imputation methods do not just restore the missing values, they modify the underlying data distribution and thus influence the behavior of the downstream tasks. Existing studies show that missing data mechanisms and imputation strategies can substantially influence group fairness, but the broader consequences of imputation on model behaviour remain insufficiently explored. In particular, the missing data mechanism determines the nature of the information that is lost, while the imputation strategy determines how this missing information is reconstructed. These two factors thus affect not only predictive performance and fairness but also model explanations and the stability of downstream behaviour. In this study, we investigate how different missing mechanisms (Missingness completely at random (MCAR), Missing at random (MAR) and missing not at Random (MNAR)) affect the downstream tasks. For these different missing mechanisms, we consider different imputation methods like K Nearest Neighbours (KNN), Multiple Imputation by Chained Equations (MICE), MissForest, and the diffusion based DiffPuter method are investigated across varying missingness rates. The analysis shows that both the missing data mechanism and imputation method contribute to the changes in downstream tasks which affect the fairness across sensitive groups, feature level explanations, and the stability of model predictions.

CRUSTAL ARCHITECTURE AND LINEAMENT MAPPING OF THE NORTHWESTERN WESTERN DHARWAR CRATON FROM AIRBORNE MAGNETIC DATA: TECTONIC IMPLICATIONS

Krati Gupta[1] and Anand SP [1]
[1]Indian Institute of Geomagnetism Navi Mumbai-410218, Maharashtra, India
Presenting author: kratigupta2610@gmail.com

ABSTRACT

The Western Dharwar Craton (WDC) formed between 3.3 and 2.7 Ga, mainly consisting of granite–greenstone belts, granitic plutons, and cross-cutting mafic dykes. Later tectono-magmatic events

reworked this crust. Regionally, the craton is dissected by prominent NNW–SSE to NW–SE fault systems, along with subordinate ENE-WSW, E-W, and NE-SW structural trends marking crustal extension and rifting.

Here, we examine the structural framework of the north western WDC using merged airborne magnetic data across land and offshore sectors. Potential-field filtering, matched bandpass filtering, and edge-detection methods were used to trace buried lineaments, test offshore continuity, and estimate source depths across the margin. Offshore, the continental shelf shows a clear NNW-SSE structural grain linked to post-Cretaceous separation of India from Madagascar and Seychelles. On the mainland, the fabric is dominated by craton-parallel NW-SE faults and secondary NE-SW lineaments that parallel regional river systems.

Power spectrum depth estimation points to three distinct magnetic source levels. The shallow zone shows dominant NW-SE and NNW-SSE lineaments. At intermediate crustal depths, NNW-SSE and NE-SW lineaments persist. In contrast, the deeper crust is dominated by ENE-WSW and NE-SW trends, reflecting older basement structures beneath shallow cover. We correlate these multi-tier trends with major tectonic episodes, particularly Paleoproterozoic dyke swarms (~2.1 Ga) and Late Cretaceous Gondwana rifting (~90–65 Ma). Features that cut through all depth slices indicate long-term structural inheritance, whereas shallow-only lineaments capture younger overprints. Tracing these lineaments across the coastline confirms multi-stage reactivation across the western craton margin.

ELASTIC FULL WAVEFORM INVERSION (EFWI) FOR HIGH-RESOLUTION NEAR-SURFACE IMAGING

Machitti Pavani[1,2], Mrinal K. Sen[3], Prakash Kumar[1,2], K. Satish Kumar[1,2]
[1]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
[3]The University of Texas at Austin, Austin, TX 78758-4445, USA
Presenting Author's email: machittipavani951@gmail.com

ABSTRACT

Full Waveform Inversion (FWI) is a high-resolution seismic imaging technique that exploits the complete information contained in seismic waveforms to estimate subsurface physical properties. The FWI has significant potential for detailed subsurface characterisation; however, its application to near-surface seismic data remains challenging due to the strong near-surface non-linearity, complex wave propagation, high surface-wave energy, and limited investigation depths in shallow environments. Conventional Multichannel Analysis of Surface Waves (MASW) methods primarily rely on the extraction and inversion of dispersion curves to estimate the shear-wave velocity (Vs) structure of the subsurface. Dispersion-curve-based approaches provide an effective means of characterising near-surface velocity variations; their representation of lateral heterogeneity may be limited by the assumptions involved in dispersion-curve extraction and inversion. In this study, an elastic Full Waveform Inversion (EFWI) approach is investigated to characterise near-surface structures using surface-wave-dominated seismic data. Initially, synthetic seismic datasets corresponding to a range of geological models, including horizontal layered, complex-layered, and checkerboard tests, were considered to evaluate the capability of EFWI under different subsurface conditions. Following the

synthetic evaluation, EFWI was applied to field seismic data acquired along a near-surface profile in the Dehradun region for seismic site characterisation and hazard-related investigations. The field dataset was processed using a surface-wave-oriented workflow, and the resulting EFWI-derived Vs models were compared with the velocity models obtained using conventional MASW dispersion-curve analysis. The comparison indicates that both approaches capture the major vertical variations in shear-wave velocity; however, EFWI provides a continuous spatial representation of velocity variations by utilising the waveform information directly. In particular, the EFWI results provide a more accurate representation of lateral velocity changes and localised subsurface heterogeneities that may not be adequately captured by conventional dispersion-curve-based models.

Keywords: Full Waveform Inversion (FWI), Surface Waves, Complex layered, Seismic hazard, Site characterisation.

IDENTIFICATION OF FRACTURE-RELATED DISCONTINUITIES USING INTEGRATED SEISMIC ATTRIBUTE ANALYSIS IN THE KRISHNA-GODAVARI BASIN, INDIA

Pelluri Latha Sri[1,2]*, Nittala Satyavani[1,2]
[1] CSIR- National Geophysical Research Institute, Gas hydrates building, Room- 207, Habsiguda, Hyderabad, 500007, India.
[2] Academy of scientific and Innovative research (AcSIR), Ghaziabad-201002, India.
lathasrilathapelluri@gmail.com

ABSTRACT

Accurate identification of fracture networks is essential for reservoir characterization and structural interpretation. However, subtle fractures are often difficult to detect on conventional seismic sections because of feeble discontinuity signatures and the presence of residual seismic noise. This study presents an integrated workflow for fracture detection using a 3D seismic dataset from the Krishna-Godavari (KG) Basin, India. The workflow combines median-filter-based seismic conditioning, variance attribute analysis, and ant-tracking enhancement. A median filter was first applied to reduce random noise while preserving structural discontinuities. The conditioned seismic volume was then used to generate a variance attribute, which highlights lateral changes associated with faults and fractures. Thereafter, ant tracking was applied to the variance volume to enhance discontinuity connectivity and improve the delineation of fracture networks. The ant-tracking results reveal a vertically continuous seismic discontinuity interpreted as a potential fracture-related feature. By examining the selected inline together with multiple crossline sections and time slices, the fracture feature has been traced from 1500 to 2200 ms, demonstrating strong structural continuity and connectivity showing from 1800 to 2100 ms. The results reveal multiple interconnected and laterally continuous fracture related discontinuities within the seismic volume. Compared with conventional seismic interpretation, the proposed workflow provides improved visualization of subtle discontinuities and enhances the delineation of fracture corridors, conduit pathways, and structurally connected fracture networks.

ENHANCING SUBSURFACE IMAGING WITH NINE-POINT FINITE DIFFERENCE OPERATOR USING REVERSE-TIME MIGRATION: APPLICATION TO OFFSHORE NANKAI 2D SEISMIC DATA

Raju Babu Allu[1,2*] and Laxmidhar Behera[1,2]
[1]CSIR-National Geophysical Research Institute (CSIR-NGRI), Hyderabad - 500007, India,
[2]Academy of Scientific and Innovative Research (AcSIR), Uttar Pradesh, Ghaziabad- 201002, India
*Corresponding author E-mail: allu.ngri21j@acsir.res.in

ABSTRACT

Reverse Time Migration (RTM) is considered as one of robust wave-equation-based migration methods for imaging complex subsurface geological structures. The numerical solution of the acoustic wave-equation significantly affects the accuracy of RTM imaging, especially in areas with high velocity contrasts, steeply dipping reflectors, and complex geological settings. To overcome this, we have proposed a nine-point finite-difference stencil (9-point FDS) for acoustic wave-field extrapolation in the RTM framework. We have demonstrated its performance for both synthetic and field seismic data sets such as SEAM Phase-I cross-section model and marine Nankai Trough of offshore Japan. 9-point FDS improve the spatial discretization accuracy and wave field simulation, allowing seismic energy to propagate more consistently across complex velocity structures. Numerical studies show that the proposed RTM workflow can accurately recover subsurface reflectivity, maintain structural continuity, and improve delineation of geological interfaces. All the complex subsurface geological structures as well as very steeply dipping reflectors with over-thrust structure are effectively imaged using 9-point FDS RTM scheme. The RTM image also show increased reflector continuity down to basement and sub-basement of the Nankai Trough. The important structures imaged are complex thrust-fault systems at a depth of 4.7-5.2 km, presence of low-velocity-layer (LVL) at a depth of 5.2-5.7 km with presence of a strong reflector impinged within it indicating a fluid saturated zone, which may be considered as oil and gas bearing sediments. Below the LVL, the basement is present extending to a depth of 5.8-6.4 km. An anomalous body of 0.1-0.4 km thick sandwiched between the basement and the decollement in the Nankai Trough, which nucleates many large magnitude earthquakes in this region. The sub-basement is steeply dipping towards SE along the seismic profile having depth varies from 6.5-6.8 km. These results demonstrate that with the help of 9-pony FDS RTM scheme has provided effective and computationally efficient high-resolution seismic images in these structurally challenging environments.

Keywords: nine-point finite difference stencil; reverse-time migration; SEAM phase-1 cross section; Nankai Trough; low-frequency artefact suppression.

INFLUENCE OF MARTIAN CRUSTAL MAGNETIC FIELD ON SOLITARY WAVE OCCURRENCE

Sahil Pandey[1*], Amar Kakad, and Bharati Kakad
[1]Indian Institute of Geomagnetism, Navi Mumbai, New Panvel 410218, India
psahil177@gmail.com

ABSTRACT

Mars does not possess a global intrinsic magnetic field. However, it has strong patches of crustal magnetic fields, concentrated primarily in the southern hemisphere. The interaction of the solar wind

with the Martian ionosphere induces a magnetosphere around the planet. Although this induced magnetosphere is small in spatial extent, it is highly dynamic and supports a variety of plasma waves and magnetospheric transients. Moreover, strong crustal magnetic fields in the southern hemisphere couple strongly with the induced magnetosphere, making Mars a unique plasma environment in the solar system. Recent observations have established that solitary waves are ubiquitous in the Martian plasma environment, similar to their presence in Earth's magnetosphere. In this study, we used a solitary wave database derived from nine years of MAVEN observations to investigate the occurrence of solitary waves in relation to the distribution of crustal magnetic fields. We find that, at lower altitudes, the occurrence of solitary waves decreases over regions of strong crustal magnetic fields, whereas an enhanced occurrence is observed over regions of relatively weak crustal fields. At higher altitudes, however, the occurrence of solitary waves is enhanced over longitudes associated with strong crustal fields, consistent with the uplift of plasma regions and magnetospheric boundaries caused by the crustal fields. Notably, this enhanced occurrence extends to altitudes above the nominal bow shock location, highlighting the potentially significant influence of crustal magnetic fields on large-scale plasma dynamics of the Martian plasma environment.

MAPPING RAYLEIGH WAVE RADIATION VARIABILITY FOR THE *29 JULY 2025* MW 8.8 KAMCHATKA EARTHQUAKE USING IONOSPHERIC OBSERVATIONS

Sunil Saini* (1), Mala S. Bagiya(1), Rabin Das(1), A. P. Dimri(1)
(1)Indian Institute of Geomagnetism, Navi Mumbai, India
Presenting author: sainisunilkc@gmail.com

ABSTRACT

Finite-fault rupture directivity influences the azimuthal distribution of Rayleigh wave energy, producing asymmetric radiation patterns. The 29 July 2025 Kamchatka megathrust earthquake ruptured, spanning roughly 490 km of the Kuril-Kamchatka subduction trench and propagated unilaterally southwestward. During earthquakes, different amounts of seismic energy radiate in different directions due to the rupture directivity of finite fault. This leads to azimuthal dependence in Rayleigh wave radiation around the earthquake source. Propagating Rayleigh waves can generate acoustic waves in the overlying atmosphere through dynamic coupling between the Earth's surface and the atmosphere. The Rayleigh-induced acoustic waves propagate upward to the ionospheric altitudes, generating Co-seismic Ionospheric Perturbations (CIP) [1], that are detectable in far-field (~600-700 km from the epicentre) Global Navigation Satellite System (GNSS)-derived total electron content (TEC) measurements [2, 3].

In this work, we examined TEC observations recorded at GNSS receivers located over 1000 km from the epicentre, primarily over Japan and Alaska, along with seismometer-recorded waveforms data. The observed CIP exhibited pronounced azimuthal amplitude asymmetry, with significantly larger amplitudes in the rupture direction (southwest) and comparatively weaker amplitudes in the opposite direction (northeast). Their propagation velocity corroborated well with the average group velocity of fundamental modes of Rayleigh waves recorded in seismic waveforms, confirming their Rayleigh wave origin. Furthermore, the directional amplitude distribution of seismic observations closely resembled that of the ionospheric observations, indicating that the ionosphere preserved the underlying Rayleigh

wave radiation. We attribute the observed asymmetry to finite-fault rupture directivity, which enhanced Rayleigh wave energy in the forward rupture direction.

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RECONSTRUCTION OF THE PAST GEOMAGNETIC FIELD INTENSITY THROUGH ARCHAEOMAGNETIC RECORDS FROM THE INDIAN SUBCONTINENT

Pradnya Mohite[1], Juili Raut[1], Anish Varma[1], K. Deenadayalan[1], B.V. Lakshmi[1], Manish Rai[2] and A. P. Dimri[1]
[1]Indian Institute of Geomagnetism, New Panvel, Navi Mumbai
[2]Archaeological Survey of India, Office of Regional Director (West), Mumbai
Presenting author: pradnya.mohite1997@gmail.com

ABSTRACT

Earth's magnetic field varies continuously in both space and time. While instrumental and observatory records provide information on its recent behaviour, archaeological artefacts preserve evidence over much longer timescales. During their last heating and cooling cycle, these artefacts acquire thermoremanent magnetization, which can retain geomagnetic information at the time of firing. Despite India's rich archaeological heritage, archaeomagnetic data remain sparse, limiting our understanding of regional geomagnetic field variations. This study aims to expand the Indian archaeomagnetic record through new archaeointensity determinations and the development of a regional palaeosecular variation (PSV) curve. A total of 307 specimens from 10 Indian archaeological sites were investigated using the Thellier–Thellier method. Rock-magnetic investigations were first carried out to characterize the magnetic mineralogy, concentration, grain-size distribution, thermal stability, and their suitability for archaeointensity determination. Following strict selection and correction procedures, 17 high-quality mean archaeointensity estimates were obtained and combined with published and unpublished data from Indian university theses to develop an updated Indian archaeomagnetic database. The combined dataset was used to construct a regional PSV curve using the Bootstrap algorithm, centred at 20.59°N, 78.96°E, covering the period from 2250 BCE to 2024 CE. The curve records substantial temporal variations in geomagnetic intensity, with relatively high intensities around 800 and 400 BCE, followed by a pronounced decrease between ~400 BCE and 200 CE. Intensity remains comparatively stable from ~200 to 850 CE, increases towards relatively high values around 1300 CE, and subsequently decreases until ~1450 CE. From ~1450 CE onwards, the intensity remains comparatively stable. While general alignment with global models was observed for certain intervals, notable discrepancies underscore the need for additional well-dated archaeomagnetic data from the Indian subcontinent. These findings offer essential insights into regional geomagnetic field behaviour and underscore the importance of creating region-specific PSV curves for underrepresented areas.

UNVEILING TROPICAL CYCLONE–INDUCED ATMOSPHERE–IONOSPHERE COUPLING FROM ATMOSPHERIC OBSERVATIONS OVER THE INDIAN SUBCONTINENT

Omkar M. Patil [1]*, Navin Parihar [1], Rajesh Singh [1], A. P. Dimri [1]
[1] Indian Institute of Geomagnetism (IIG), Navi Mumbai, India
E-mail: omkarmpatil5@gmail.com

ABSTRACT

Atmospheric gravity waves (AGWs) play a crucial role in the vertical coupling of the atmosphere–ionosphere system, while tropical cyclones (TCs) are recognized as important transient sources of AGWs [1,2]. This study investigates atmosphere–ionosphere coupling associated with four extreme tropical cyclones over the Indian subcontinent during the last two decades: VSCS Phailin (2013), ESCS Fani (2019), SuCS Amphan (2020), and ESCS Tauktae (2021). Meteorological observations reveal persistent deep convective activity throughout lifecycle of four TCs, with convective clouds reaching higher tropospheric altitudes during storm intensification. Reduced cloud-top temperatures are closely associated with enhanced lightning activity, with pronounced lightning enhancements during intensification stages, particularly within the storm wind-field regions. Concurrent with these intense convective processes, enhanced AGW activity is observed in the mesosphere–lower thermosphere (MLT) region. The results suggest that mesoscale-convective-systems associated with the TCs acted as effective sources of AGWs, which propagated both vertically and horizontally to higher altitudes. TC-associated AGWs are identified and characterized using vertical temperature profiles from the Sounding of Atmosphere using Broadband Emission Radiometry (SABER) instrument and horizontal wave structures observed in Day/Night-Band (DNB) imagery from the Visible Infrared Imaging Radiometer Suite (VIIRS). Pronounced AGW activity is observed during the maximum-intensity stages of four TCs, with distinct variations in both vertical-and-horizontal wavelengths. The vertical and horizontal wavelengths of TC-induced AGWs are quantified, and their evolution during different stages of TC-development is examined. Although AGWs have been inferred from atmospheric observations in previous studies [2], this study provides, for the first time over the Indian region, a simultaneous observational quantification of their vertical and horizontal characteristics. The results provide new observational evidence of TC-driven wave activity in MLT region and highlight the potential role of AGWs in linking intense tropical convection with upper-atmospheric variability and atmosphere–ionosphere coupling over the Indian subcontinent.

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POSTER

ADVANCES IN GEOPHYSICS FROM GEODYNAMICS TO METALLOGENY, AND GREEN ENERGY TRANSITION

THE EFFECTS OF EARTHQUAKE SWARMS HAVE BEEN OBSERVED IN THE SOUTH SCOTIA SEA, AFFECTING BOTH ANTARCTICA AND SOUTH AMERICA.

A. Akilan*, C. Varun, and H.V.S. Satyanarayana
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad, India.

ABSTRACT

The continent of Antarctica is largely detached from human activities taking place in other regions of the world. It is regarded as an optimal site for investigating natural events such as earthquakes and their consequences. An earthquake swarm occurred from November 16 to 18, 2013 (DOY 320 to 322) in the South Scotia Sea, resulting in atmospheric disturbances in the adjacent areas. Variations in atmospheric conditions and Zenith Total Delay (ZTD) were noted over section of East Antarctica and the Antarctic Peninsula, which are in proximity to the Scotia Sea region. In particular, Changes in ZTD were recorded at GNSS stations PALM, SYOG, and MAW1 on the continent. A significant reduction in ZTD was observed at stations close to the earthquake swarm, accompanied by notable fluctuations in atmosphere pressure across various locations in the Antarctica Peninsula and East Antarctica. The average precipitable water vapor (PWV) increased from 4.0 mm to 4.5 mm, reaching a peak of 9.9 mm at the SYOG in East Antarctica, while pressure dropped by 21 hPa and temperature rose. The sea surface temperature (SST) reached 3^{o}C above the climatological averages for the western South Atlantic Ocean. In contrast, stations located in western Antarctica and certain regions of eastern Antarctica, distant from the Scotia Sea (such as MCM4, DAV1, CAS1 and DUM1), showed no significant impact. This suggests and atmospheric linkage between the earthquake swarms in the Scotia Sea ridges and the atmosphere over Antarctica that closer to the Scotia Sea during the seismic activity.

Keywords: GPS, Earthquake swarm, ZTD, atmospheric parameters, Antarctica

IMAGING IRON ORE SUSCEPTIBILITY ZONES USING 3D MAGNETIC INVERSION WITH K-MEANS CLUSTERING: A CASE STUDY FROM SANINDIPUR IRON AND BAUXITE MINES, ODISHA

Ajak John Ateng*, Kuldeep Sarkar, Nimatullah, Shreya Maurya, and Anand Singh
Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai
Email: ajakateng7@gmail.com/25d0467@iitb.ac.in

ABSTRACT

In open-cast iron ore mines, pockets of ore often remain concealed below the surface, and finding them can extend a mine's productive life. Since iron-rich rocks are far more magnetic than the surrounding material, magnetic surveys are a natural tool for this kind of search. A total field anomaly (TFA) map, however, only shows how these contrasts look at the surface, without revealing how deep they lie or what shape they take. This study tackles that problem at the Sanindipur mine in Sundargarh district, Odisha, where a ground magnetic survey was conducted to locate remaining pockets of iron ore within the existing mine. Data were collected using a GEM 19T proton precession magnetometer along traverses that followed the mine benches and open areas, and were subsequently corrected and gridded. The TFA data were then inverted in three dimensions to recover a subsurface susceptibility model, using a preconditioned conjugate gradient method that minimises a regularised misfit function balancing data fit against model smoothness. K-means clustering was then applied to this model,

grouping cells with similar susceptibility into distinct zones, with the high-susceptibility cluster marking the target zone for iron ore. The measured TFA ranges from roughly -50 to over 150 nT, and the anomaly calculated from the inverted model closely reproduces its main highs and lows. Clustering divides the model into clearly separated susceptibility zones, shown as depth slices and a 3D volume. Together, these results demonstrate that 3D inversion with K-means clustering offers a practical, data-driven way to pinpoint iron ore pockets for further exploration. Planned next steps include validating the model against borehole and geochemical data, incorporating gravity or resistivity data for joint interpretation, and extending the survey to adjacent blocks.

Keywords: 3D Magnetic inversion, K-means clustering, Susceptibility modelling, Iron ore exploration.

COMPARATIVE EVALUATION OF NZVI, NANO-OXYGEN BUBBLES, AND HYBRID BIOREMEDIATION FOR ARSENIC REMOVAL FROM CONTAMINATED WATER

Kushal Pal Singh* and N. Sathaiah
CSIR- National Geophysical Research Institute, Hyderabad-500007(India)
*Presenting author: kpsingh.ngri@csir.res.in

ABSTRACT

The present laboratory study evaluates the effectiveness of three remediation strategies—nanoscale zero-valent iron (nZVI), nano-oxygen bubbles (NOB), and a hybrid NOB–mixed bacterial culture system—for arsenic (As^{3+}) removal from contaminated water. The initial arsenic concentration of 10.00 mg/L was progressively reduced by all treatment systems. nZVI demonstrated the highest removal efficiency, reducing arsenic concentration to 0.010 mg/L by day 24, corresponding to 99.90% removal. NOB achieved 99.44% removal, with a final concentration of 0.056 mg/L, whereas the hybrid NOB–mixed culture system achieved 93.30% removal, reaching 0.67 mg/L by day 30. The superior performance of nZVI is primarily attributed to arsenic adsorption onto iron corrosion products and to co-precipitation associated with Fe(0) oxidation. NOB increased dissolved oxygen availability, promoting oxidative transformation of arsenic and modifying redox conditions that govern arsenic mobility. The hybrid system generated dynamic redox conditions through the coupled processes of oxygenation and microbial activity, thereby facilitating arsenic biotransformation and removal. Comparative performance demonstrated that nZVI provided the most rapid and effective arsenic remediation, followed by NOB and the hybrid treatment system. The results highlight the potential of nZVI for efficient arsenic removal from contaminated water and demonstrate that NOB-based treatment can provide an effective oxygenation-assisted remediation pathway. The findings provide a basis for developing and optimizing nanomaterial-assisted and biologically integrated strategies for sustainable arsenic remediation in contaminated aquatic environments.

Keywords: Arsenic, NOB, nZVI, Remediation, Adsorption

PREDICTING ELECTRICAL SIGNATURES OF CRITICAL MINERAL SYSTEMS: A SYNTHETIC MODELLING APPROACH

Cheema Moran[1*], Ved P. Maurya[1,2], and Prakash Kumar[1,2]
[1]CSIR-National Geophysical Research Institute, Hyderabad 500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad- 201002, India
*Presenting Author: Cheema Moran, email: cheemamoran1@gmail.com

ABSTRACT

The increasing global demand for critical minerals and rare earth elements (REEs), driven by clean-energy technologies and advanced manufacturing, has highlighted the need for efficient and cost-effective exploration approaches. Many critical mineral deposits occur within structurally complex Precambrian terranes, where faulting, intrusions, and lithological heterogeneity can significantly influence geophysical responses and complicate subsurface interpretation. Understanding the expected signatures of different mineralization geometries prior to field investigations is therefore essential for improving survey design and reducing exploration uncertainty. This study presents a series of synthetic two-dimensional Electrical Resistivity Tomography (ERT) and Induced Polarization (IP) forward and inverse models to investigate geophysical responses associated with representative critical mineral and REE exploration targets. Based on available data resources, three geological scenarios were considered: (i) a fault associated with a mineralized horizon, (ii) a lenticular-shaped mineralized body, and (iii) a dyke-like intrusive mineralization body emplaced within a host formation. Synthetic resistivity and chargeability datasets were generated and inverted to evaluate the ability of integrated ERT-IP imaging to resolve structural features and associated mineralized zones.

The results demonstrate that resistivity imaging is effective in delineating subsurface geometry and structural discontinuities, including fault zones and intrusive contacts, while chargeability imaging provides complementary information related to sulphide-bearing and alteration-associated mineralization. The modelling further highlights that conductive mineralized zones may not always correspond to high chargeability responses and vice-versa, emphasizing the importance of integrated interpretation. Comparison of the three geological scenarios illustrates how mineralization geometry and structural setting influence the spatial distribution of resistivity and chargeability anomalies. The study establishes association of ERT-IP anomalies with different critical mineral and REE target geometries. The synthetic results can subsequently be used to guide electrode arrangement, assess inversion results, define expected anomaly patterns, and provide reference models for comparison with future field datasets from the mineral systems.

Keywords: Critical mineral, synthetics, resistivity, induced polarization, fault

GEOPHYSICAL SURVEYS USING UNMANNED AERIAL SYSTEMS IN MINERAL EXPLORATION

Muhammed Yaseen V, K Gangadhar, Navin Raja
Centre of Exploration Geophysics, University College of Science, Osmania University
Presenting author: mhdysntpv@gmail.com

ABSTRACT

Unmanned Aerial Systems (UAS) are emerging as efficient platforms for geophysical data acquisition in mineral exploration. Their ability to operate at low altitudes, access difficult terrain, and acquire

high-density spatial data provides important advantages over conventional ground-based and manned airborne surveys. Among the various geophysical applications, UAV-based magnetic surveying offers an effective approach for mapping variations in magnetic properties associated with geological structures and mineralized zones. .

This poster presents the application of UAS in geophysical exploration, with particular emphasis on UAV-based magnetic surveying. A case study from the Sidhan Block, Jabalpur District, Madhya Pradesh, India, is discussed, where a customized octacopter equipped with a Geometrics MagArrow laser-pumped Caesium-133 vapour magnetometer was employed for Mn–Fe mineral exploration. The survey was conducted at approximately 30 m above ground level with 50 m flight-line spacing, with N–S flight lines oriented across the ENE–WSW trending geological fabrics. The acquired magnetic data were processed to generate a relative magnetic-field anomaly map.

The survey delineated magnetic patterns associated with the regional geology and identified a magnetic high/gradient corresponding to the known Mn–Fe mineralized zone. This interpretation was corroborated by drill-hole BH-8A and geochemical investigations, with samples from the magnetic-high area indicating manganese concentrations ranging from 5.9% to 52% Mn. The complete survey and data processing were accomplished in approximately one day, compared with 6–7 days required by the traditional approach. The study demonstrates the potential of UAS-based geophysical surveys as rapid, cost-effective, and environmentally favourable tools for reconnaissance and prospecting in mineral exploration.

Keywords: Unmanned Aerial System, UAV, Drone, Geophysical Survey, Magnetic Survey, Mineral Exploration, Mn–Fe Mineralization, Caesium Vapour Magnetometer, Magnetic Anomaly.

Reference:

Abhijeet Mukherjee, Nikhil Sarwate, V.M. Tiwari , Ram Raj Mathur and C.B. Verma1

Unmanned Aerial Vehicle (Customised Octacopter Drone) based Magnetic Survey for Exploration of Mn-Fe in Sidhan Block, Jabalpur District, Madhya Pradesh, India Jour. Geol. Soc. India (2024) 100 (8) : 1208-1209

DEVELOPMENT OF A CONCEPT-DRIVEN GEOLOGICAL MODEL TO IDENTIFY THE POTENTIAL OF GEOLOGIC HYDROGEN IN THE EASTERN INDIA

Pampa Malik[1], Saurabh Datta Gupta[1]
[1]Department of Applied Geophysics, Indian Institute of Technology (Indian School of Mines), Dhanbad
Corresponding Email ID: 24DR0235@iitism.ac.in

ABSTRACT

The global energy sector is seeking clean, sustainable energy sources as alternatives to fossil fuels. As part of this, India has set itself a target to achieve net-zero carbon emissions by 2070. Achieving this target requires a transition to cleaner, more sustainable energy sources to reduce greenhouse gas emissions and address climate change. In this context, geologic hydrogen, commonly known as natural, white, or gold hydrogen, has emerged as a promising low carbon energy resource, which contributes significantly to global decarbonization efforts as well. Unlike manufacturing, geological processes can generate natural hydrogen, such as water-rock reactions and radiolytic processes in association with

crystalline basement rocks, mafic-ultramafic rocks, sedimentary basins, faults, and hydrothermal systems.

The current study focuses on the Rajmahal region, which presents a geologically complex setting characterised by Precambrian basement rocks, Gondwana sedimentation, extensive Mesozoic–Cretaceous volcanic activity, intertrappean sediments, structural discontinuities, and prolonged interaction between rocks and fluids. It shows favourable conditions for hydrogen generation however, to find the specific reservoir, five major elements - source, generation, migration, reservoir, and seal or trap are required to be present. Analysis shows that presence of all elements in this area in form of reactive mineral assemblages, water availability, pathways for fluid migration, and trapping environments towards successful exploration. Water-rock reaction, which is also known as serpentinization, is the primary driving scope for hydrogen generation in this study area where iron - rich mineral reacts with water and produce hydrogen through oxidation-reduction reactions.

Utilizing a single method for this study shows highly uncertain approach. Hence, an integrated geoscientific interpretation approach was adopted with incorporation of available geological, geophysical data and other information. As a outcome of the study, a conceptual geological model was developed which shows successful possibilities for the present of natural hydrogen in Rajmahal Trap in the eastern India.

INTEGRATED GRAVITY–AEROMAGNETIC INTERPRETATION AND 3D POTENTIAL FIELD INVERSION FOR MINERAL EXPLORATION IN THE SAKOLI FOLD BELT, CENTRAL INDIA

Ranadheer Satla[1,2], B Nageswara Rao[1]
[1]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500 007, India.
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201 002, India.
Presenting Author: Satlaranadheer94@gmail.com

ABSTRACT

The Sakoli Fold Belt (SFB), covering an area of approximately 3500 km² (20°30′–21°30′N, 79°15′–80°15′E), represents a major Proterozoic volcano-sedimentary domain of the Central Indian Tectonic Zone (CITZ). It comprises diverse lithological assemblages, including gneisses of the Bengpal, Tirodi and Amgaon complexes and rocks of the Sakoli Group, and hosts structurally controlled mineral occurrences. This study integrates ground gravity and magnetic observations with high-resolution IGRF-corrected aeromagnetic data from the National Geoscience Data Repository of the Geological Survey of India to investigate basement configuration, lithological distribution and structural architecture, with implications for mineral exploration. Two prominent residual gravity highs, associated with magnetic highs in the central and northeastern parts of the Sakoli Fold Belt, are interpreted to reflect the mafic to intermediate intrusive bodies including metapelites, metavolcanic rocks and banded iron formations (BIFs), which contribute to the observed positive gravity and magnetic responses. In contrast, NW–SE-trending elongated magnetic lows are attributed to zones of reduced magnetic susceptibility and are interpreted as possible fault and shear zones. To further constrain the spatial extent and structural significance of these anomalous domains, Horizontal Gradient Magnitude (HGM) analysis was applied to the upward-continued gravity and magnetic anomalies at 1,

2, 5 and 10 km levels. Two-dimensional gravity–magnetic modelling and unconstrained three-dimensional inversion indicate that the SFB attains a maximum thickness of approximately 5 km, consistent with estimates from radial power-spectrum analysis and 3D Euler deconvolution. The spatial correlation of these gradients with mapped geology and known mineralised zones indicates the significance of these structural corridors in controlling mineralisation.

Key words: Sakoli Fold Belt, Aeromagnetic, BIF

ATTENTION-BASED SEISMIC REPRESENTATION LEARNING FOR HIGH-RESOLUTION SUBSURFACE IMAGING

Ritesh Yadav, Upendra K. Singh
Department of Applied Geophysics, IIT (ISM) Dhanbad
Presenting author: 24dr0150@iitism.ac.in

ABSTRACT

Full-waveform inversion (FWI) is a powerful physics-based technique for reconstructing high-resolution subsurface velocity models from seismic observations. However, it's highly nonlinear optimization, sensitivity to the initial model, and dependence on waveform-based data comparison can limit convergence and the recovery of fine-scale subsurface structures. In this study, we propose an attention-based deep learning framework for enhanced FWI through learned seismic data representations. The proposed framework employs a Transformer architecture that converts seismic data into patch-based feature representations and uses self-attention to capture both local and long-range dependencies within the seismic wavefield. Observed and simulated seismic data are transformed into a common latent feature space, where their representations are compared to construct an adaptive data-misfit measure for guiding the inversion. The learned representation is integrated with wave-equation-based forward modelling, enabling iterative updating of the velocity model while retaining the physical constraints of seismic wave propagation. The methodology is evaluated using the synthetic Marmousi2 model to assess its capability for high-resolution subsurface velocity reconstruction. The reconstructed velocity model achieves an SNR of 23.58 dB and an SSIM of 0.8220, indicating good agreement with the reference model and preservation of subsurface structural features. Vertical velocity profiles extracted from the inverted model at positions of 3.6, 7.2, and 14.4 km yield RMSE values of 0.130, 0.105, and 0.068 km/s, respectively. These results demonstrate the capability of the proposed approach to recover velocity variations while preserving important subsurface details. The study highlights the potential of Transformer-based latent representations as an effective strategy for improving seismic data comparison and enhancing high-resolution velocity reconstruction within physics-driven FWI.

GEOCHEMICAL ATTENUATION OF FLUORIDE IN WATER USING NATURAL ZEOLITE: A REACTIVE COLUMN STUDY

N. Sathaiah*, D. Praveen, and Kushal Pal Singh
CSIR- National Geophysical Research Institute, Hyderabad-500007(India)
*Presenting author: sathaiah.ngri@csir.res.in

ABSTRACT

A laboratory-scale reactive column experiment was conducted to evaluate the fluoride attenuation capacity and geochemical reactivity of natural zeolite. The column was packed with natural zeolite, providing exchangeable cation sites and reactive mineral surfaces. An aqueous sodium fluoride (NaF)

solution containing approximately 452 mg/L fluoride was used as the influent and passed through the zeolite bed under controlled hydraulic conditions for 60 days. Samples were collected periodically to monitor temporal changes in aqueous geochemistry. pH, redox potential (Eh), total dissolved solids (TDS), and electrical conductivity (EC) were measured at approximately 10-day intervals. Fluoride, major anions (NO_3^- and SO_4^{2-}), and dissolved cations, particularly Al^{3+}, were analyzed to assess changes in aqueous composition and mineral–water interactions. Fluoride concentrations decreased from 452 mg/L to 120 mg/L by day 23 and further to 41.5 mg/L by day 60. Fluoride attenuation was evaluated in relation to cation exchange, surface adsorption, mineral dissolution, aqueous complexation, and precipitation of sparingly soluble fluoride-bearing phases**.** The concurrent decline in dissolved Al and F suggests coupled mobilization of Al and sequestration of F, potentially involving the precipitation of Al–F-bearing phases. Decreases in TDS and EC further indicate removal of dissolved ionic species through sorption, ion exchange, and/or secondary mineral formation.

This study demonstrates the potential of natural zeolite as a low-cost, sustainable, and geochemically reactive medium for fluoride remediation, while providing insights into the ion exchange, adsorption, and mineral precipitation processes that control fluoride attenuation.

Keywords: Adsorption; Natural zeolite; Fluoride attenuation; TDS; Mineral precipitation

APPLICATION OF ARTIFICIAL INTELLIGENCE FOR BASE METAL DEPOSIT CLASSIFICATION: A COST-EFFECTIVE RECONNAISSANCE-STAGE APPROACH USING IN-SITU LA-ICP-MS TRACE ELEMENTS, USING SPHALERITE GEOCHEMISTRY

Sima Gorai*, Bulusu Sreenivas
CSIR-National Geophysical Research Institute
Presenting author: sima.geol90@gmail.com

Abstract

Understanding the genetic characteristics of base-metal deposits is essential for developing effective and cost-efficient mineral exploration strategies, particularly during the reconnaissance stage. Geochemical characteristics of ore minerals such as sphalerite can provide valuable information on the physicochemical conditions and genetic environment of mineralization; however, conventional classification approaches are often challenged by overlapping trace-element signatures among different deposit types. This study demonstrates the application of Artificial Intelligence (AI) for the classification of base-metal deposit types using in-situ Laser Ablation-Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) trace-element geochemistry of sphalerite. A comprehensive global dataset comprising 3280 published sphalerite analyses from Epithermal, Mississippi Valley Type (MVT), SEDEX, Skarn, and Volcanogenic Massive Sulfide (VMS) deposits was compiled to develop a multi-class classification framework. Extremely Randomized Trees (Extra Trees) and Extreme Gradient Boosting (XGBoost) algorithms were employed to capture complex and non-linear relationships within the multivariate trace-element dataset. The models achieved overall classification accuracies of 97.26% and 96.95% for Extra Trees and XGBoost, respectively, on the independent test dataset, demonstrating their strong capability to discriminate among genetically distinct deposit types. The trained models were subsequently applied to in-situ LA-ICP-MS trace-element data from sphalerite in the Zawar Zn-Pb deposit, Rajasthan, India. Both AI models consistently classified the Zawar

sphalerite as belonging to the MVT deposit type, supporting its hydrothermal MVT-type genetic affinity. The results demonstrate that AI-assisted interpretation of sphalerite trace-element geochemistry can provide a rapid and effective means of discriminating base-metal deposit types and may serve as a cost-effective geochemical screening tool during reconnaissance-stage mineral exploration. This approach has the potential to improve exploration targeting by prioritizing prospective areas before undertaking more extensive and resource-intensive exploration programs.

SOLID EARTH GEOSCIENCES

TRANSDIMENSIONAL BAYESIAN INVERSION OF TELESEISMIC P-WAVE CODA FOR IMAGING SEDIMENT AND BASEMENT ARCHITECTURE IN THE BENGAL BASIN

A Manikho Rajina[1]*, Satish Maurya[1], Gollapally Mohan[1]
[1]Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai, India
Presenting author: 23d0457@iitb.ac.in

ABSTRACT

The Bengal Basin is one of the most tectonically active and seismically vulnerable regions of the Indian subcontinent. The presence of thick, unconsolidated sediments in these regions can significantly amplify seismic waves, underscoring the necessity for detailed characterization of shallow crustal structures in seismic hazard assessments. This study investigates sedimentary thickness, basement geometry, and shear-wave velocity (Vs) structure using transdimensional joint inversion of teleseismic P-wave polarization and P-receiver functions (RFs) recorded at 30 broadband seismic stations in the Bengal Basin. Near-surface Vs values range from approximately 0.3 to 1.0 km/s, indicating widespread unconsolidated to weakly consolidated sedimentary materials with considerable potential for seismic-wave amplification. The estimated basement depth varies from 14 to 22 km and generally increases from west to east. This eastward deepening and the substantial lateral variability of the interface delineate the asymmetric architecture of the basin and agree broadly with earlier seismic-refraction and geological investigations that identified rapid basin deepening across the western margin and sediment thicknesses locally reaching 17–20 km. The exceptionally thick low-velocity succession is likely to produce prolonged shaking and frequency-dependent amplification during large regional earthquakes. These results provide improved constraints on Bengal Basin evolution and offer an updated structural framework for ground-motion modelling, site-response analysis, and seismic-hazard assessment.

GEOFUSIONNET: A CROSS DATA DEEP LEARNING FRAMEWORK FOR SEISMIC AND WELL-LOG FUSION FOR SUBSURFACE PROPERTY ESTIMATION

Rahul Sharma1* , Priyanshu Sharma 1* , Aakash Nair 1* Shobit Mishra 1 , Bharath Shekar 1
1 Department of Earth Science, Indian Institute of Technology, Bombay
Presenting author*- geophy2326rahul@kuk.ac.in priyanshujiiiiii@gmail.com aakashrnair@gmail.com

ABSTRACT

Accurate subsurface resource characterization is essential for applications such as coal quality estimation, reservoir evaluation, and lithology prediction, yet existing approaches primarily rely on sparse borehole measurements or single-modality interpretation, limiting their spatial continuity and predictive accuracy. To address these limitations, we propose GeoFusionNet, a multimodal deep learning framework that integrates seismic data with well log measurements to learn complementary subsurface representations for continuous property prediction. The proposed architecture employs modality-specific encoders, a cross-modal fusion module to capture correlations between seismic and borehole information, and a prediction head that generates high-resolution subsurface property estimates. By jointly exploiting the broad spatial coverage of seismic data and the high-resolution point information provided by well logs, GeoFusionNet improves feature representation, reduces uncertainty, and generalizes effectively across heterogeneous geological settings. Experimental results on benchmark and field datasets demonstrate that the proposed framework consistently outperforms state-of-theart unimodal and multimodal baselines, achieving superior prediction accuracy, enhanced spatial

consistency, and robust generalization, highlighting its potential as a scalable solution for intelligent subsurface resource characterization. Keywords: Multimodal Deep Learning, Seismic Well Log Integration, Cross-Modal Fusion, Subsurface Resource Characterization, Coal Quality Estimation

SEISMIC IMPEDANCE INVERSION FOR RESERVOIR CHARACTERIZATION USING HARMONY SEARCH AND ARTIFICIAL GORILLA TROOPS OPTIMIZATION

Abhay Kumar[1], S. P. Maurya[1] and Ajay P. Singh[1]
[1]Department of Geophysics, Banaras Hindu University
Presenting author: abhay30052001@gmail.com

ABSTRACT

Seismic exploration plays a crucial role in imaging subsurface geological structures and identifying potential hydrocarbon-bearing zones. Seismic inversion further enhances the interpretation of seismic data by transforming seismic responses into quantitative subsurface properties, such as acoustic impedance, which can provide valuable information for reservoir characterization. In this study, two global optimization techniques, Harmony Search Optimization (HSO) and Artificial Gorilla Troops Optimization (AGTO), are employed for seismic impedance inversion and reservoir characterization. The inversion process aims to minimize the mismatch between the observed seismic data and the synthetic seismic response generated from the estimated impedance model. The performance of both optimization methods is initially evaluated at the well location by comparing the inverted impedance with the impedance derived from well-log data. The results show a good correlation between the inverted and well-log impedance profiles with HSO achieving an average correlation coefficient of 0.80, while AGTO achieves a slightly higher average correlation coefficient of 0.82. These results demonstrate their capability to recover the subsurface impedance distribution at the well location. The optimized inversion methods are subsequently applied across the 3D seismic volume to investigate the spatial distribution of impedance and identify potential reservoir zones. Both HSO- and AGTO-based inversion results consistently reveal a low-impedance zone in the time interval 1040–1065 ms two-way travel time. The consistency of this low-impedance feature in the results obtained from both optimization techniques indicates its potential significance as a reservoir characterization.

CHARACTERIZATION OF SEISMICITY AND STRESS REGIMES IN THE INDO-BURMESE ARC AND EASTERN HIMALAYA

R. Abhirami and P.S. Sunil
Department of Marine Geology and Geophysics, School of Marine Sciences,
Cochin University of Science and Technology, Kochi, India
Presenting Author: abhiramiratnakar@cusat.ac.in

ABSTRACT

The Indo-Burmese Arc (IBA) and Eastern Himalaya constitute a tectonically complex region where plate convergence, continental collision, and subduction interact to produce highly heterogeneous deformation and seismicity. Characterizing the spatial and depth-dependent variations in seismicity and stress is therefore essential for understanding the active tectonic processes governing this margin. This study integrates b-value estimation, stress-inversion parameters (A_φ and SH_{max}), and seismic moment release derived from seismicity and focal mechanism solution (FMS) catalogues to delineate the

seismic character and stress regime. Earthquakes are categorized into shallow (<80 km) and intermediate depth (≥80 km) events to assess the depth dependence of these characteristics. Shallow seismicity exhibits marked spatial variations in b-values, with relatively low values concentrated along collision boundaries and transpressional to reverse-faulting domains, accompanied by enhanced seismic moment release. SHmax is predominantly oriented N-S to NE-SW, consistent with the northward motion of the Indian Plate and the associated effects of indentation, oblique convergence, and lateral shear. Near the Eastern Himalayan Syntaxis (EHS), SH_{max} rotates from E-W to SE-NW, indicating significant spatial variations in the regional stress field associated with Himalayan collision and rotational deformation. In contrast, the central and southern IBA are characterized by comparatively higher b-values and predominantly strike-slip to oblique-normal faulting, reflecting distributed deformation and slip partitioning associated with oblique convergence. At intermediate depths, where intraslab seismicity dominates, SH_{max} exhibits predominantly NE-SW orientations north of ~21°N and NW-SE orientations farther south, broadly consistent with the geometry of the subducting Indian slab. Distinct segmentation in b-values may reflect variations in slab related processes, including dehydration embrittlement, slab bending, and slab pull forces. Overall, the results characterize the IBA as a transitional tectonic system in which shallow deformation is governed primarily by oblique convergence, slip partitioning, and lateral shear, whereas intermediate-depth stress patterns are increasingly influenced by slab geometry and related processes.

REDUCING SITE-INDUCED BIAS IN EARTHQUAKE EARLY WARNING SYSTEMS: ADVANTAGES OF BOREHOLE SENSORS AND INTEGRAL-BASED PARAMETERS

Abhishek Tiwari, Mohit Agrawal, Mittal H

ABSTRACT

Earthquake Early Warning Systems (EEWS) rely on rapid magnitude estimation from the initial portions of seismic waveforms, before the arrival of the later, more destructive phases. However, seismic recordings obtained at shallow depths are strongly influenced by local near-surface geological conditions, which can introduce substantial variability and systematic amplification into magnitude estimates. In this study, contemporaneous surface and borehole recordings from Japan's K-NET and KiK-net networks are compared to systematically evaluate the influence of local site effects on two established EEWS parameters: peak vertical displacement (Pd) and cumulative absolute displacement (CAA). Least-squares regression analyses were performed for successive P-wave time windows ranging from 1.0 to 10.0 s using an extensive dataset comprising 21,069 strong-motion records from 867 earthquakes recorded at 1,545 stations.

The statistical results indicate that surface recordings obtained from relatively unconsolidated soils consistently produce positively biased magnitude estimates compared with their corresponding borehole or competent-bedrock recordings, as reflected by larger regression intercepts (a). In contrast, borehole measurements substantially reduce the scatter in magnitude estimation. For a 5-s time window, the integrated CAA parameter provides the best overall performance, achieving an RMSE of 0.43. To identify and mitigate the physical contribution of local site amplification, a Standard Spectral Ratio (SSR)-based deconvolution approach was subsequently implemented. Its effectiveness was

evaluated at representative anomalous stations, including AKTH0 and EHMH0. At AKTH0, the pronounced resonance observed between approximately 1.2 and 15 Hz, with spectral amplification exceeding 100 units, was effectively suppressed, bringing the surface response closer to the corresponding bedrock reference. At EHMH0, the procedure successfully reduced strong high-frequency noise in the 10–40 Hz range while preserving the fundamental seismic phase characteristics.

These results demonstrate that integral-based EEWS parameters, particularly when combined with borehole observations or empirical SSR-based site corrections, can provide a more robust framework for reducing site-related magnitude bias and false or saturated alerts. The close time-domain correspondence between the corrected surface waveforms and the directly recorded borehole velocity traces further confirms the effectiveness of the proposed correction strategy for improving the reliability of operational earthquake early warning systems.

Keywords: Earthquake early warning system, Cumulative absolute absement, Peak displacement, standard spectral ratio

A NOVEL FIELD AND PROCESSING TECHNIQUE FOR SEISMIC (MASW) SURVEY WITH MULTI-OFFSET SHOT (MOS)

Abul Aas[1], Sanjay Rana[1], Satish Kumar Sinha[2]
Parsan, New Delhi, INDIA, abul@parsan.biz[1]
Rajiv Gandhi Institute of Petroleum Technology, Jais, Amethi-INDIA, ssinha@rgipt.ac.in[2]
Corresponding author: Abul Aas

ABSTRACT

Multi-channel Analysis of Surface Waves (MASW) is a frequently used near-surface geophysical approach for obtaining vertical one-dimensional (1D) shear-wave velocity (Vs) profiles for seismic site characterization study.

Generally, the MASW data is acquired using 24 in line geophone and with fixed interval and offset shot is taken near the fisrt or last geophone (Figure 1a). In this way shot gather is collected which comprises of 24 traces, then it is processed to obtain Vertical 1D Vs profile. This conventional method requires more time to deploy the geophone and also the traces are influenced by near and far field effect.

A novel method is proposed for MASW data acquisition, which is reciprocity of the conventional method. In the proposed method instead of using group of 24 in line geophones only single geophone can be used with multi offset shot (Figure 1b). If consecutive 10 offset shots are taken, then single geophone will record 10 traces, placing these traces one after other will constitute the common receiver gather (CRG) traces. Processing of these gather traces will give Vertical 1D Vs profile. But limitation of this methodology is dependent on the energy and repeatability of the seismic energy source. Signal of the source gets attenuated after travelling through some distance in case of sledgehammer its signal can be easily recorded up to 120-meter distance after which its signal gets attenuated. The sledgehammer source can be used up to maximum 120 m offset starting from 5 m offset. The seismic source that are being used for the data acquisition should produce similar type of waveform when it strike the base plate that called repeatability of the source signature.

By using new methodology, the survey can be performed in multi-direction as shown in Figure 2 which will give more reliable Vs at the central point.

Keywords: MASW, Dispersion Curve

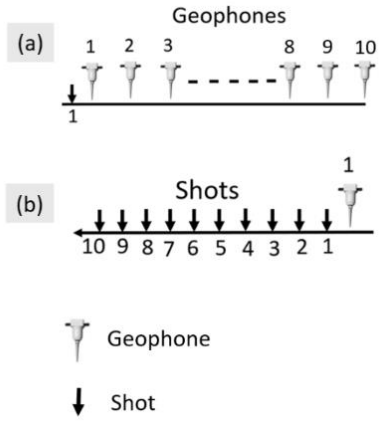


Figure 1: (a) Conventional MASW data acquisition geometry using a single shot and a linear array of 10 geophones. (b) Proposed MASW acquisition geometry based on the principle of source–receiver reciprocity,employing a single fixed geophone and multiple offset shot (10).

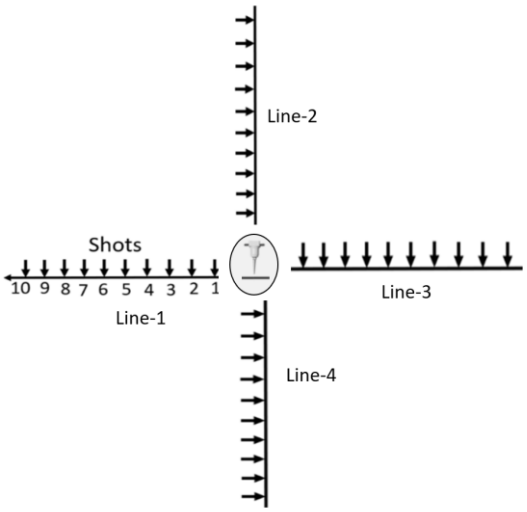


Figure 2: It shows the multi-directional shot profile and single geophone

EXPLAINABLE AI AND MACHINE LEARNING BASED SEASONAL GROUNDWATER POTENTIAL ZONE MAPPING USING SPATIAL AND LONG TERM TEMPORAL DATA

Ankit Ashish*[1], Aayush[1] and Saumen Maiti[1]
Machine Learning and Geocomputing laboratory, Department of Applied Geophysics, IIT (ISM), Dhanbad 826004,Jharkhand (India)
*Presenting author: 25MT0072@iitism.ac.in

ABSTRACT

Groundwater is one of the most precious resources and plays an important role in meeting domestic, agricultural and industrial water requirement in Odisha, India and is a critical component of the hydrological system. Groundwater potential zone (GWPZ) mapping is an important way for groundwater exploration and sustainable resource management. However, traditionally GWPZ

mapping use methods that are based on expert based subjective judgement and most of current existing GWPZ mapping studies rely on static datasets and limited seasonal changes. Therefore, this study presents a Machine Learning and Explainable AI based framework for Seasonal groundwater potential zone mapping using spatial and long-term temporal data.

The study integrates spatial datasets include elevation, slope, geomorphology, TWI (Topographic Wetness Index), drainage density, SPI (Stream Power Index), Distance from River, soil characteristics, land use land cover with long term seasonal temporal parameter such as rainfall, NDVI, Evapotranspiration and other relevant hydrogeological parameters. This Study used machine learning algorithms such as Extreme Gradient Boosting (XGBoost), Random Forest, Support Vector Machine (SVM) to model the relationship between groundwater level and selected hydrogeological and climatical factors and generated Four Seasonal GWPZ maps of Odisha. Model performance is assessed using appropriate statistical and validation metrics and used SHAP (Shapley Additive exPlanations) to provide contribution of individual features to Seasonal GWPZ maps. This study provides the framework which supports groundwater exploration, artificial recharge planning and hydro geophysical investigation and sustainable groundwater resource management in Odisha.

SEISMIC SITE CHARACTERIZATION OF THE JHARIA COALFIELD USING AMBIENT-NOISE HVSR INVERSION

Ankit Patel, Mohit Agrwal

ABSTRACT

The Jharia Coalfield, one of India's major coal-producing regions, is characterized by complex near-surface geological conditions resulting from coal extraction, underground mine workings, subsidence, fractures, and prolonged underground coal fires. These conditions can significantly modify the dynamic properties of the subsurface and influence local seismic site response. The present study aims to characterize the near-surface seismic structure of the Jharia Coalfield using the Horizontal-to-Vertical Spectral Ratio (HVSR) technique and to evaluate spatial variations in shear-wave velocity.

Ambient seismic noise recordings from 44 stations distributed across the study area were processed to obtain HVSR curves and identify the fundamental resonance frequency (f_0). Quality-control procedures and peak-picking criteria were applied to assess the reliability of the observed HVSR responses before inversion. A four-layer shear-wave velocity model was subsequently estimated for each station using a random-search inversion approach involving 10,000 trial models per station. The theoretical Rayleigh-wave ellipticity response calculated using the disba framework was compared with the observed HVSR response, and model selection was based on curve misfit (RMSE) and fundamental-frequency agreement.

Uncertainty analysis was performed using the best 5% of the accepted models at each station to obtain median values and percentile ranges for layer shear-wave velocities and thicknesses. The representative median models were then subjected to an independent forward check against the observed HVSR curves to evaluate their consistency. The resulting models were used to estimate Vs30, providing a quantitative parameter for seismic site classification. The preliminary results show significant spatial

variability in the estimated subsurface shear-wave velocities and Vs30 values across the investigated stations, indicating heterogeneous near-surface conditions within the coalfield.

The study demonstrates the potential of HVSR-based inversion as a cost-effective approach for seismic site characterization in complex coal-bearing terrain. The resulting Vs30 distribution and shear-wave velocity models provide a basis for assessing local seismic amplification and for investigating the influence of mining-related subsurface heterogeneities on seismic site response in the Jharia Coalfield.

Keywords: Jharia Coalfield; HVSR; ambient seismic noise; shear-wave velocity; Vs30; seismic site characterization; inversion; site response; coal mining.

SHALLOW VADOSE ZONE HETEROGENEITY CONTROLS RECHARGE IN CRYSTALLINE AQUIFER: INSIGHTS FROM FIELD-LAB STUDIES, SOUTHERN INDIA

Enatula Appalanaidu[1,2*], Sahebrao Sonkamble[1,2]
[1] CSIR-National Geophysical Research Institute, Hyderabad – 500007, India
[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad – 201002, India
[*] Corresponding Author, email:appalanaidu.ngri@csir.res.in, appalanaiduenatula@gmail.com

ABSTRACT

In semi-arid crystalline terrains, spatial variability within the vadose zone plays a pivotal role in determining recharge efficiency by controlling the redistribution of infiltrated rainfall among soil-water storage, deep percolation, and evapotranspiration. This study integrates field and laboratory hydrogeological experiments with numerical simulation to characterize shallow vadose zone soil heterogeneity in the Nagavali watershed, Southern India. The methodology combines a) groundwater level monitoring, b) soil core sampling to ~100 cm depth for saturated hydraulic conductivity (Ks) and grain-size analysis, c) Thiessen polygon-based recharge assessment, and d) HYDRUS-1D simulations to link soil hydraulic properties with recharge dynamics. Results from water-level monitoring (2023-2024) indicate increasing groundwater stress and a strong dependence on seasonal recharge. The K_s exhibits relatively high values near the surface, declines at intermediate depths, and shows localized increases at depth, revealing pronounced vertical and spatial heterogeneity. Recharge distribution aligns with shallow Ks patterns and the predominantly loamy-sand vadose zone, which favours rapid infiltration and promotes downward percolation toward the underlying aquifer. HYDRUS-1D simulations reveal strong seasonal recharge regulation within the 5 m weathered profile. Soil water storage net increase of 9 cm during the monsoon, with delayed recharge after profile wetting around day 300. These findings demonstrate that shallow vadose zone heterogeneity controls recharge in crystalline terrains and highlight the value of integrated vadose zone investigations and numerical modelling for sustainable groundwater management.

Keywords: Vadose zone heterogeneity; Groundwater recharge; Saturated hydraulic conductivity; HYDRUS-1D; Crystalline rock aquifers; Southern India

SEISMIC SIGNAL-BASED DETECTION OF LANDSLIDES FOR REAL-TIME EARLY WARNING

Arushi, Sandeep
Department of Geophysics, Institute of Science, Banaras Hindu University
Presenting author: arushitripathiajay22@gmail.com

ABSTRACT

Landslides are among the most damaging geological hazards in mountainous regions, causing significant loss of life and infrastructure. Conventional landslide monitoring methods, including field observations, geomorphological mapping, and geotechnical instrumentation, often provide limited spatial coverage and may not capture rapidly evolving slope failures. This highlights the need for advanced early warning approaches based on remotely detected seismic signatures. This study investigates a seismic signal-based approach for rapid landslide detection using recordings from seismic stations located within approximately 100 km of landslide sources. Waveform data were obtained from publicly accessible seismic networks and data services, including FDSN, IRIS, INGV, OREFUS, and GEOFON. To distinguish landslide-generated signals from background noise, we analyse the Short-Time Fourier Transform (STFT) mean energy across different frequency bands using normalized seismic signals. The results show a clear contrast between landslide signals and ambient noise, with the mean energy ratio consistently exceeding a defined threshold. The dominant frequency content of the investigated landslide signals generally occurs within the 0.5–5 Hz range. Based on these characteristics, a threshold-based detection scheme is proposed for real-time implementation. A landslide event can be identified when the energy criterion is satisfied over three consecutive time windows, thereby reducing the likelihood of false detections caused by transient noise. The proposed approach provides a simple and computationally efficient framework for distinguishing landslide signals from background seismic noise and has potential for integration with regional seismic networks for rapid landslide detection and early warning.

SEISMIC IMAGING OF THE LONAR IMPACT CRATER EJECTA BLANKET VIA ACTIVE-SOURCE MASW

Ashish Kumar[*], Rajendra Kumar Dash[*], Dilnas Fathima[*], Vivek Kumar[*]
[*]Indian Institute of Technology Bombay, Powai, Mumbai-400076

ABSTRACT

The ~570 ka Lonar Impact Crater, formed entirely in the basaltic terrain of the Deccan Volcanic Province, provides an excellent analogue for impact structures across the Moon and other terrestrial bodies. To characterize the shallow subsurface architecture of its impact melt and ejecta, we conducted active-source seismic surveys across six sites over the Lonar ejecta blanket. Multi-channel Analysis of Surface Waves (MASW) was performed using a 7 kg sledgehammer source paired with 5 Hz geophones, deployed at 2.5 m receiver spacing over total spread lengths ranging from 60 m to 100 m. Processing in SeisImager/SW (via the Pickwin and WaveEq modules) yielded Rayleigh wave dispersion curves, which are being inverted to construct shear-wave velocity profiles down to 30 m depth. These velocity models will provide critical insights into exploring the impact cratering process and the stratigraphy of basaltic ejecta sheets.

Keywords: Lonar Crater, Shear Wave Velocity, MASW, Ejecta Blanket, Dispersion Curves

A GLOBAL SINGLE-FORCE CATALOG OF LARGE LANDSLIDES AND ROCK–ICE AVALANCHES

Athul Palliath[1,2*], Himangshu Paul[1,2]
[1]CSIR–National Geophysical Research Institute, Hyderabad, India; [2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, India
*Presenting author e-mail: athulgeophysics@gmail.com

ABSTRACT

Large rock avalanches, rock–ice avalanches and glacier collapses are among the most destructive processes in high mountains, and most occur in remote terrain. Their long-period seismic radiation records their dynamics: where slide dimensions are small compared with seismic wavelengths, a landslide acts on the solid Earth as a point single force equal and opposite to the rate of change of momentum of the sliding mass. We apply one uniform workflow to 17 mass movements from 2000–2026 in nine regions on four continents, spanning two orders of magnitude in volume. For each event we invert long-period regional and teleseismic waveforms for a centroid single force (CSF) with a Bayesian bootstrap inversion. This gives force azimuth, plunge, amplitude, centroid time and duration with posterior uncertainties. Force Amplitudes are treated as band-limited, order-of-magnitude quantities. We validate the solutions against published results in literature and runout directions mapped from satellite imagery. We also test which parameters remain robust across event size, station coverage and recording era, from sparse networks in 2000 to dense arrays in the 2020s. The result is a consistent catalog of first-order landslide dynamics from seismic data alone, relevant to rapid characterization of future events in remote regions such as the Himalaya.

Keywords: landslide seismology; single-force inversion; rock–ice avalanche; glacier collapse; long-period seismic waves;

Preferred mode of presentation: Poster

HAMILTONIAN-DRIVEN RECURRENT QUTRIT DYNAMICS: A QUANTUM MACHINE LEARNING FRAMEWORK FOR SEISMIC WAVEFORM REPRESENTATION AND ANALYSIS

Bijayananda Dalai[1] and Prakash Kumar[1,2]
[1]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India
Presenting Author email: bijayanandadalai@gmail.com

ABSTRACT

Seismic waveform analysis depends on resolving time-dependent variations in amplitude, phase, frequency content and coupling among components. Representing these variations within a dynamical formulation can support accurate inference while making temporal evolution accessible for interpretation. This study introduces a *Hamiltonian-driven quantum machine-learning* framework in which seismic information is encoded through the evolution of a simulated quantum state. The framework centres on a recurrent qutrit, represented by a three-level complex state evolving under special unitary SU(3) dynamics generated by the eight Gell-Mann matrices. At each temporal step, the waveform representation and the preceding eight qutrit expectation values determine the coefficients of a trainable Hamiltonian. Its unitary action updates the qutrit state, while the resulting observables are propagated forward as recurrent memory. The qutrit receives either time-resolved features extracted

from three-component seismic waveforms or block-wise observables generated by an eight-qubit Hamiltonian encoder. The qubit encoder employs sign-preserving data re-uploading with trainable local fields, Pauli-X/Pauli-Y exchange (XX+YY) terms, and Pauli-Z (ZZ) interactions. The evolving qutrit observables are projected onto the target seismic quantity, directly linking the learned state trajectory to model prediction. Experiments use event-disjoint records from the publicly available INSTANCE-GM dataset. The proposed framework and a convolutional baseline are evaluated using identical records and common training, development and test partitions, enabling consistent comparison. Results show that recurrent qutrit evolution improves predictive performance over the convolutional baseline while maintaining a compact dynamical state representation. The qutrit state remains normalized throughout recurrent evolution, and finite gradients propagate through the Hamiltonian processing chain. Analysis of the learned trajectories illustrates how waveform information is progressively accumulated across temporal steps before contributing to the final prediction. These results demonstrate the potential of recurrent Hamiltonian qutrit dynamics as a quantum machine-learning representation for seismic waveforms, combining data-driven prediction with an explicit state-evolution mechanism for downstream seismic waveform-analysis applications.

Keywords: Hamiltonian learning; recurrent qutrit; quantum machine learning; SU(3) dynamics; seismic waveform analysis

FILTERING OF GRAVITY DATA USING EMPIRICAL MODE DECOMPOSITION AND DISCRETE WAVELET TRANSFORM

Chabungbam Yaiyaisana[1*] , Dr. Mahak Singh Chauhan[2]
[1]Department of Geophysics, Kurukshetra University, Kurukshetra, India
[2]CSIR-National Geophysical Research Institute, Hyderabad
*Email: chyaiyaisana@gmail.com

ABSTRACT

Decomposition of gravity data is one of the fundamental steps in gravity data processing for filtering the various frequencies and the isolation of anomalies of interest at different depths. Conventional methods such as polynomial trend fitting and upward continuation methods are based on fixed mathematical assumptions or a priori depth estimates. Wavelet-based methods relax some of these constraints but remain limited by fixed basis functions and rigid filtering structure. In this study, the Empirical Mode Decomposition (EMD) and its 2-D extension, the Bidimensional Empirical Mode decomposition (BEMD); a fully data adaptive method is compared with Discrete Wavelet Transform (DWT) decomposition using Daubechies-4 and Coiflet-3 wavelet families, for regional-residual gravity separation. The two approaches are tested on synthetic sinusoidal signals and a synthetic 2-D multi-prism gravity model under varying noise conditions (0%, 2%, 5%) to analyze regional trend-recovery accuracy and signal reconstruction error. We have applied same methodology on the real data set of the Arabian Foreland and the eastern Anatolia region of the southeastern part of Turkey and yielded significant results.

Keywords: Gravity filtering, EMD, DWT

ILLUMINATING CRUSTAL DYNAMICS OF SOUTHEASTERN TIBETAN REGION BY ESTIMATING FREQUENCY-DEPENDENT BODY-WAVE ATTENUATION

Debajyoti Bera1,*, Rahul Biswas2 , and Niptika Jana1
1Department of Applied Geophysics, Indian Institute of Technology (Indian School of Mines) Dhanbad, India
2National Geophysical Research Institute, Hyderabad, India
* dbera0302@gmail.com

ABSTRACT

Southeastern Tibet is characterized by strong tectonic deformation, significant crustal heterogeneity, crustal thickening, lateral crustal transport, and underthrusting of the Indian lithosphere. Seismic imaging has identified intracrustal low-velocity zones in the region, which have been associated with elevated temperature, fluids, and partial melting. However, velocity structure alone cannot uniquely constrain the physical state of the crust. Seismic attenuation provides an additional constraint because it is sensitive to anelastic energy loss and small-scale crustal heterogeneity. In this study, we investigate the frequency-dependent attenuation of local-earthquake P- and S-waves beneath southeastern Tibet using recordings from the Namche Barwa (XE) seismic network acquired between July 2003 and December 2004. We use an empirical approach in which the observed spectral amplitude is represented as the product of an event-dependent source term and a distance- and frequency-dependent attenuation function. The source contribution is separated through a constrained leastsquares inversion, allowing records from earthquakes of different sizes and distances to be combined without prescribing a fixed source spectral model. The resulting attenuation functions are parameterized using geometrical spreading and exponential anelastic decay to estimate frequency-dependent QP and QS. The obtained Q values and frequency exponents indicate appreciable body-wave attenuation with strong frequency dependence. QS is consistently higher than QP across the analyzed frequency band, with QS/QP ratios ranging from 1.31 to 1.57. These ratios may reflect the combined influence of crack and fluid conditions, scattering, phase-dependent radiation, and windowing effects. The estimated attenuation parameters provide new crustal-scale constraints on the propagation of local P- and Swaves in southeastern Tibet and offer an independent perspective on the heterogeneous physical state of the crust.

CRUSTAL STRUCTURE AND SEISMOGENESIS OF THE LADAKH–KARAKORAM TRANS-HIMALAYA: INSIGHTS FROM RECEIVER FUNCTIONS AND LOCAL SEISMICITY

Dhanabir Wangjam[12*], Devajit Hazarika[12], Naresh Kumar[1]
[1]Wadia Institute of Himalayan Geology, Dehradun
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh 201002,India
* Corresponding author email: dhanabir@wihg.res.in

ABSTRACT

The Ladakh–Karakoram Trans-Himalaya forms the western segment of the Himalaya–Karakoram–Tibet orogen and preserves a record of Tethyan subduction, collision, crustal underthrusting, exhumation, and subsequent intracontinental deformation. Major tectonic elements, including the Shyok and Indus suture zones, the exhumed Tso Morari Crystalline Complex, and the active Karakoram Fault, provide important constraints on the region's evolution and present-day geodynamics. Despite

its tectonic significance, the crustal architecture, composition and seismotectonic characteristics of the Ladakh–Karakoram sector remain comparatively poorly constrained.

We investigate the crustal structure and seismicity using teleseismic receiver functions (RF) recorded at 22 broadband stations distributed across the Zanskar region, Shyok Suture Zone (SSZ), and eastern Ladakh–Karakoram Zone, complemented by local earthquake data. Common Conversion Point imaging and RF inversion reveal pronounced three-dimensional variations in crustal structure. The Moho is laterally continuous but deepens northward from ~60 km beneath the Zanskar Shear Zone (Padum) to ~74 km beneath the SSZ (Sasoma). Along the Karakoram Fault, crustal thickness increases from ~70 km at Turtuk to ~80 km in eastern Ladakh. The Main Himalayan Thrust lies at ~30–35 km beneath Zanskar and the SSZ, deepening eastward to ~55 km beneath eastern Ladakh. The prominent intracrustal converted phase beneath eastern Ladakh may represent the interface between serpentinized ultramafic rocks and eclogitized Indian lower crust, suggesting significant lower-crust modification associated with tectonic underthrusting and metamorphism.

H–K stacking yields Vp/Vs ratios of 1.81–1.90. The exceptionally high value (~1.90) at Sasoma is consistent with a mafic lower crustal component and possible mantle-derived magmatism or mafic underplating, matching geological evidence for widespread mafic magmatism in the SSZ. Seismicity clusters along the Karakoram Fault near the SSZ and Pangong Strand, and within the Zanskar Shear Zone, extending to ~66 km depth, though concentrated above upper-to-middle crust up to ~40 km. Our results demonstrate strong lateral variation in the crust beneath the Ladakh–Karakoram region and demonstrate that inherited collisional structures, lower-crustal modification, and active fault systems collectively control present-day deformation and seismicity in this sector of the India–Eurasia plate boundary.

Keywords: Moho depth, Vp/Vs ratio, Poisson's ratio, seismicity, Karakoram Fault

ITERATIVE MIGRATION VELOCITY REFINEMENT THROUGH RESIDUAL MOVEOUT *ANALYSIS* FOR IMPROVED 2D SEISMIC IMAGING: A CASE STUDY FROM POLAND.

Dikal Ram P[1*], Biswajit Mandal[1,2], Vivekanand Pandey[1], Prakash Kumar[1,2]
[1]CSIR-National Geophysical Research Institute (CSIR-NGRI), Hyderabad - 500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Uttar Pradesh, Ghaziabad- 201002, India
*Corresponding author E-mail: dikal3bil@gmail.com

ABSTRACT

Accurate migration-velocity estimation is essential for reliable seismic imaging in areas with lateral velocity variations, dipping reflectors, and variable reflection quality. This study presents an iterative migration-velocity refinement workflow based on residual moveout (RMO) analysis applied to a selected 2D land seismic profile from Poland. The dataset exhibits variable reflection character, continuous and discontinuous reflectors, dipping events, and weak deeper reflections, providing a suitable framework for assessing migration-velocity uncertainty. The data were preprocessed to attenuate coherent and incoherent noise while preserving primary reflections. Stacking velocity analysis was performed for NMO correction, and the corrected gathers were stacked to generate an initial image. Stacking velocities were converted to an RMS velocity model for Kirchhoff time

migration. Although migration improved reflector positioning, continuity, and focusing, residual moveout in the migrated gathers indicated velocity errors. RMO analysis was used to identify spatially varying errors and guide iterative velocity updates. The updated model was remigrated, and this migration–RMO–velocity-update cycle was repeated until residual curvature was reduced and gather flatness improved. The final model was evaluated using gather flatness, reflector continuity, focusing, and preservation of dipping events. Iterative refinement produced a more kinematically consistent velocity model and improved the focusing and continuity of the migrated image. The results demonstrate that RMO-guided velocity refinement effectively links migrated-gather velocity errors to improved seismic imaging and highlights the value of integrating velocity analysis, Kirchhoff migration, RMO interpretation, and iterative model updating for 2D imaging in structurally complex settings.

Keywords: Residual move-out analysis; migration velocity refinement; Kirchhoff migration; velocity-model building; seismic reflector imaging; 2D field seismic data

IMAGING SHALLOW SUBSURFACE BENEATH THE DECCAN TRAPS USING AMBIENT NOISE CROSS-CORRELATIONS

Dilnas Fathima[1], Vivek Kumar[1], Gokul K. Saha[2], Dipak K. Chaubey[3], Shyam S. Rai[3]
[1]Indian Institute of Technology Bombay, Powai, Mumbai 400076
[2]CSIR National Institute of Data Science and AI, Bangalore – 560037
[3]Indian Institute of Science Education and Research Pune, Pune – 411008
Presenting author: dilnassajid2000@gmail.com

ABSTRACT

The sub-basaltic crust beneath the Deccan Volcanic Province remains poorly constrained. Here, we cross-correlate ambient noise recorded along a broadband profile traversing the Deccan Plateau and adjacent rift zones to extract vertical-component Rayleigh wave dispersion curves between 1 and 10 s. This period range directly images the upper 10 km of the crust, illuminating velocity structure beneath the basaltic cover. We also plan to integrate transverse-component Love wave dispersion curves to estimate radial anisotropy. The resulting velocity structure will highlight magmatic pathway geometry, test for structural continuity across regional rift zones, and reveal whether the sub-basaltic crust represents a hidden extension of the Dharwar Craton or a distinct tectonic block.

GNSS-DERIVED CRUSTAL STRAIN ESTIMATION IN PALGHAR, MAHARASHTRA

Gayathri Deepthi*, Anand S. P., and M. Ponraj
Indian Institute of Geomagnetism, New Panvel, Navi Mumbai,
e-mail: gaya3deepthi11@gmail.com

ABSTRACT

Intra-plate seismicity has been a concern, of late, in the stable continental region (SCR) of India. Several regions in the plate interior, like Khandwa, Jawhar, Valsad/Navsari, Amravati, Talala, etc., have been plagued by earthquake swarms with random temporal variations. One such region is Palghar of Maharashtra, which has been experiencing moderate seismic swarm-like activity since 2019. It has been the site of more than 10,000 micro- to small-sized earthquakes (M_W 0.5-4.2) concentrated at

shallow depths (< 15 km). The region is categorised under Zone III in the seismic zonation map. Located in the Western Ghats, the region is mostly covered by thick (~1.5 km) fractured Deccan basalt and mafic intrusions, oriented in N-S and NE-SW directions. The intense swarm activity in and around the region is monitored by a continuous geodetic (GPS) network of 6 stations and campaign network of 5 sites. Data obtained were processed using GAMIT/GLOBK post-processing software. Time series and strain analysis were used to determine the strain that has been accumulated in the region. Preliminary results observed from the raw time series suggest north and eastward movement of sites. Velocities calculated in the Fixed Indian Reference (FIR) frame show localised deformation acting in the region. Strain analysis reveals that the region has undergone notable strain buildup. Extensional strain is observed in the northern part, while shortening dominates the southern part along the Ghod fault. Dilatation and maximum shear strain patterns are concentrated to the east, indicating the area is to be vulnerable. The spatial pattern, as well as the observed accumulation of crustal strain, can be linked to various factors, such as fault/lineament intersections, pore-pressure accumulation, the presence of intrusives, and/or combinations of these factors. Detailed results will be presented.

MICROTREMOR-BASED SHALLOW SUBSURFACE SHEAR-WAVE VELOCITY STRUCTURE AND SEISMIC SITE CHARACTERIZATION OF PRAYAGRAJ CITY, INDIA

Girish Chandra Rahi*[1], Uma Shankar[1]
[1]Department of Geophysics, Institute of Science, Banaras Hindu University, Varanasi, 221005
Presenting author: girishchandrarahi2016@gmail.com

ABSTRACT

Prayagraj city, situated in the Indo-Gangetic Basin, is underlain by thick Quaternary alluvial sediments that can strongly influence local seismic ground response. Characterizing shallow subsurface conditions is therefore important for assessing site effects and seismic hazard in rapidly developing urban areas. The study aims to characterize the shallow shear-wave velocity structure, fundamental site frequency, amplification behavior, sediment thickness, and seismic vulnerability of Prayagraj city using microtremor observations. Multiple single-station and array microtremor measurements were conducted across the study area. The horizontal-to-vertical spectral ratio (HVSR) technique was employed to estimate fundamental frequency (f_0), amplification factor (A_0), and vulnerability index (Kg). Array observations were analyzed using the frequency–wavenumber (f–k) method to obtain dispersion characteristics and constrain shear-wave velocity (Vs) profiles. Forward and inverse modelling were used to evaluate the consistency of the derived subsurface models and estimate Vs30 and sediment thickness. The fundamental frequency ranges from 0.26 to 1.94 Hz, with most locations exhibiting low frequencies of 0.26–0.82 Hz. Amplification factors range from 1.36 to 18.75, while Kg varies from 21 to 173. Estimated Vs30 values of approximately 203–216 m/s indicate predominantly soft to medium-stiff ground conditions, broadly corresponding to NEHRP Site Class D. Dispersion analysis provides reliable phase velocities over approximately 1.5–4.5 Hz. Estimated sediment thickness ranges from approximately 24 to 207 m. Low fundamental frequencies and greater sediment thickness in central and river-adjacent areas indicate thick, relatively soft alluvial deposits and stronger potential for local seismic amplification. In contrast, relatively higher frequencies in southern parts suggest comparatively stiffer subsurface conditions. The integrated microtremor-based results reveal

significant spatial variability in seismic site response and provide a useful basis for seismic microzonation, urban planning, and site-specific seismic hazard assessment in alluvial urban environments.

SHALLOW SEISMIC REFRACTION TOMOGRAPHY FOR GROUNDWATER INVESTIGATION AT SADHANA FOREST, TAMIL NADU, INDIA.

Gondu Lahari*[1], V. Vijaya Rao[1], Tanvi Arora[1,2], N. Prem Kumar[1], Mohammed Rafique Shamshoddin Attar[1], Ronak Dahiya[2] Kolli Laxminarayana[1,2], P. Karuppannan[1], Biswajit Mandal[1,2], Prakash Kumar[1,2]
[1]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500007.
[2]Academy of Scientific Innovation and Research (AcSIR), Ghaziabad-201002, India.
*Corresponding Author E-mail: laharigondu493@gmail.com

ABSTRACT

Sadhana Forest is located near Auroville, Tamil Nadu, approximately 10 km north of Puducherry and the Bay of Bengal, within the Kaluvelly watershed and about 65 km from the nearest Cauvery River channel. The regional geological setting comprises Mesozoic–Cenozoic sedimentary formations overlying an Archean crystalline basement, including high-grade Charnockitic rocks associated with the regional Southern Granulite Terrain. The sedimentary succession includes sandstone, clay, and limestone formations. Six seismic refraction profiles were acquired within the accessible portions of Sadhana Forest, where vegetation and site constraints influenced the survey layout. The survey comprised 11 spreads, each 120 m long, with a receiver spacing of 5 m and a shot spacing of 27.5 m. First-arrival travel times were picked from the recorded seismic data and used to generate conventional velocity models and two-dimensional tomographic models using Plotrefa Software. The reliability of the models is evaluated using chi-square and absolute RMS travel-time residuals, together with a synthetic checkerboard test. A three-layered velocity model is derived from the seismic data. The interpreted P-wave velocities range from ~ 200 to 1500 m/s and increase with depth. The shallow zone, with velocities of approximately 200–400 m/s, is interpreted as loose, highly weathered, or unconsolidated near-surface material. The intermediate zone, with velocities of approximately 600–1100 m/s, is interpreted as relatively compacted or weathered unconsolidated sediment or weathered sandstone. The higher-velocity zone (~1000–1500 m/s) may represent relatively compacted or saturated sedimentary material, providing complementary information for groundwater assessment. The Vanur Sandstone constitutes an important aquifer, while the overlying Ottai Clay acts as an aquiclude. These findings demonstrate the applicability of shallow seismic refraction surveys for hydrogeophysical characterization and groundwater investigation in forested environments.

Keywords: Seismic refraction, tomography, Kaluvelly watershed, Vanur Sandstone, groundwater exploration, hydrogeophysics, P-wave velocity, Sadhana Forest.

A SPATIALLY VARYING MAGNITUDE-THRESHOLD FRAMEWORK FOR PRE-INJECTION SEISMICITY RISK ASSESSMENT FOR CO_2 STORAGE IN THE DECCAN BASALT, INDIA

Hari Prasath S, Dip Das, Nimisha Vedanti
CSIR-National Geophysical Research Institute, Hyderabad-500007, India
Presenting author: hariprasaths1111@gmail.com

ABSTRACT

As geological carbon storage emerges as a climate mitigation strategy, ensuring safe CO2 injection in formations like the Deccan Basalt requires understanding regional seismicity and induced earthquake risks. Therefore, we developed a spatially varying magnitude (Mw) threshold to identify favorable injection regions in the western Deccan, where larger-magnitude triggered earthquakes can be accommodated with minimal risk of significant damage or adverse human perception, thereby allowing greater volumes of fluid to be injected. To achieve this, we analyzed 775 historical earthquakes (Mw 1-5, depth 0-10 km) recorded over the past 66 years for regional ground motion understanding. The study area is divided into 14,096 grid cells (2×2 km spacing); each grid cell contains VS30 (time-averaged shear-wave velocity in the upper 30 m), population data, and building-class type probabilities from the vulnerability class of India. RAIY07 and BAVSM19 are the two Ground Motion Prediction Equations (GMPEs) used, with 50:50 weighting. To evaluate risk, Peak Ground Velocity (PGV) is converted to Modified Mercalli Intensity (MMI) for people's perception of nuisance. Concurrently, we spatially matched grid-based Peak Ground Acceleration (PGA) values with the building classes from the Vulnerability Atlas of India and building geometry (height and area) from the Global Buildings Atlas for structural fragility analysis. Threshold limits are set at MMI level III (affecting 2% of households) for the nuisance function and Damage State 1 (affecting 0.2% of household buildings) for fragility functions. Based on these thresholds, spatially varying risk maps were generated. The limiting earthquake magnitude for each cell is determined by the lowest magnitude between the nuisance and fragility. Results show that nuisance governs 49.7% of the grids, while structural damage governs 50.3%. The acceptable magnitude ranges from 2.0 to 3.74, with a median of 3.27. Ultimately, setting these local safety predefined limits provide a baseline for identifying sensitive and safer areas, allowing us to safely run the subsurface CO2 injection operations.

EVALUATING BROADBAND SEISMIC STATION PERFORMANCE THROUGH AMBIENT NOISE ANALYSIS IN THE EASTERN CHHOTANAGPUR PLATEAU

Himanshu Gautam, Mohit Agrawal
Indian Institute of Technology (Indian School of Mines) Dhanbad
himanshugautam150901@gmail.com

ABSTRACT

The present study investigates the space, time and component-wise variability of ambient seismic noise over Chhotanagpur plateau region of eastern India using the continuous broadband seismic waveform data from five selected locations (Peterbar, Nirsa, Giridih, Deoghar and Dhanbad) in Jharkhand. The three components of ground motion, vertical (BHZ), north–south (BHN) and east–west (BHE), are used to study the variations of the observed noise environment. Power spectral density (PSD) and probabilistic power spectral density (PPSD) methods are used to characterize spectral distribution of

seismic noise and recording conditions at the selected locations. The resulting noise spectra are compared with the new low noise model (NLNM) and new high noise model (NHNM) to estimate the relative noise levels and to find the frequency ranges with large variation. The temporal characteristics of the ambient noise are investigated at daily, monthly, seasonal and yearly scales, allowing persistent and time-dependent patterns to be identified. Differences in noise characteristics between the vertical and horizontal components of ground motion are examined by making component-wise comparisons. Furthermore, the comparative analysis between the five sites allows an assessment of the spatial variation of the seismic noise environment in the study region. Variations observed in different frequency and period ranges are discussed in terms of possible environmental and anthropogenic sources that may affect seismic recordings. We also study seasonal variations of spectral properties to look for changes related to changing environmental conditions and local activities. The results provide a detailed characterization of the ambient seismic noise conditions at the selected sites and show the spatial, temporal and component dependent nature of seismic noise in the Chhotanagpur plateau. This study provides a useful baseline for assessing the quality of seismic data and for future seismological studies in the region.

USE OF REAL-TIME SEISMIC AMPLITUDE MEASUREMENT FOR DETECTING FLOOD SIGNALS IN THE ITANAGAR CITY, ARUNACHAL PRADESH

Jeny Sam[1], Athul P.[2], Himangshu Paul[2] and Naba K. Bora[2]
[1]Cochin Institute of Science and Technology, Kochi
[2]CSIR-National Geophysical Research Institute, Hyderabad
jenysam22@gmail.com

ABSTRACT

Changing climate conditions are increasingly altering rainfall patterns, leading to greater variability in rainfall intensity, duration, and distribution. In many places, these extreme rainfall events frequently cause flash floods. Recent studies show the influence of rivers on the amount of seismic noise. These give scope for the seismic monitoring of hydrogeological hazards. Turbulent river water can be a source of seismic noise. We compare the ambient noise features with hydrological data and evaluate the potential of using seismic records for hydrological studies. Continuous seismic data from Arunachal Pradesh were analysed to detect the 2022 flood in the Dikrong River, Itanagar, using the Real-time Seismic Amplitude Measurement (RSAM) method. RSAM transformed raw seismic noise into averaged amplitude trends, allowing clear identification of anomalous signals. Among all stations, only IZSI consistently recorded distinct variations, with spectrograms (~72 h) showing flood onset ~15 hours into the record, marked by strong energy bands in the 4–8 Hz range. Seismogram analysis confirmed transient amplitude growth and decay, which is similar to the typical rise and fall of turbulent water flow. This study underscores the importance of establishing seismic stations near river channels in hilly terrain to identify such hazards. These findings demonstrate RSAM's effectiveness in distinguishing flood signals from background noise and also establish it as a reliable tool in Environmental Seismology, capable of advancing hazard monitoring.

CHARACTERIZATION OF S-WAVE ATTENUATION IN MYANMAR USING THE 2025 MW 7.7 EARTHQUAKE

Jirmili Ingtipi[1] and Nitin Sharma[2]
[1]Department of Geophysics, Kurukshetra University, Kurukshetra;
[2]CSIR–National Geophysical Research Institute (NGRI), Hyderabad
Presenting author: jirmiliingtipi3094@gmail.com

ABSTRACT

The 28 March 2025 Mw 7.7 Myanmar earthquake, which occurred along the active Sagaing Fault, provides an opportunity to characterize crustal seismic-wave attenuation along the propagation paths sampled by the available stations. This study estimates the frequency and distance dependent shear-wave quality factor (Qs) using ground motion records from five seismic stations spanning the epicentral distances between 137 and 572 km. We estimate Qs across eight central frequency bands (2.75–20.25 Hz) using the spectral decay method. The overall combined power-law relationship, $Qs(f) = 300.8 \cdot f^{0.554}$ indicate decrease in intrinsic attenuation at higher frequencies, reflecting substantial spatial heterogeneity in crustal attenuation across the stations. The estimated Qs values strongly correlates with epicentral distance ($Qs = 7.186 \cdot d - 374.15$), indicating less attenuating propagation characteristics of shear waves in the region. Our findings provide useful constraints on seismic attenuation, thereby improving the characterization of ground-motion amplitude and frequency content for seismic hazard estimation. Our findings provide useful constraints on seismic attenuation that can contribute to improved ground-motion characterization and seismic hazard estimation.

Keywords: Shear wave attenuation, Quality factor (Qs), Spectral decay, Myanmar earthquake, Sagaing Fault, Seismic hazard

A DEEP LEARNING NEURAL OPERATOR FOR SEISMIC WAVEFORM INVERSION

Joseph Lalngaihawma[1,2*] and Ajay Malkoti[1,2]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India
Email: joseph.ngri24j@acsir.res.in

ABSTRACT

Conventional seismic imaging methods, such as seismic tomography and migration, may not fully resolve complex subsurface structures since these methods rely on simple ray approximations. Full Waveform Inversion addresses this limitation by utilizing most of the information contained in seismic data. However, this method is a nonlinear, ill-posed inverse problem that requires a good initial velocity model to avoid local minima. Further, it requires substantial computational resources in terms of memory and computing power. These challenges have driven the search for alternative approaches, such as Deep Learning (DL), that can learn the complex nonlinear relationship between seismic data and subsurface properties. DL models (e.g., CNN, Unet) use local operations, limiting their ability to capture global spatial relationships. Frequency-domain DL models can capture global spatial relationships efficiently, but have frequency bias, limiting their ability to resolve fine-scale features. Therefore, in this study, we develop a Deep Learning Neural Operator (DLNO) model that uses an encoder-decoder structure with multiple resolution levels for DL-based seismic waveform inversion. This allows the model to combine global features with multi-scale feature learning through

downsampling and upsampling. The design of the model is expected to improve the structural boundaries and finer velocity structures while capturing global spatial relationships. The model uses multiple DLNO blocks with varying channel widths and frequency modes, which is followed by a refinement stage to improve the final velocity representation. Seismic shot gathers are provided as input, and the model can predict a subsurface velocity model. The model is trained with a hybrid loss function that combines several loss functions to capture not only global error but also multi-scale structural errors and errors near interfaces. The proposed model is evaluated on synthetic seismic datasets to observe its ability to recover complex velocity structures and reduce the smoothing of fine-scale features observed with the standard models.

MULTILAYER PERCEPTRON NEURAL NETWORK-BASED INVERSION OF ELECTRICAL RESISTIVITY TOMOGRAPHY DATA FOR GROUNDWATER CONTAMINATION SITE CHARACTERIZATION.

Jyoti[1]*, Payal Rani[2]
[1] Department of Geophysics, Kurukshetra University, Kurukshetra, Haryana, India
[2]CSIR-National Geophysical Research Institute (NGRI), Hyderabad, India Presenting author:
95jyotisaini@gmail.com

ABSTRACT

Electrical Resistivity Tomography (ERT) is a widely used geophysical method for studying the subsurface in areas such as groundwater exploration, environmental investigations, archaeology, and mineral exploration. In a two-dimensional electrical resistivity survey, apparent resistivity measurements are acquired using multiple electrodes and then inverted to obtain the true subsurface resistivity model. However, the inversion process is ill-posed, nonlinear, and computationally expensive. This can affect the accuracy of subsurface characterization in complex geological settings. This study presents a Multilayer Perceptron Neural Network (MLP-NN) as an alternative approach for ERT inversion. The model was trained on a synthetic dataset generated with the pyGIMLi forward modeling tool. It was designed to predict seven target characterization parameters: the lateral and vertical centroid positions of the anomaly, its width and height, the resistivity of the anomalous body, the subsurface top layer, and the matrix resistivity. To evaluate its performance, the MLP-NN results were compared with two well-known inversion techniques: the iterative inversion available in pyGIMLi and the least-squares inversion used in RES2DINV. Later, the trained MLP-NN model was further validated using published field ERT data acquired along a contaminated site. Results showed good agreement across all three inversion models, with similar subsurface resistivity patterns and anomaly shapes. Small differences appeared mainly at greater depths and near the profile edges, where ERT sensitivity naturally decreases. Overall, the MLP-based approach provides reliable results while reducing computational time, making it a promising alternative for rapid, reliable ERT data interpretation.

Keywords: Electrical resistivity, Machine Learning Inversion, Multilayer Perceptron Neural Network (MLP-NN), subsurface contamination

INTEGRATED BOREHOLE GEOPHYSICAL LOGGING FOR FRACTURE CHARACTERIZATION IN HARD-ROCK TERRAIN: A CASE STUDY FROM HYDERABAD, INDIA

K.N.S.S.S.Srinivas*, M. Srihari Rao, P. Pavan Kishore, S. Trupti, H.V.S.Satyanarayana
CSIR-National Geophysical Research Institute

ABSTRACT

Identification and characterization of fractures in crystalline hard-rock environments are important for subsurface characterization and assessment of rock mass conditions. This study presents an integrated borehole geophysical logging approach for identifying and characterizing fractures in two shallow boreholes, 60 m and 80 m deep and separated by approximately 10 m, at the CSIR-NGRI campus, Hyderabad, India. A comprehensive suite of borehole geophysical logs was acquired to identify significant fractures and fracture zones within the crystalline bedrock. Acoustic Televiewer (ATV) imaging provided oriented, high-resolution images of the borehole walls, enabling detailed identification, characterization and orientation analysis of fractures. These observations were integrated with full-wave sonic, electrical resistivity and caliper logs. Fractured intervals are characterized by reduced sonic velocities, pronounced decreases in electrical resistivity and increases in borehole diameter, providing complementary geophysical signatures of fracturing. The identified fracture zones show good correspondence with the ATV-derived borehole images and variations in shear-wave velocity obtained from Multichannel Analysis of Surface Waves (MASW) investigations. The integrated interpretation demonstrates that the combination of borehole imaging and conventional geophysical logs provides high-resolution, in situ information on fracture occurrence and characteristics in hard-rock terrain. Correlation with surface geophysical measurements further supports the identification of fractured intervals. The study highlights the effectiveness of integrating borehole and surface geophysical methods for detailed subsurface characterization in crystalline hard-rock environments. The approach has significant potential for civil engineering applications, including subsurface characterization, assessment of rock mass conditions, and hazard mitigation.

Keywords: Borehole geophysical logging; Acoustic Televiewer; Full-wave sonic; Electrical resistivity; Caliper log; Fracture characterization; MASW; Hard-rock terrain

EARTHQUAKE SOURCES PROCESS AND SEISMOTECTONICS

Keloth Sri Venkata Durga Kalyani, DubbaVijay Kumar, and G. Udayalaxmi
Department of Geophysics, Osmania University, Hyderabad
Email ID: kalyanichawhan4@gmail.com

ABSTRACT

Earthquakes are natural geological phenomena produced mainly by the sudden release of accumulated strain energy within the Earth's crust. The earthquake source process describes how this energy is released along a fault, including the initiation, propagation, rupture direction, fault displacement, and resulting seismic radiation. Understanding the source process helps determine important parameters such as focal depth, seismic moment, rupture velocity, fault orientation, and stress drop. Seismotectonics examines the relationship between earthquake activity and the tectonic structures responsible for crustal deformation. It combines seismological observations with geological and

tectonic information to identify active faults, plate boundaries and zones of crustal instability. Analysis of earthquake source mechanisms, hypocentral distribution and focal mechanisms provides valuable information about the prevailing stress regime and tectonic movements of a region. Together, earthquake source studies and seismotectonic investigations improve our understanding of crustal dynamics and help identify areas of potential seismic hazard.

Earthquakes occur when stress accumulated in the Earth's crust exceeds the strength of rocks, resulting in sudden fault rupture and the release of elastic strain energy. The point where rupture begins is called the hypocenter or focus, while its surface projection is the epicenter. Seismic waves generated during rupture travel through the Earth and are recorded by seismological instruments. Analysis of these waves provides information about the earthquake source and the physical properties of the crust.

The earthquake source process involves several stages, including rupture initiation, propagation along the fault, displacement of rock masses, and radiation of seismic energy. Parameters such as seismic moment, focal mechanism, rupture area and stress drop are important for understanding the size and nature of an earthquake.

Seismotectonics focuses on the connection between seismicity and tectonic structures. The spatial and temporal distribution of earthquakes can reveal active faults and ongoing deformation associated with plate movements. Focal mechanism solutions, geological mapping, and seismicity patterns are commonly used to determine the type of faulting and regional stress field. Therefore, the combined study of earthquake source processes and seismotectonics is essential for understanding regional tectonic evolution and assessing seismic hazards.

Key Words: Earthquakes, resulting seismic radiation, seismic moment, Seismotectonics, geological mapping, faulting, regional tectonic.

RESISTIVITY CORRECTION FRAMEWORK FOR LITHOLOGICAL AND GROUNDWATER QUALITY EFFECTS IN AEM INTERPRETATION

Kattula Bhima Raju[1,2*], Peela Madhu[1,2], Subash Chandra[1,2]
[1]CSIR National Geophysical Research Institute, Uppal Road, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad- 201002, India
*Corresponding Author Email: raju.gpy12@gmail.com

ABSTRACT

Airborne electromagnetic data (AEM) acquired from Surat city and its surroundings, covering approximately 300 sq.km near the Arabian Sea coast, were analyzed to assess the impact of seawater intrusion (SWI) on coastal aquifers. This region is experiencing significant SWI primarily driven by excessive groundwater extraction and the impacts of industrial growth. Alongside the AEM data, water-level measurements and in-situ electrical conductivity (EC) measurements were obtained from borewells to monitor groundwater conditions and assess the spatial distribution of salinity. A robust inverse correlation was observed (R^2=0.76) between AEM-derived resistivity and groundwater EC, highlighting the strong influence of groundwater quality on resistivity. The relationship exhibits a distinct non-linear trend, with a transition occurring around ~2000 µS/cm. Below this threshold, resistivity shows an approximately linear relationship with groundwater EC, whereas above the

threshold, groundwater EC increases exponentially with decreasing resistivity, indicating the influence of water quality. The study further establishes a critical low resistivity that marks the transition boundary dividing the SWI and fresh water zone, particularly in the western parts of the study area.

Based on this relationship, a site-specific Resistivity Correction Factor (RCF) was developed to minimize the influence of groundwater quality on resistivity and improve lithological interpretation. Application of RCF enabled the reconstruction of lithological sections by reducing the effects of groundwater quality. The corrected resistivity model provided improved discrimination of lithological units. Subsequently, a 3D hydrogeological model was developed from the corrected AEM resistivity data, revealing enhanced delineation of aquifer systems and improved understanding of the hydrological connectivity of aquifer systems with the river and adjoining sea, and providing a clearer representation of subsurface hydrogeological features after accounting for water quality effects.

Key words: Electromagnetic, Resistivity, Seawater Intrusion, Groundwater quality, and Resistivity Correction Factor.

GEOPHYSICAL PROSPECTING FOR MINERALIZED POTENTIAL ZONES IN PEDDAVURA AND CHINTHAKUNTLA SCHIST BELTS IN NALGONDA DISRTICT, TELANGANA

[1]Kota Ashwini, **[2]Dr G. Udaya Laxmi**
[1]Research Scholar, Department of Geophysics
[2]Associate Professor, Department of Geophysics
Osmania University, Hyderabad
ashwinikota25@gmail.com

ABSTRACT

This proposal aims to conduct an extensive and detailed geophysical investigation of the Peddavura and Chintakuntla schist belts situated in the Nalgonda District of Telangana, with the primary goal of identifying and characterizing zones of potential mineralization. These schist belts are recognized for their complex and varied geological framework, which includes diverse lithological units and intricate structural features such as faults and shear zones. Such geological complexity makes these belts highly prospective for hosting economically significant mineral deposits.

Integrated Geophysical Techniques for Subsurface Mineral Exploration in the Chintakuntla Block and Peddavura, Deccan Volcanic Province: The Deccan Volcanic Province (DVP) is one of the world's largest continental flood basalt provinces, covering approximately 0.5 million square kilometres in the west-central part of India. This region, with basement rocks spanning from the Archaean to the Phanerozoic, holds significant potential for untapped mineral resources. The southern edge of the DVP is home to the Proterozoic Bhima and Kaladgi sedimentary basins, which are well known for their rich deposits of gold, uranium, and copper. In recent times, several geophysical studies have linked tectonic activities with the underlying geological structures, resulting in the identification of the Greater Dharwar Terrain. Emerging studies also indicate the presence of Rare Earth Elements (REEs), which are crucial for industries such as electronics and renewable energy. Despite these promising geological features, large parts of the DVP remain unexplored because of the obscuring basaltic cover. The

Chintakuntla block, located within this unexplored domain, represents a promising frontier for mineral explorations.

The research will adopt a multidisciplinary geophysical approach, integrating several advanced techniques to achieve a comprehensive subsurface characterization. Key methods will include magnetic surveys to detect variations in the Earth's magnetic field caused by different rock types and mineral concentrations; electrical resistivity tomography (ERT) to image subsurface resistivity contrasts indicative of mineralized zones; induced polarization (IP) surveys to identify chargeability anomalies related to disseminated sulphide minerals; and Gravity measurements to map density variations that may correspond to mineral bodies or structural features. By combining these complementary geophysical datasets, the study aims to generate a high-resolution model of the subsurface geology and mineralization patterns.

Furthermore, the geophysical data will be rigorously analysed and integrated with existing geological maps, structural interpretations, and geochemical data to enhance the understanding of the spatial distribution, geometry, and depth extent of mineralized zones. This correlation will help in delineating lithological boundaries, identifying key structural controls such as fault and shear zones that influence mineral deposition, and estimating the size, grade, and economic potential of the mineralized bodies.

UNDERGROUND BURIED UTILITY DETECTION FROM B SCAN GROUND PENETRATING RADAR IMAGE USING DEEP LEARNING MODEL

Krishna Kumar Yadav[1], Ashvini Kumar Yadav[1], Satish Kumar Sinha[1] and Alok Saini[2]
[1]Rajiv Gandhi Institute of Petroleum Technology Jais, Amethi, Uttar Pradesh, India
[2] Remote sensing Applications Centre Lucknow, Uttar Pradesh, India
Presenting author: krishnaky@rgipt.ac.in

ABSTRACT

Ground-penetrating radar (GPR) is as a non-invasive method for exploring what lies beneath the ground, particularly for detecting and identifying the underground utilities like water pipes, electrical cables, and gas lines. The precise and efficient detection of these buried utilities is important in civil engineering, urban planning, and infrastructure maintenance. However, analyzing numerous GPR B-scan images manually is a time-consuming task, and the outcomes are heavily reliant on the expertise of the individual conducting the analysis and the available prior knowledge. At the same time, automating the analysis of these generated GPR B-scan images presents a significant challenge.

In this paper for the automated detection of underground utilities in GPR B-scan images, utilizing the You Only Look Once (YOLO) v8 deep learning model along with RoboFlow. The study employs a one-step object detection algorithm, YOLO v8, which is based on a convolutional neural network. Here, we marked the GPR image target for training by Roboflow. After using RoboFlow to label all hyperbola targets from GPR images. A total of 171 GPR B scan image samples of which the proportion of training set in the whole data set is 70%, the validation set is 20%, and the test set is 10% in the whole data. The model output consists of bounding boxes around detected hyperbola, along with associated confidence scores. A carefully crafted loss function is employed to balance object localization accuracy and class confidence.

In summary, our result is to achieve automatic and precise detection of underground utilities within B-scans. By treating utilities as distinct objects, our method offers speed and accuracy, making it suitable for real-world applications in utility management, construction, and urban planning. This work contributes to enhancing the safety, efficiency, and environmental sustainability of energy industry operations by providing valuable subsurface information and insights.

IMPROVED NODE AND BRANCH DETECTION ALGORITHM FOR 2D FRACTURE NETWORK CHARACTERIZATION.

Kuntal Saha[1*], Sudipta Sarkar[1], Sirshendu Kumar Biswas[2], Tridib Kumar Mondal[1]
[1]Geological Studies Unit, Indian Statistical Institute, 203 B.T. Road, Kolkata-700108, West Bengal, India.
sahakuntal616@gmail.com, sudiptasarkar.malda76@gmail.com, tridibkumarmondal@gmail.com
[2]Earth and Planetary Systems Science Program, Graduate School of Advanced Science and Engineering, Hiroshima University, Japan. biswassirshendu@hiroshima-u.ac.jp / sirshendu.skb@gmail.com
*Corresponding and presenting author: Kuntal Saha (sahakuntal616@gmail.com)

ABSTRACT

Topological analysis simplifies a fracture trace map to nodes and branches, classifying fracture terminations and intersections into isolated (I), abutting (Y), and crossing (X) nodes. All connectivity measures depend on node identification. Branch counts are derived from these node classifications, giving probabilistic estimates of isolated (I-I), partly connected (I-C), and doubly connected (C-C) branches, where C is a connecting node (Y or X). However, while nodes constitute an important component of network topology, the actual numeric count and spatial distribution of different branch types provide a more robust measure of connectivity and network organization. Manual tracing often introduces overshoots, undershoots and gaps at fracture junctions. Common fracture network analysis tools like *FracPaQ* report node proportions and line connections without identifying branches, whereas *NetworkGT* identify branches from the raw digitized trace and *fractopo* uses fixed-tolerance snapping, but both require separate repair tools to optimize frequent digitization artifacts. We therefore develop a new node and branch detection algorithm whose advanced detection step automatically closes such gaps, trims overshooting tips to fracture junctions, and merges near-coincident contacts into one node. Input vector traces are imported with coordinate transformations resolved and curved segments converted into polylines, offering selectable dynamic or absolute snapping values. Several inbuilt filtering measures prevent spurious crossing and intermediate V-nodes that frequently arise during manual digitization of curved fracture. Nodes are categorized into I, Y, and X types based also on their topological degree (number of incident branches), and branches are classified by their bounding nodes into six pairwise types (I-I, I-Y, I-X, Y-Y, X-Y, and X-X). We applied this new algorithm to fracture network analysis in the metavolcanic rocks of the Chitradurga Schist Belt, India. Preliminary results demonstrate successful automated fracture network extraction across complex outcrops, revealing a systematic southward increase in network connectivity along the schist belt.

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY AND ROCK MAGNETIC RESULTS FROM LEH-LADAKH DYKES: PRELIMINARY INVESTIGATIONS

Manan Singh, Pratikshya Behera, Pradnya Mohite, B.V. Lakshmi, K. Deenadayalan, Garima Shukla, A.P. Dimri
Indian Institute of Geomagnetism
Presenting author: manansingh1129@gmail.com

ABSTRACT

The magnetic fabric of mafic to intermediate dykes provides important constraints on magma emplacement, flow dynamics, and the relationship between dyke intrusion and regional tectonic structures. In this study, we investigate the anisotropy of magnetic susceptibility (AMS) of 7 dykes exposed in the vicinity of Leh, Ladakh, NW Himalaya, using both in-phase (ipAMS) and out-of-phase (opAMS) susceptibility measurements. The study aims to investigate the magnetic fabrics recorded by the dykes and to evaluate the extent to which in-phase and out-of-phase AMS reflect mineralogical controls, crystallographic fabrics, subfabrics, and/or emplacement-related processes. The ipAMS data reveal normal magnetic fabrics, characterized by relationship of K_1, K_2 and K_3 to the dyke plane. The principal susceptibility axes show preferred orientations, with K_3 displaying perpendicular relationship to the dyke orientation. The degree of anisotropy and shape parameter indicate weak to moderate magnetic anisotropy and predominantly oblate susceptibility ellipsoids. These fabrics are interpreted to reflect magmatic flow during the formation. In the opAMS measurements exhibit similar directional and scalar characteristics relative to the ipAMS fabrics. The comparison between the two components indicates absence of distinct magnetic subfabrics and suggests that the frequency-dependent response is controlled by magnetic mineralogy, grain size, domain state. Integrating the ipAMS and opAMS results with magnetic mineralogy, field relationships and structural data suggests that the magnetic fabrics of the Leh dykes record magmatic flow/emplacement-related processes. The relationship between dyke orientation and magnetic fabric further provides constraints on magma flow direction, emplacement mechanism. These results demonstrate the utility of combining ipAMS and opAMS measurements for resolving the origin and geological significance of magnetic fabrics in Himalayan dyke systems.

Keywords: Rock Magnetism, Paleomagnetism, AMS, Dykes

WHAT DYKE INDUCED GRABEN SAYS ABOUT THE SUBSURFACE DYNAMICS OF PLANETARY LITHOSPHERE: A COMPARATIVE STUDY OF LUNAR AND MARS

Chakraborty, Manojit[1*], Saha, Kuntal[1], Dey, Anubhab[1], Ruj, Trishit[2], Mondal, Tridib Kumar[1,]
[1]Geological Studies Unit, Indian Statistical Institute, Kolkata-700108, West Bengal, India
[2]Institute for Planetary Materials, Okayama University, 827 Yamada, Misasa, Tōhaku District, Tottori 682-0193, Japan
Presenting author: Chakraborty, Manojit, manojitchakrabortycollege@gmail.com
*Corresponding Author

ABSTRACT

Dyke-induced grabens develop when magma intrusion produces extensional deformation and faulting in the overlying crust. Their surface geometry can therefore constrain the emplacement conditions of otherwise inaccessible underlying dykes. On Earth, exposed dykes are commonly used to estimate magma overpressure and emplacement depth and, consequently, to infer subsurface magmatic processes. However, dykes are rarely exposed at the surface on other terrestrial bodies, such as Mars and the Moon. In such cases, dyke-induced grabens provide an important surface proxy for investigating otherwise inaccessible subsurface magmatic systems.

Here, we investigate whether the morphology of dyke-induced grabens can quantitatively constrain magma overpressure and emplacement depth across planetary environments. We reconstruct the geometry of parent dykes from the morphometry of dyke-induced grabens in two settings: the tectonically active Cerberus Fossae system on Mars and a dyke-induced graben part of Rima Sirsalis from the near side mare-highland boundary region of the Moon.

For the Martian Cerberus Fossae dykes, our calculations yield magma overpressures of 60-103 MPa and emplacement depths of 20-53 km. For the lunar dyke in the Rima Sirsalis, the corresponding estimates are 12-13 MPa and approximately 33-34 km. These estimates agree with independent geophysical constraints: the Martian depth range overlaps the source-depth range of low-frequency marsquakes detected by InSight's seismometer. In contrast, the lunar emplacement depth lies close to the lower end of the global mean lunar crustal thickness inferred from GRAIL gravity data.

Our preliminary results indicate that although the host rock properties and gravity of the two planets are not similar, the basic subsurface magmatic emplacement mechanism is similar for both grabens. This study therefore provides a means of independently constraining magma overpressure and emplacement depth and offers a complementary method for validating geophysical models of subsurface magmatism.

Keywords: Cereberus Fossae; Lunar Graben; Dyke; Magma Overpressure; Moon

Crustal Structure and Tectonic Evolution of Northeast India Revealed by Ambient Noise Group-Velocity Tomography

Mohit Agrawal,
Associate Professor, Observational Seismological Laboratory, Department of Applied Geophysics, IIT(ISM), Dhanbad-826004
Emal: mohit@iitism.ac.in

Abstract

Northeast India is a tectonically complex region shaped by the collision of the Indo-Eurasian plates to the north and the subduction of the Indo-Burma plate along its eastern margin. This study utilized ambient noise data from 20 permanent and three temporary broadband seismic stations to investigate the crustal structure of the region. Ambient noise records were cross-correlated to obtain group velocity maps for periods between 6 and 25 s. Short-period tomographic results (<10 s) delineate the boundary between undifferentiated granites and Eocene rocks across the Shillong Plateau and reveal major geomorphological features of the Bengal Basin, Indo-Burma Ranges, and Brahmaputra River Valley. At longer periods (>10 s), the results indicate that the basement rocks of the Shillong Massif are separated from the sediments of the Bengal Basin by the northward-dipping Dauki thrust fault. The fault maintains a relatively constant dip up to approximately 16 s period, beyond which it becomes progressively steeper with increasing depth. The observed group velocity patterns suggest that tectonic stresses may have contributed to the uplift and lateral expansion of the Shillong Massif. In addition, the crust beneath the Bengal Basin gradually thickens toward its eastern margin, supporting the presence of oblique subduction along the Indo-Burmese arc. A boundary near 25° latitude separates relatively low and high seismic velocities in the Indo-Burma region from north to south, consistent with the greater crustal thickness observed in the southern part of the Indo-Burma Ranges.

PROCESSING AND MODELLING OF SATELLITE MAGNETIC DATA FOR DEVELOPING LITHOSPHERIC MAGNETIC ANOMALY MODEL OF THE INDIAN (LAMI) REGION

Monica Rawat and Anand.S.P.
Indian Institute of Geomagnetism, Navi Mumbai, Maharashtra
Email id: monicarawat10@gmail.com

ABSTRACT

Satellite magnetic observations provide a valuable means of investigating the lithospheric structure and tectonic framework of the Earth. However, the relatively weak lithospheric magnetic signal is influenced by external and temporal field variations, differences in satellite altitude, incomplete and overlapping orbital tracks, and the dominant core magnetic field. This study presents a systematic processing strategy for correcting these effects in Swarm magnetic observations and developing a regional lithospheric magnetic anomaly model for the Indian region. Swarm A and C data are integrated with CHAMP observations and processed to a common altitude of approximately 440 km. The processing includes environmental screening, altitude normalization, temporal corrections, removal of incomplete and overlapping orbital passes, and subtraction of the core magnetic field using the CHAOS-7 model. The corrected observations are then used to construct the Lithospheric Magnetic Anomaly Model of India (LAMI) through damped least-squares inversion, with spherical harmonics expanded from degrees 6 to 55. The resulting model provides improved spatial continuity of lithospheric magnetic anomalies across both continental and offshore regions. Distinct magnetic signatures are associated with major geological and tectonic provinces, including the Dharwar Craton, Central Indian Tectonic Zone, Eastern Ghats, Deccan Volcanic Province, Himalayan region, and adjacent oceanic domains. The results demonstrate the importance of rigorous data screening and systematic corrections in minimizing non-lithospheric contributions and enhancing regional satellite magnetic field models. The integrated CHAMP–Swarm approach provides an effective framework for investigating the lithospheric architecture and tectonic evolution of the Indian region from satellite magnetic observations.

SOURCE LOCATION OF THE 2025 GOVINDGHAT LANDSLIDE AND BRIDGE COLLAPSE EVENT, UTTARAKHAND, INDIA USING SEISMIC MONITORING

Monika Bhatia *[1], Rajesh Rekapalli[1, 2], Sandeep Gupta[1, 2,] Kethavarapu Raviteja[1, 2], and Venkatesh Vempati[1]
[1] CSIR-NGRI, Hyderabad, Telangana-500007, India.
[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh- 201 002, India.
Email: (monikabhatia98@gmail.com)

ABSTRACT

Mass movements and associated infrastructure failures generate complex, transient seismic signals that contain valuable information on source processes and direction. Here, we investigate the three-component broadband seismic signals generated by the 5 March 2025 Govindghat landslide/bridge-collapse event in Uttarakhand, India, using time–frequency polarization analysis to estimate the source direction and location. Seismic waveforms recorded at 5 stations were analyzed in the time–frequency domain using polarization attributes, including the degree of polarization and major-axis orientation. Directional information was extracted from prominent transient seismic phases, and source directions were estimated from the dominant polarization orientations at individual stations. Back-projection of

these direction vectors provided an independent estimate of the source location, which was subsequently compared with both the independently known event location and a seismic waveform cross-correlation-based location. The estimated polarization azimuths showed strong agreement with the theoretical station-to-source directions, with the best-performing stations exhibiting only very small angular deviations. Although geometric errors generally increased with station distance, the estimated directions remained closely aligned with the expected source azimuth, indicating that distance-dependent geometric metrics can magnify relatively small angular uncertainties. The polarization-derived source location was also close to the known event location and accurate compared to the independent cross-correlation-based estimate. Across all stations, the geometric error ranges between 0.5 and 820 m. These results demonstrate that three-component time–frequency polarization analysis can robustly extract source-direction information from complex transient seismic signals, providing a rapid and complementary approach for locating landslides, bridge collapses, and other cascading mass-movement hazards, particularly where conventional event-location methods are difficult to apply.

Keywords: Seismic Networks, Landslide, Govindghat, Bridge Collapse, Polarization, Cross-Correlation.

INTEGRATED FIRST-BREAK TRAVEL-TIME TOMOGRAPHY AND ELASTIC FULL WAVEFORM INVERSION FOR HIGH-RESOLUTION SEISMIC IMAGING IN KACHCHH, WESTERN INDIA

Mukesh Rathore[1,2], Prakash Kumar[1,2], Biswajit Mandal[1,2], Mrinal K. Sen[3]
[1]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
[3]The University of Texas at Austin, Austin, TX 78758-4445, USA
Presenting Author's email: rathoremukesh1999@gmail.com

ABSTRACT

Full Waveform Inversion (FWI) is a seismic imaging technique that utilizes the complete seismic waveform to estimate subsurface physical properties. Unlike conventional first-break travel-time tomography, which primarily uses first-arrival information, FWI incorporates amplitude, phase, and travel-time information from the entire seismic signal. This makes FWI suitable for complex geological environments characterized by strong lateral velocity variations, steeply dipping structures, faults, and heterogeneous subsurface features. However, its performance strongly depends on the quality of the initial velocity model and the availability of low-frequency data to minimize cycle-skipping effects.

In this study, FWI is applied to real seismic data acquired from the Kutch region of western India, which is characterized by complex geological structures and significant subsurface velocity variations. First-break travel-time tomography was initially performed using picked first arrivals to estimate the subsurface velocity model. The resulting tomographic model was then used as the initial model for FWI, providing a good starting model for waveform-based inversion. FWI was subsequently performed using the complete seismic waveforms to refine the velocity model by minimizing the misfit between observed and modelled data.

The inverted results demonstrate improved imaging of subsurface velocity variations and structural features compared with the first-break tomography model. The use of the complete waveform enables FWI to exploit information beyond first arrivals, providing greater sensitivity to features that may not

be adequately constrained by travel-time tomography alone. The application to the Kutch field dataset demonstrates the effectiveness of combining first-break travel-time tomography with FWI for constructing reliable velocity models in complex geological settings. This integrated approach provides a practical framework for seismic imaging and characterization of the subsurface in the Kutch region.

Keyword: Seismic Imaging, Full waveform Inversion (FWI), First Break Tomography, Velocity Model, High Resolution, Complex Structure

LITHOLOGICAL CONTROLS ON RADIOGENIC HEAT PRODUCTION AND SPECIFIC HEAT CAPACITY IN THE TATAPANI GEOTHERMAL PROVINCE, CENTRAL INDIA

Munazza Fatima[1,2]*, Labani Ray[1,2], Nishu Chopra[1,2], Nidharshan B M[1], Pragyan Mohapatra[1], Sandeep Kumar Prajapati[1,2]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
*Presenting author (email: munazzafatima0702@gmail.com)

ABSTRACT

The Tatapani Geothermal Province (TGP), located in the SONATA zone of central India, is the prominent geothermal manifestations and represents one of the important geothermal systems of the country. Understanding the distribution of internal heat sources and the thermal properties of crustal rocks is essential for constraining the subsurface thermal regime. In the present study, the radiogenic heat production (RHP) and specific heat capacity (C_p) of rocks from the Proterozoic Chhotanagpur Granite Gneiss Complex (CGGC) and overlying Gondwana formations are investigated as part of an integrated thermophysical characterization of the TGP. A total of 135 representative rock samples were collected from outcrops and borehole cores across the study area.

The results reveal considerable variation in radioelement abundances and radiogenic heat production among the studied lithologies. Within the CGGC, migmatite exhibits the highest radiogenic heat production, followed by granite gneiss, granitoids and paragneiss, whereas dolerite shows the lowest value. Among the Gondwana formations, sandstones exhibit comparatively low radiogenic heat production, whereas shale, arkosic sandstone, alternating sandstone-shale and sandy shale display relatively higher values. The higher radiogenic heat production of felsic and metapelitic lithologies is associated with enrichment of Th and U and the presence of accessory minerals such as monazite, zircon and titanite. Th and U show stronger correlations with radiogenic heat production than K, indicating their dominant contribution to radiogenic heat production in the studied rocks. Furthermore, the Gondwana rocks exhibit higher specific heat capacity than the CGGC rocks, which is attributed mainly to the higher porosity and water-filled pore spaces that enhance their capacity to store thermal energy. The results highlight that felsic rocks of the CGGC represent important crustal heat-producing lithologies in the TGP, whereas Gondwana formations, characterized by relatively higher specific heat capacity and porosity, have greater potential for thermal energy storage. These findings provide important constraints on the subsurface thermal regime of the TGP.

Keywords: Radiogenic heat production; Radioelement abundances; Gamma-ray spectrometer; Lithological control; specific heat capacity; Chhotanagpur Granite Gneiss Complex; Gondwana; Tatapani Geothermal Province.

A PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR NORTHWEST HIMALAYA USING OPENQUAKE

Dr. Imtiyaz A. Parvez[1], Dr. S. Sangeetha[1], Nainshi Saini[1]
[1]CSIR-National Institute of Data Science and AI (CSIR-NIDSA), Bengaluru, India
Presenting Author: Nainshi Saini
E-mail: nainsisaini785@gmail.com

ABSTRACT

The Northwest Himalaya, encompassing Jammu & Kashmir and Ladakh, lies along the actively deforming India–Eurasia collision zone and is characterized by significant seismic activity and critical infrastructure, including major hydropower projects. This study presents a Probabilistic Seismic Hazard Assessment (PSHA) of the region at reference bedrock conditions (Vs30 = 750 m/s), considering 10% and 2% probabilities of exceedance (PoE) in 50 years, corresponding to 475- and 2475-year return periods, respectively. A homogenized earthquake catalogue comprising 39,858 events was compiled and declustered using the Uhrhammer (1986) window method, resulting in 20,232 independent events. Magnitude-dependent catalogue completeness was evaluated using the Stepp (1972) method. The seismicity was represented by seven area-source zones (Zone_1–Zone_7). A fault-source model for the major active faults of the Northwest Himalaya is being developed as an extension of the regional hazard framework. Earthquake recurrence parameters were estimated using Gutenberg–Richter regression and the Weichert (1980) maximum-likelihood method and incorporated through a source-model logic tree with weights of 0.4 and 0.6, respectively. Maximum magnitudes (Mmax) for individual source zones were estimated using the Kijko–Sellevoll (2004) method and benchmarked against the maximum observed magnitudes. Nodal-plane distributions were characterized using focal-mechanism data from 343 Global Centroid Moment Tensor events. Classical PSHA was implemented in OpenQuake Engine v3.25.1 using the ASK14 and BSSA14 ground-motion models with equal weights. PGA and uniform hazard spectra were calculated across the study region for both return periods. Preliminary bedrock PGA estimates based on the area-source model range from 0.37–0.57 g for the 475-year return period and 0.63–0.99 g for the 2475-year return period, indicating substantial spatial variability in seismic hazard; final hazard estimates incorporating the fault-source model are in progress. The results will provide a regional seismic hazard baseline for seismic design, infrastructure planning, and risk-informed development of critical infrastructure in the seismically active Northwest Himalaya.

PREDICTION OF SEISMIC SOIL LIQUEFACTION USING SPT-BASED CASE HISTORIES AND MACHINE LEARNING TECHNIQUES

Naorem Denilson Singh [*1] Upendra K. Singh[1]
Applied Geophysics, IIT(ISM) Dhanbad
Presenting author: 25mt0302@iitism.ac.in

ABSTRACT

Seismic soil liquefaction occurs in loose saturated soils under undrained conditions, where the soil suddenly loses its shear strength during a strong earthquake shaking. It is one of the largest sources of damage to buildings, foundations and infrastructure, such as pipelines and roads. That's why predicting which sites are at risk is a key part of earthquake-resistant design.

The conventional approach to this problem involves the use of stress-based empirical methods, which compare the shaking demand on the soil with its resistance and then determine whether or not the site is liable to liquefaction by applying a number of correction factors and referring to a fixed boundary curve. Since machine learning is able to detect nonlinear patterns that the simpler methods fail to pick up, it has become a popular alternative. However, the majority of the current models still depend on laboratory-determined soil properties that are not always accessible in the field, and they are generally evaluated only in terms of accuracy, without giving sufficient consideration to recall, even though in practice the problem of missing a real liquefaction event is much greater than that of issuing a false alarm.

The aim of this study is to address the problem by developing a model that makes use only of parameters which can be measured directly in the field—including depth, SPT blow count, fines content, groundwater depth, peak ground acceleration, earthquake magnitude, and overburden stress—without the need for any derived indices or laboratory tests. It makes use of 540 case histories from the 1999 Chi-Chi and 2016 Meinong earthquakes, and four different models—Logistic Regression, Decision Tree, Random Forest, and SVM—are tested with a split of 80:20 and 5-fold cross-validation. The Random Forest model performed the best, achieving an accuracy of 97.2% and a recall of 100%, which means that it identified every instance of liquefaction in the test set. It was found that peak ground acceleration and the blow count are the best predictors, something that is in agreement with what we already know regarding liquefaction. In general, the results indicate that simple, field-ready machine learning models can provide a practical method for quickly and safely screening for liquefaction risk.

EARTHQUAKE-DRIVEN STRESS REDISTRIBUTION AND FAULT REACTIVATION POTENTIAL IN THE KASHMIR VALLEY, NORTHWESTERN HIMALAYA

Naseer Ahmad Bhat and Bikram Singh Bali
Department of Geology, University of Kashmir, Srinagar-190006, J&K, India
E-mail: geonaseerbhat@gmail.com, baligeol@gmail.com .

ABSTRACT

The Kashmir Valley occupies a tectonically complex sector of the northwestern Himalaya, where active thrust, strike-slip and oblique fault systems interact with the regional stress field generated by ongoing India-Eurasia convergence. Understanding how moderate-to-large earthquakes perturb the surrounding stress field and influence the stability of active faults is therefore essential for evaluating the spatial distribution of seismic potential in the region. In the present study, selected earthquakes occurring between 2001 and 2026, including the 2005 Kashmir earthquake sequence and subsequent moderate-magnitude events, are investigated using the Coulomb failure stress criterion to evaluate their influence on major receiver faults within and around the Kashmir Valley. The earthquake sources are characterized using hypocentral location, depth, magnitude and focal-mechanism parameters represented by both nodal planes, while the principal receiver structures include the Uri, Balapora, Loridor–Baramulla, Gulmarg, Magam, Central Kashmir, Laam, Mughal Road, Shopian-related structures, Mawer Fault and the Main Himalayan Thrust.

The resulting Coulomb stress pattern demonstrates a spatially heterogeneous response, reflecting the contrasting geometries and kinematics of the interacting fault systems. Positive Coulomb stress changes

are obtained on most of the evaluated receiver faults, indicating an increase in failure tendency under the assumed frictional and stress conditions. The largest positive ΔCFS values occur on the Balapora Fault (+0.68 bar) and Gulmarg Fault (+0.54 bar), suggesting that these structures are comparatively more favourably oriented for stress-induced reactivation. The Uri (+0.32 bar), Loridor-Baramulla (+0.28 bar), Laam (+0.36 bar), Central Kashmir (+0.12 bar), Shopian-related (+0.20 bar) and MHT (+0.16 bar) structures also exhibit positive stress changes, indicating varying degrees of stress promotion. In contrast, the Magam Fault records a negative ΔCFS of -0.22 bar, representing an inhibiting stress perturbation under the modelled conditions, whereas the Mughal Road Fault (+0.09 bar) shows only a weakly positive response. The modelled stress distribution indicates that earthquake-induced stress transfer is not uniform across the Kashmir Valley. Instead, it is strongly controlled by source-receiver geometry, fault orientation, depth, mechanism and the relative position of individual structures with respect to the earthquake rupture. The results further demonstrate that earthquakes occurring outside the immediate valley can modify the Coulomb stress state of faults within the valley, emphasizing the importance of considering the broader western Himalayan seismotectonic system rather than treating Kashmir as an isolated tectonic domain. The combined earthquake-fault analysis highlights zones where positive Coulomb stress accumulation coincides with active fault structures and therefore provides an important framework for understanding fault interaction, stress redistribution and spatial variations in seismic potential across the Kashmir Valley.

Overall, the study demonstrates that Coulomb stress transfer provides a useful quantitative link between regional earthquake activity and the present-day mechanical state of Kashmir Valley faults. Integration of the modelled ΔCFS field with GNSS-derived deformation, strain localization, fault geometry and observed seismicity can provide a more comprehensive assessment of active deformation and earthquake hazard in the northwestern Himalaya.

Keywords: Kashmir Valley; Coulomb failure stress; ΔCFS; stress transfer; earthquake interaction; receiver faults; Main Himalayan Thrust; Balapora Fault; Gulmarg Fault; Laam Fault; Mawer Fault; seismic hazard; western Himalaya; focal mechanisms; seismotectonics.

TRACING REE AND TRACE ELEMENT SIGNATURES IN MAJOR LITHOLOGIES OF THE TATAPANI GEOTHERMAL PROVINCE, CENTRAL INDIA

Nidharshan B M[1*], Labani Ray[1,2], Pragyan Mohapatra[1], Nishu Chopra[1,2]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
*Presenting author: nidharshan2508@gmail.com

ABSTRACT

Geothermal energy is a clean, sustainable, renewable energy source with a low carbon footprint that can provide round-the-clock power. In geothermal exploration, the study of rare earth elements (REEs) and trace elements provide important insights into hydrothermal processes, provenance, tectonic setting, and radioelement enrichment. This study investigates the behaviour of REEs and trace elements, together with petrographic observations, in major lithologies of the Tatapani Geothermal Province (TGP), for the first time.

Pegmatite exhibits relatively flat LREE patterns with slightly enriched HREE, variable Eu anomaly with negative Ce and Gd anomalies. Eu variability is related to differences in plagioclase abundance, whereas the negative Gd anomaly in sandstone and pegmatite is interpreted primarily as hydrothermal water-rock interaction rather than solely the REE tetrad effect, supported by proximity to the Tatapani hot spring and alteration in pegmatite. Negative Ce anomaly indicates an oxidizing environment during late-stage hydrothermal evolution. Rb vs Y + Nb and Nb vs Y plots indicate a syn-collisional setting, while Pb enrichment and Nb depletion suggest a subduction-related component. Granite gneiss shows enriched LREE, nearly flat HREE pattern, and a negative Eu anomaly. Similar trace-element characteristics suggest that granitic gneiss may represent the source or precursor of pegmatite. Positive U, Th and Zr (except few) anomalies indicate enrichment of accessory minerals hosting heat-producing elements, supported by petrography. Sandstone indicates a predominantly felsic provenance based on Cr/Th, La/Sc and Th/Sc ratios, while Th/Sc–Zr/Sc plot suggests an active-margin setting. This study records andalusite hornfels in the region for the first time. Its mineralogy indicates a pelitic protolith subjected to contact metamorphism under Hornblende hornfels facies. Enriched LREE, flat HREE, positive Ce, and Pb–Zr–Th–U enrichment suggests heat-producing accessory minerals contributing to the radiogenic heat budget. Thus, the integrated approach of REE, trace-element geochemistry, and petrography, provides insights into element mobility, tectonic evolution, hydrothermal alteration, and heat source characterization in the TGP.

Keywords: Rare earth elements; Trace elements; Hydrothermal alteration; Heat-producing elements; Petrography; Tatapani Geothermal Province.

MAGNETIC FABRIC AND SEDIMENTARY DEFORMATION ALONG THE DHUBRI FAULT, NORTHEAST INDIA: PRELIMINARY INVESTIGATIONS

P. Nidhin[1,2], Mujahed Baba[1,3], Pratikshya Behera[1], Manan Singh[1], B.V. Lakshmi[1], K. Deenadayalan[1], P. S. Sunil[2]
[1]Indian Institute of Geomagnetism, New Panvel, Navi Mumbai 410 218,
[2] Department of Marine Geology & Geophysics, School of Marine Sciences,
Cochin University of Science and Technology, Kochi 682016, Kerala
[3] Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon, 425001,
Presenting author: nidhinp.geo@gmail.com

ABSTRACT

The Dhubri Fault is a major tectonic structure in northeastern India and an important zone of deformation along the western Shillong Plateau. However, the nature of deformation preserved in sediments adjacent to the fault remains poorly constrained. Deformed sediments without visible structures are difficult to use for reconstructing tectonic history. Here, we present preliminary results of an anisotropy of magnetic susceptibility (AMS) study located close to the Dhubri Fault in the Sillong Plateau, Assam, NE India. AMS provides a sensitive tool for identifying subtle sedimentary fabrics and post-depositional deformation. Rock magnetic experiments show that haematite is the carrier of the magnetic signal, so the fabric is stable and preserved. The susceptibility ellipsoids are oblate, with sub-horizontal maximum axes (K_1) defining the magnetic lineation and near-vertical minimum axes (K_3) forming the poles to the magnetic foliation. This geometry reflects an original depositional fabric with an incipient tectonic overprint. K_1 trends ENE-WSW, and stress inversion gives a NNW-SSE σ_1 (maximum compressional stress axis) and an ENE-WSW σ_2 (minimum horizontal compressional stress

axis), while strain inversion gives an ENE-WSW ε_1 (maximum extensional strain axis) and a NNW-SSE ε_2 (minimum horizontal extensional strain axis). K_1 coincides with both ε_1 and σ_2, indicating that shear under the tectonic regime reoriented the magnetic grains. These findings show that AMS can record strain and constrain deformation patterns even in sediments that appear undeformed.

AMORTIZED UNCERTAINTY QUANTIFICATION IN TRANSIENT ELECTROMAGNETIC SOUNDING INVERSION USING DEEP LEARNING

Nimatullah[1], Kuldeep Sarkar[1], Pankaj K. Mishra[2] and Anand Singh[1]
[1]Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai 400076, India
[2]Geological Survey of Finland (GTK), Espoo, Finland
Presenting author: nimatullahkhan24@gmail.com

ABSTRACT

Layered-earth interpretation of transient electromagnetic (TEM) data is still dominated by deterministic 1D inversion schemes that return a single resistivity profile, giving practitioners no formal way to judge how tightly individual layers are actually constrained. A rigorous alternative is to treat the problem as Bayesian inference, but the Markov chain Monte Carlo (MCMC) samplers normally used for this purpose are far too slow to run on the thousands of soundings collected in a typical modern survey. This work explores a deep-learning route around that bottleneck: a conditional normalizing flow is trained to map paired low-moment and high-moment TEM measurements directly onto the posterior distribution of a 25-layer resistivity model, so that once training is finished, an entire posterior can be produced for any new sounding in a single forward pass, with no per-sounding optimization loop required. Training data consist of 50,000 model-response pairs drawn from a wide, geologically informed prior and simulated with an open-source 1D electromagnetic forward solver, with realistic multiplicative log-Gaussian noise (approximately 3% relative error) injected to mimic field conditions. Evaluated on an independent synthetic test set, the trained flow reproduces the true resistivity with a posterior-median R^2 of 0.871 and an RMSE of 0.208 in $\log_{10}\ \Omega\cdot$m, and its predicted uncertainty grows with depth in close agreement with a physics-based estimate of the depth of investigation, even though no depth information was supplied during training. A simulation-based calibration check further shows that the posteriors are not just narrow but genuinely trustworthy, with the nominal 68% and 95% credible intervals achieving empirical coverages near 70% and 96%. When the trained model is applied to two field TEM datasets, its posterior medians and credible bounds track an independently obtained smooth (SPIA) inversion closely down to each sounding's estimated depth of investigation, after which the two diverge gradually rather than abruptly. Taken together, these findings indicate that a single trained normalizing flow can substitute for expensive sounding-by-sounding Bayesian sampling while still matching established smooth-inversion software on real data.

Keywords: Transient electromagnetic method, Bayesian inversion, conditional normalizing flow, uncertainty quantification, deep learning, depth of investigation.

PHYSICS-GUIDED NEURAL NETWORK APPROACH FOR 2-D MAGNETIC SUSCEPTIBILITY IMAGING OF COMPLEX MULTI-SOURCE STRUCTURES

Nimatullah, Kuldeep Sarkar, Shreya Maurya, and Anand Singh
Department of Earth Sciences, Indian Institute of Technology Bombay, India
Presenting author: naimatullah1804@gmail.com

ABSTRACT

Two-dimensional (2-D) magnetic inversion aims to recover subsurface magnetic susceptibility distributions from measured total-field magnetic anomalies. Because the inverse problem is intrinsically non-unique, conventional approaches based on iterative optimisation with regularisation can have difficulty resolving multiple neighbouring magnetic sources with different susceptibilities. In particular, overlapping anomalies may cause regularised inversions to smooth adjacent bodies or combine them into a single diffuse feature, reducing the clarity of recovered geological boundaries. Here, we present a physics-guided deep learning (PGDL) framework that integrates a U-Net convolutional neural network (CNN) with the magnetic forward operator. The proposed loss function combines a model-space reconstruction term with a physics-based data misfit, thereby constraining the predicted susceptibility model to reproduce the observed magnetic response. A synthetic dataset comprising 200,000 two-dimensional forward models was generated to represent a broad range of geological configurations, including tilted bodies, intrusive structures, fault-related geometries, and multiple interacting sources. Of these models, 120,000, 40,000, and 40,000 were assigned to training, validation, and testing, respectively. Evaluation on the independent test set gives model-domain coefficients of determination (R^2) of 0.930–0.953 for the PGDL predictions. In comparison, conventional SimPEG L2 (Tikhonov) inversion achieves very high data-domain fits ($R^2d \geq 0.996$), but its recovered models commonly exhibit boundary smearing and deviations in susceptibility amplitude. The proposed framework was further evaluated using field magnetic observations from two profiles across the banded iron formation belt of eastern Rajasthan, India. The PGDL results provide clearer separation between adjacent susceptibility bodies and sharper structural boundaries than the corresponding regularised least-squares solutions, while retaining consistency with the measured magnetic anomalies. These results demonstrate the potential of physics-guided deep learning as an efficient inversion strategy for complex magnetic settings where conventional regularisation may compromise the resolution of closely spaced susceptibility structures.

INTEGRATED GRAVITY–MAGNETIC STUDY FOR DELINEATION OF SHALLOW CRUSTAL ARCHITECTURE ACROSS THE SONRAI–MADAWARA SECTOR, SOUTHERN BUNDELKHAND CRATON INDIA

Niranjan P Sankar, Ananya Parthapradip Mukherjee and Animesh Mandal
Department of Earth Sciences, Indian Institute of Technology Kanpur
Presenting author: npshankar25@iitk.ac.in

ABSTRACT

The Sonrai–Madawara sector in the southern Bundelkhand Craton, Lalitpur district, Uttar Pradesh, represents a structurally complex craton–basin transition where the Archaean Bundelkhand Gneissic Complex, Palaeoproterozoic Bijawar Group and overlying Vindhyan Basin converge with the Madawara Igneous Complex between the Madawara–Karitoran and Sonrai–Girar shear zones. Much

of this architecture is concealed beneath Vindhyan sediments and alluvium, making integrated geophysical imaging essential for understanding the subsurface configuration. This study integrates ground gravity and magnetic data to delineate concealed lithological boundaries, structural discontinuities and intrusive bodies. The complete Bouguer anomaly ranges from approximately −64.8 to −22.6 mGal, revealing a broad regional SW-NE trending high-to-low anomaly gradient associated with significant subsurface density variations. Regional–residual separation and first vertical derivative enhancement identify localized anomalies and prominent linear–curvilinear trends of high-to-low transitions, interpreted as buried faults, contacts and shear-related structures. Gravity spectral analysis indicates dominant source depths of approximately 3.2, 1.2 and 0.4 km, representing deep to shallow density interfaces. The total magnetic anomalies range from approximately −401 to +455 nT. Reduction-to-pole transformation deciphers high magnetic anomaly domains that are coincident with high residual gravity anomaly zones. These zones are inferred to be associated with mafic–ultramafic rocks, dyke-like bodies and their concealed extensions as well as volcanic rocks of the Bijawar group. Magnetic spectral analysis indicates predominantly shallow sources at approximately 1.4, 0.5 and 0.3 km, while Euler deconvolution resolves clustered magnetic sources spatially associated with major structural trends and intrusive domains. The combined gravity–magnetic study provides a coherent subsurface framework for the Sonrai–Madawara sector, highlighting the concealed structural boundaries and the subsurface continuity of intrusive bodies across the craton–basin transition. The results provide an important geophysical basis for constructing an integrated shallow-crustal model of the southern Bundelkhand Craton and for understanding the tectono-magmatic architecture of the region.

CRUSTAL THERMAL STRUCTURE OF THE BUNDELKHAND CRATON, CENTRAL INDIA: CONSTRAINTS FROM SURFACE HEAT FLOW AND 2-D CONDUCTIVE THERMAL MODELLING

Nishu Chopra[1,2,*], Rosemary Sunny[1], Labani Ray[1,2], S.P. Singh[3]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India
[3]Dept. of Geology, Institute of Earth Sciences, Bundelkhand University, Jhansi-284128, India
*Presenting author (Email- nishuchopra.ngri@csir.res.in)

ABSTRACT

Surface heat flow is a key parameter for characterizing the thermal regime of the Earth and is the product of geothermal gradient and thermal conductivity of the representative rocks. In the present study, surface heat flow is determined from temperature measurements in boreholes at 21 locations across the Bundelkhand Craton in central India. The calculated surface heat flow, radiogenic heat production, and temperature–pressure-dependent thermal conductivity are used to construct 2-D steady-state conductive thermal models to better understand the crustal thermal structure of the study region.

The geothermal gradient shows considerable spatial variation across the Bundelkhand Craton, whereas thermal conductivity measurements of 42 representative rock samples show minor variation among the studied lithologies. The surface heat flow varies across the Northern, Central, and Southern regions of the Craton, with comparatively higher values in the Central region. The high surface heat flow in the

Central region may reflect the influence of deep-seated magmatism associated with carbonatite and alkaline rocks, together with other geological and tectonic heterogeneities. The 2-D thermal model shows significant lateral variations in Moho temperature, highlighting the influence of crustal composition and thermal properties on the subsurface thermal regime. The calculated Moho temperatures are broadly comparable to those reported for stable Archaean cratons worldwide, suggesting that the Bundelkhand Craton exhibits a thermal regime characteristic of ancient stable shields. The results show that improved spatial coverage of surface heat flow measurements, together with temperature-pressure-dependent thermal conductivity, is essential for better constraining the crustal thermal structure and deep-crustal temperatures.

Keywords: Geothermal gradient; Thermal conductivity; Surface heat flow; Thermal modelling; Bundelkhand Craton.

EMPIRICAL MODELING OF CUMULATIVE INTENSITY MEASURES FROM REGIONAL SEISMICITY IN THE UTTARAKHAND HIMALAYA

Nitin Sharma[1,2]*, Mangalampally Ravi Kumar[1] , Raman Vijaya Raghavan[1] and Prakash Kumar[1]
[1]CSIR- National Geophysical Research Institute, Hyderabad, 500007, India
[2]Academy of Scientific & Innovative Research(AcSIR), Ghaziabad, Uttar Pradesh – 201002, India
*presenting author email: withnitin@gmail.com

ABSTRACT

We develop empirical models for Arias Intensity (Ia), Cumulative Absolute Velocity (CAV), and significant duration (D5–95) using strong-motion records from small-to-moderate earthquakes in the Uttarakhand Himalaya. The dataset comprises records from 86 shallow earthquakes with moment magnitudes (Mw) of 3.0–5.5 and hypocentral distances of 4.3–270.5 km. The developed models describe how Arias Intensity (Ia), Cumulative Absolute Velocity (CAV), and significant duration (D5–95) vary with earthquake size, source-to-site distance, and site characteristics. They also quantify the variability associated with these ground-motion measures and investigate the potential influence of station elevation. The results show that significant duration is more strongly influenced by source-to-site distance than earthquake size. A strong correlation is observed between Arias Intensity (Ia) and Cumulative Absolute Velocity (CAV), indicating similar trends in their response to earthquake ground motion. The proposed models provide regional estimates of cumulative ground-motion characteristics and contribute to improved seismic hazard assessment in the Uttarakhand Himalaya.

CHARACTERIZING CRUSTAL ANISOTROPY ALONG THE KABAW FAULT USING LOCAL EARTHQUAKE SHEAR-WAVE SPLITTING ANALYSIS

Nitish Kumar Tiwari[1], Niptika Jana[1],*, and Arjun[1]
[1] Indian Institute of Technology (Indian School of Mines) Dhanbad, Department of Applied Geophysics, Dhanbad, 826004, India
nitpkj@iitism.ac.in, niptika.jana.1201@gmail.com

ABSTRACT

We present a shear wave splitting analysis of 439 high-quality local earthquake measurements from a 71 station broadband seismic network operated across the Kabaw and Sagaing fault zones of Central

Myanmar (July 2016-February 2018), aimed at characterizing crustal anisotropy along this segment of the Indo-Burman plate boundary. Fast polarization directions (FPDs) and delay times (δt) were obtained using the Multiple Filter Automatic Splitting Technique (MFAST) and combined with existing shear-wave velocity (Vs) models along three profiles (A–A′, B–B′, C–C′) spanning the Indo-Burman Ranges, the Central Myanmar Lowland, and the Sagaing Fault. Anisotropy strength (A%) averages approximately 1.5% regionally but varies laterally and with depth, generally coinciding with a mid-crustal low-velocity zone (LVZ) interpreted as a mechanically weak layer. Zones of elevated anisotropy (up to ~3%) are concentrated in the upper-to-intermediate crust near the Kabaw and Sagaing faults, while FPDs rotate systematically along strike rather than following a simple depth trend. These results suggest that crustal deformation beneath Central Myanmar is spatially heterogeneous, controlled jointly by active fault geometry, inherited crustal fabric, and fluid-assisted weakening within the Indo-Burman subduction system.

FINITE-DIFFERENCE MODELLING OF 2D ACOUSTIC WAVES: NUMERICAL DISPERSION IN HOMOGENEOUS MEDIA AND WAVEFIELD EFFECTS OF A FAULT ZONE

Naresh Pachipala[1,2]*, Biswajit Mandal[1,2], Prakash Kumar[1,2]
[1] CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500007, India
[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
*Corresponding author:Email: nareshyadav0403@gmail.com

ABSTRACT

The finite-difference (FD) method is one of the most widely used techniques for simulating seismic wave propagation, valued for its simplicity, computational efficiency, and ability to handle complex velocity models for which no analytical solution exists. This study implements a two-dimensional FD scheme for the constant-density acoustic wave equation and applies it to homogeneous and heterogeneous media. In the homogeneous case, a second-order (3-point) scheme was validated against the analytical 2D Green's function. With adequate grid sampling, the numerical seismogram matched the analytical solution almost perfectly, and the wavefront remained circular. When the wavelength was under-sampled, strong numerical dispersion appeared: amplitudes were distorted, an oscillatory tail followed the main arrival, and the error was direction-dependent, strongest along the grid axes and weaker along the diagonals. This grid anisotropy is a numerical artifact, since the medium is physically isotropic. In the heterogeneous case, a fourth-order (5-point) operator was applied on a 200 × 200 grid (dx = 10 m) containing a vertical low-velocity zone, representing a fault zone, with velocity 20% below the 3000 m/s background. Energy was trapped and slowed inside the zone, and seismograms recorded above it showed much larger amplitudes than those outside, reproducing the amplification observed over real faults. At high source frequency, oscillatory tails appeared inside the fault zone; because the grid was under-resolved, these are likely at least partly numerical dispersion, showing why grid-refinement tests are needed. Overall, FD accuracy depends on the number of grid points per minimum wavelength, the Courant stability condition, and operator order.

Keywords: finite-difference method; acoustic wave equation; numerical dispersion; grid anisotropy; heterogeneous media; fault zone; wavefield amplification; Courant criterion

MACHINE LEARNING APPLICATIONS FOR UNDERSTANDING THE COMPLEX ALLUVIAL AQUIFER SYSTEM OF THE GANGA-YAMUNA DOAB, MIDDLE GANGA BASIN, INDIA

Peela Madhu[1,2*], Payal Rani[1,2], Subash Chandra[1,2]
1. CSIR-National Geophysical Research Institute, Hyderabad, India
2. Academy of Scientific and Innovative Research, Ghaziabad, India
Corresponding author email: madhupeela1999@gmail.com

ABSTRACT

Airborne Electromagnetic (AEM) data were acquired in parts of the Ganga-Yamuna Doab (GYD), Middle Ganga Plain, Uttar Pradesh to unravel the complexities of the aquifer system in terms of lithology, structural settings, groundwater pathways and hydrogeological connectivity. Translation of AEM resistivity data into lithological and hydrogeological parameters is an essential part that is mostly carried out manually by comparing AEM resistivity with borehole data. The AEM surveys provide large-scale resistivity data, whereas borehole data provide precise lithology information but at a point scale in a discrete manner. Besides the huge set of AEM data, the inherent issue of non-unique resistivity inversion and translation of resistivity into meaningful lithological and hydrogeological models is a challenging task. To address this challenge, we present a supervised machine learning framework using a random forest classifier. First, available borehole lithology logs were spatially collocated with AEM resistivity data and categorized into two hydrofacies based on hydraulic permeability: highly permeable sand hydrofacies (fine, medium, coarse sand and gravel) and low-permeability clay hydrofacies (clay and silt). The AEM resistivity was statistically analyzed to identify the dominant resistivity patterns and correlated with borehole-derived hydrofacies. Finally, these correlated data were used to train a random forest classifier and predict lithology in terms of sand and clay probabilities as well as sand and clay binary classification.

This study highlights the role of machine learning techniques in providing an automated and accurate translation of AEM geophysical data into hydrogeological parameters in the complex alluvial aquifer system with precise knowledge of permeable and impermeable layers, aquifer boundaries, and vertical and lateral heterogeneities with higher accuracy than conventional interpretation methods.

Keywords: Ganga-Yamuna Doab, Complex alluvial aquifer system, AEM Resistivity, Lithology, Hydrofacies, Machine Learning, Random Forest Classifier

ASSESSMENT OF THERMOPHYSICAL PROPERTIES AND GEOTHERMAL RESERVOIR CHARACTERISTICS OF THE TATAPANI HOT SPRING REGION, CENTRAL INDIA.

Pragyan Mohapatra*[,1], Labani Ray[1,2], Nishu Chopra[1,2], Fatima Munazza[1,2], Nidharshan B M[1], Ankita Roy[1], Sasi Kumar Uddandam[1,2], Nagaraju Podugu[1]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
*Presenting author: mohapatrapragyan5@gmail.com

ABSTRACT

Thermophysical properties of rocks, particularly thermal conductivity, density, and porosity, are key parameters governing subsurface heat transfer, fluid circulation, and thermal storage within geothermal

systems. Understanding their variations is therefore essential for characterizing subsurface thermal heterogeneity and evaluating the geothermal reservoir potential of complex geological settings. The Tatapani hot spring region in Chhattisgarh, central India, is regarded as a prominent geothermal field in the Son–Narmada-Tapti (SONATA) geothermal province and hosts active hot springs with temperatures reaching up to 98 °C. The geothermal manifestations occur near the boundary between the Chotanagpur Granite Gneiss Complex (CGGC) and Gondwana basin along the ENE-WSW trending Tatapani fault zone, where lithological and structural contrasts may strongly influence subsurface heat transport and fluid movement.

In this study, thermal conductivity, density and porosity of about 111 representative rock samples from CGGC and Gondwana were systematically investigated in the laboratory under ambient temperature conditions. The weighted-average results reveal distinct thermophysical characteristics between the two geological units. The major rock formations of the CGGC generally exhibit higher density and lower porosity, comparatively lower thermal conductivity, whereas major rock formations of the Gondwana are relatively less dense and more porous but show higher thermal conductivity. The correlation between density and porosity indicates a distinct inverse relationship for Gondwana rocks, whereas most CGGC rocks exhibit a positive trend. The differences in mineral composition and grain size primarily influence thermal conductivity, whereas differences in mineral composition and pore volume contribute to variations in bulk density and porosity. These factors, combined with the distinct lithological characteristics and geological histories along with integrated petrographic and geochemical studies in the present study contribute to the observed variations in their thermophysical properties. These findings offer critical constraints on subsurface heat transfer, thermal models, reservoir characterization and geothermal potential in the Tatapani geothermal region.

Keywords: Thermal conductivity; Density; Porosity; Chotanagpur Granite Gneiss Complex; Gondwana; Geothermal system; Reservoir characterization; Tatapani hot

UNCLOCKING CRITICAL MINERLS RESOURSES THROUGH ADVANVCES IN GEOPHYSICS

Gumpula Prasanna Rani, Dubba Vijay Kumar and G. Udhaya Laxmi
Department of Geophysics, Osmania University, Hyderabad
Email.id:prasannagumpula70@gmail.com

ABSTRACT

The global shift towards electrification renewable energy and low-carbon technologies is increasing the demand for critical minerals such as Lithium, Nickel, Cobalt, Graphite and rare earth elements. Today, minerals exploration is not only about finding where these minerals occur, but also about system-the geological structures, sources pathways and process that control their formation and concentration. In this context, geophysics plays an important role in linking surface geology with the hidden architecture of the earth surface. Different geophysical methods provide information about different physical properties of subsurface. Gravity and Magnetic methods help in identify variations in density and magnetic susceptibility, which can reveal lithological boundaries, instructive bodies, basement structures and major geological controls, Electrical and Electromagnetic methods provide information on subsurface conductive and chargeability, which can be useful for identify sulphide mineralization alteration zones and hydrothermal pathways. Seismic methods further contribute by

imagining subsurface geometry. However, geophysical anomalies are not unique and cannot be consider direct evidence of mineralization on their own. Their real value comes from integrating geophysical and petro physical information within a mineral – systems framework. Recent developments in airborne and ground – based surveys, 3D inversion joint and cooperative inversion, uncertainty analysis high – performance computing and data – driven interpretation or improving out ability to characterize concealed mineral system.

This contribution examine the evolving role of advance geophysical methods in detecting and characterizing concealed critical mineral systems, with a focus on connecting physical property variations with the geological process that control mineralization. It also highlights how integrated geophysical approach can support India's critical – mineral security and contribute to the sustainable resource base needed for the countries long term transaction a low – carbon and renewable – energy future.

Key words: Lithium,Pathways, Electrical, Electromagnetic, Chargeability, Mineralization, Susceptibility.

SEISMIC NOISE SOURCE CHARACTERISATION FOR A LOCAL NODAL SENSOR DEPLOYMENT

PSHSN Dattatreya[a*], Pratul Rajan[a,b], Biswajit Mandal[a,b], Karuppannan P[a], Prakash Kumar[a,b]
[a]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500007, India
[b]Academy of Scientific Innovation and Research (AcSIR), Ghaziabad-201002, India
*Corresponding Author E-mail: dattacss@hotmail.com

ABSTRACT

The field of ambient seismic noise has become a prominent discipline in the modern era for near-surface imaging and monitoring. Recent studies rely on ambient noise source characterisation to understand shallow features and their responses to natural and anthropogenic activities. Many studies have achieved good results by integrating unsupervised methods into characterisation or classification. In the present study, we implemented a two-step approach to characterise and classify ambient noise. We converted the waveform to frequency vs time (samples) using the Continuous Wavelet Transform (CWT) and focused on event identification: if the amplitude exceeds a particular threshold, we consider it an event. We used features such as frequency, amplitude, duration, bandwidth, azimuth, and origin time to classify noise. We examined a long and continuous dataset to identify similar events and variations in event occurrence between noisy and quiet environments. The unsupervised technique considers closely spaced (anomalous/outlier) events as clusters. To avoid this false/duplicate classification, we incorporated data reduction and modularity to reduce the data and conduct the test on each group. After classification using the unsupervised method, we identified patterns in noise sources, which were compared with footsteps, vehicle movements, train impact, seasonal noise variations, etc. This technique will be useful for site assessment as well as seismic data processing for future seismic sensor deployments in urban environments.

Keywords: Noise source characterisation, CWT, classification, attributes, quiet environment, modularity, outliers, unsupervised technique

MACHINE LEARNING-BASED DETECTION OF LANDSLIDE EVENTS USING SEISMIC WAVEFORMS

Rachna, Sandeep
Department of Geophysics, Institute of Science, Banaras Hindu University
Presenting author: studyhardly1986@gmail.com

ABSTRACT

Machine learning (ML) techniques are increasingly being applied to seismic signal analysis because of their computational efficiency and ability to identify complex patterns in large datasets. This study explores an ML-based framework for the automatic detection of landslide-generated seismic signals using waveform characteristics in the frequency domain. Approximately 350 three-component seismic waveforms associated with landslide events were collected from broadband seismic stations available through global seismic networks. Several spectral and time–frequency features, including Power Spectral Density (PSD), Short-Time Fourier Transform (STFT), and spectral entropy, were extracted from the recorded signals. These features were used to train and evaluate different machine learning algorithms, including Isolation Forest, XGBoost, and One-Class Support Vector Machine (SVM), for identifying landslide-related seismic anomalies. For independent testing, a landslide event recorded simultaneously at multiple seismic stations within a 50 km radial distance was considered. A multi-station detection framework was developed to estimate the likelihood of a common seismic anomaly occurring across multiple stations within a short time window. If the anomaly probability exceeds a predefined threshold at a sufficient number of stations, the event can be classified as a potential landslide rather than an isolated transient or background-noise signal. The performance of the different ML algorithms will be compared to identify their relative effectiveness for automated landslide detection. The proposed framework provides a basis for near-real-time, network-based landslide monitoring and can be further optimized and validated using continuous seismic data for operational early-warning applications.

CRUSTAL SEISMIC STRUCTURE BENEATH CENTRAL TIBET FROM TELESEISMIC RECEIVER FUNCTION ANALYSIS

[1]Raees C [2]Nagaraju Kanna
[1]CSIR-National Institute of Data Science & AI
[2]Pondicherry University
Presenting Author: RAEES C (craeesgeophy@gmail.com)

ABSTRACT

The Himalayan–Tibetan region represents a major continental collision zone characterized by substantial crustal deformation and thickening associated with the convergence of the Indian and Eurasian plates. In this study, we investigate the crustal seismic structure beneath Central Tibet and the adjoining Himalayan region using teleseismic receiver function analysis. Three-component broadband seismic waveform data from five stations (WT02, WT03, WT05, WT06, and WT18) were used. Teleseismic earthquakes with magnitudes greater than 5.5 and epicentral distances of 30°–90° were selected for analysis. The waveforms were processed using SAC, rotated from ZNE to ZRT, and radial receiver functions were calculated using iterative time-domain deconvolution. Receiver functions were evaluated for quality, with high-quality traces subsequently stacked in ±10° back-azimuth bins to enhance coherent converted phases. The stacked receiver functions were modelled using the rftn96 module of the Computer Programs in Seismology by comparing observed and synthetic receiver

functions and iteratively adjusting shear-wave velocity and layer thickness. The resulting one-dimensional velocity models reveal a layered crust comprising upper, middle, and lower crust, with significant lateral variations in shear-wave velocity and crustal thickness. Estimated Moho depths range from approximately 60 to 78 km, with the maximum depth observed at station WT06. The observed crustal thickening and lateral variations are consistent with the complex tectonic deformation associated with the India–Eurasia continental collision and may reflect crustal shortening, stacking, and possible underthrusting/underplating.

DEEP LEARNING-BASED AUTOMATED CLASSIFICATION OF BENTHIC FORAMINIFERA FROM PETROGRAPHIC THIN SECTIONS

Rahul Singh, Sanjay Arjun Pandit, Kumar Hemant Singh, Ravi Kant, Soutik Bhakta
Indian Institute of Technology Bombay
Presenting author: 213060019@iitb.ac.in

ABSTRACT

Accurate identification of benthic foraminifera from petrographic thin sections is essential for carbonate reservoir characterization, paleoenvironmental reconstruction, and stratigraphic interpretation. However, traditional fossil identification relies heavily on expert interpretation and manual petrographic analysis, which can be time-consuming and subject to observer variability. Recent advances in machine learning and computer vision provide new opportunities for automated fossil recognition and quantitative analysis of geological datasets.

In this study, we develop a deep learning framework for genus-level classification of benthic foraminifera using petrographic thin-section images. A dataset comprising 529 annotated images representing seven benthic foraminiferal genera was compiled for model training and evaluation. Transfer learning was applied to fine-tune four pretrained architectures: EfficientNet-B0, ConvNeXtV2, Vision Transformer (ViT), and MobileNetV3. Data augmentation techniques, including random cropping, horizontal and vertical flipping, and color jittering, were implemented to improve model generalization.

Model optimization was performed using stochastic gradient descent with categorical cross-entropy loss, and performance was evaluated using standard classification metrics including accuracy, precision, recall, and F1-score.

The models achieved strong classification performance, with ConvNeXtV2 and ViT reaching approximately 99% accuracy, while EfficientNet-B0 and MobileNetV3 achieved around 90-95% accuracy.

The proposed framework provides a reproducible approach for automated fossil recognition and scalable quantitative analysis of petrographic thin-section datasets within the field of mathematical geosciences. Its integration into petrographic analysis and reservoir modelling workflows has the potential to enhance geological consistency, improve stratigraphic resolution, and support decision-making in carbonate reservoir exploration and field development.

SEISMIC IMAGING OF THE LITHOSPHERIC STRUCTURE BENEATH THE WESTERN HIMALAYA-HINDU KUSH-WESTERN TIBET COLLISION ZONE USING AMBIENT NOISE TOMOGRAPHY

Rajendra K. Dash[1], Vivek Kumar[1], Shyam S. Rai[2]
[1]Indian Institute of Technology Bombay, Powai, Mumbai-400076
[2]Indian Institute of Science Education and Research Pune, Pune-411008
Presenting author: rkdash@iitb.ac.in

ABSTRACT

The Western Himalaya, Hindu Kush, Pamir, and Western Tibet form a complex continental collision zone where the ongoing convergence between the Indian and Eurasian plates continues to deform the crust and upper mantle. Although previous seismic studies have provided important insights into the lithospheric structure of this region, the deeper parts of the lithosphere remain poorly resolved, particularly beneath the Western Himalaya and Hindu Kush. In this study, we expand the existing seismic dataset by incorporating broadband observations from northwestern India and the western Himalaya to develop an improved regional seismic velocity model. We use both earthquake and ambient seismic noise cross-correlation to extract Rayleigh-wave signals between station pairs and obtain dispersion measurements to investigate variations in seismic velocity across the region. Currently, we are assessing data quality, processing continuous seismic recordings, performing cross-correlations, and extracting reliable dispersion measurements for subsequent tomographic inversion. The resulting shear-wave velocity model will provide new constraints on the deeper crustal and upper-mantle structure beneath the Western Himalaya, Hindu Kush, Pamir, and Western Tibet.

LAND GRAVITY ANOMALIES ACROSS THE GANGA PLAIN AND GEODETIC UPLIFT RATES OF THE HIMALAYAN FRONTAL THRUST IN THE DEHRADUN RE-ENTRANT: HEIGHT CORRECTIONS USING GLOBAL AND GRAVIMETRIC GEOIDS

***Rajesh S[1,2] and Param K. Gautam[2]**
1. Indian Institute of Science Education and Research (IISER), Berhampur, Odisha
2. Wadia Institute of Himalayan Geology, Dehradun, Uttarakhand
*rajesh@iiserbpr.ac.in

ABSTRACT

Global static geoid datum, like EGM2008, is widely used to compute the Orthometric heights from the GNSS-RTK based ellipsoidal height measurements. The existing global gravity data hardly show any signatures of tectonically active Himalayan Frontal Thrust (HFT). The under-represented gravity signatures of HFT in such data sets often lead to the interpretation that HFT is a topographic expression and not a basement high; although, studies suggest frontal deformation can cause uplift of the basement. To understand this, an integrated land gravity-GNSS-RTK survey was carried out along a 100 km long profile taken from the Ganga Plain in the Frontal Himalaya to the Mussoorie Hills in the Lesser Himalaya across the Dehradun re-entrant by the standard leap-frog method.

In this work three computed regional gravimetric geoids, namely 1) IndGG-CUT2021 2) IndGG-SH2021 and 3) IndGG-LSMSA2021 are used, besides EGM2008 geoid to correct the GNSS-RTK based ellipsoidal heights to the Orthometric heights. The global EGM2008 model is obtained by using the fully expanded spherical harmonic solution coefficients up to degree and order 2160. The discrepancies between the gravimetric geoids are very low (<1 cm). Discrepancies in the computed

local orthometric heights with respect to the global model varies from 75 to 95 cm in elevated regions. Apart from Bouguer spherical cap correction, the Complete Bouguer Anomaly (CBG) is also computed through full scale topographic correction on the free air anomaly with Bullard-C correction. The BG anomaly varies from -125 mGal in the Gangetic plane to -167 mGal, and over the Shiwalik high it is around -145 mGal. The CBG anomaly varies from -155 mGal in the planes to -172 mGal towards the elevated region. Integrated results from the BG and the CBG anomalies, combined with the geodetic uplift rate (~7 mm/yr), show that the HFT is not only a topographic high but also a basement high with a positive gravity expression that developed as part of the ongoing deformation along the Himalayan frontal arc.

GEOPHYSICAL INVESTIGATION FOR SEEPAGE ASSESSMENT IN AN EARTHEN DAM

Rakesh Nikam*, G.D.Naidu, and Suneetha Naidu
Central Water and Power Research Station, Pune-411024
Email: rakeshnikam.earth@gmail.com

ABSTRACT

Seepage through an earthen dam and its foundation is a major concern for dam safety, as it can lead to internal erosion, voids, and progressive weakening of the embankment. Identifying seepage zones and their possible pathways is therefore important for evaluating the condition of the dam and planning suitable remedial measures. In the present study, geophysical investigations were carried out at various earthen dams to assess subsurface conditions and identify zones affected by seepage. Electrical Resistivity Tomography (ERT) was used to investigate variations in subsurface resistivity along selected profiles across the dam body, downstream area, and foundation. The resistivity sections were interpreted based on the contrast between relatively dry and saturated materials and were correlated with available geological and site-condition information. Low-resistivity zones observed at different locations were interpreted as possible seepage-prone zones. The results helped in identifying the probable locations and extent of seepage within the embankment and its foundation. The study demonstrates the usefulness of electrical resistivity surveys as a non-destructive method for identifying the distressed zones which are prone to seepage through earthen dams. The findings can provide useful inputs for dam safety assessment, continuous monitoring, and selection of appropriate measures for controlling seepage.

Keywords: Earthen Dam, Seepage zones, Electrical Resistivity Tomography

SEISMIC NOISE AND SITE CHARACTERISATION IN THE LADAKH-KARGIL REGION: IMPLICATIONS FOR EARTHQUAKE SOURCE QUANTIFICATION

Ransom Vasanth[1], Naresh Kumar[1,] Devajit Hazarika[1,]
[1] Wadia Institute of Himalayan Geology, 33, GMS Road, Dehradun 248001, India.
Presenting author: ransom@wihg.res.in

ABSTRACT

We assess the spectral characteristics of seismic noise across the Ladakh-Kargil region and its spatio-temporal variability over a broad frequency range. Evaluating background noise is essential for determining the detection capability of local seismic networks. It is additive and helps us understand

site effects in the tectonically active regions of the Himalaya and Trans-Himalaya. We use continuous broadband data from 10 stations operating over three years (2023-2026). The analysis covers 0.01 to 18 Hz, encompassing primary and secondary microseisms as well as high-frequency cultural and local environmental noise. Power Spectral Density (PSD) is estimated for three-component data at each station, and the corresponding PDFs are computed. The data also utilized for site characterization based on the Horizontal-to-vertical spectral ratios along with seismic attenuation classification. Using this multi-year dataset, we aim to: (i) characterize the baseline noise power spectra of the remote and within cultural noise stations(ii) investigate natural and anthropogenic spatio-temporal variations at different central frequencies (iii) enhance the data suitability by earthquake source characterization based on the spectral response in specific frequencies and (iv) develop a mechanism through noise reduction by utilizing the pattern of environmental and cultural noise for the enhancement of earthquake source quantification for this high-elevation cold-desert terrain Further data utilization is aim local earthquake source parameters, to study the spatio-temporal distribution of the regional stress field, linking noise, source properties and stress to the seismotectonic setting of Ladakh-Kargil.

Keywords: Seismic Noise, Source Characterisation, Spatio-Temporal Stress Distribution, Power Spectral Density (PSD), Ladakh-Kargil Region

AN ADAPTIVE MACHINE-LEARNING CONSENSUS FRAMEWORK FOR AUTOMATED WINDOW SELECTION IN MAGNETOTELLURIC DATA PROCESSING

Reegan Raj I[1,2*], Prasanta K. Patro[1,2]
[1]CSIR-National Geophysical Research Institute, Hyderabad, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India
Presenting author: reeganraj1001@gmail.com

ABSTRACT

Magnetotelluric (MT) data processing is a critical step in identifying and rejecting noise-contaminated time windows prior to robust averaging. Different software packages have been developed for this purpose, including SigMT, a recently developed MT processing package. The default processing in SigMT relies on a Mahalanobis-distance criterion applied to each frequency band, which can also reject potentially useful impedance estimates. To address this limitation, we present a machine-learning-based quality-control framework that replaces the single criterion with a four-method consensus comprising DBSCAN density clustering, Isolation Forest anomaly detection with a self-calibrating contamination parameter derived from the DBSCAN inlier fraction, Mahalanobis distance in a reduced four-feature subspace selected to minimize collinearity, and electric-magnetic coherence. A time window is retained when at least three of the four methods agree. In addition, a density-aware cluster gate is applied in genuinely multi-modal bands to identify cases where the consensus methods alone may be insufficient. The parameters were evaluated across multiple field sites rather than adopted solely from fixed assumptions. The proposed method produced more stable impedance results than the default processing and retained useful data in frequency bands where coherence alone rejected the data. The resulting improvement in impedance estimation produced more stable apparent resistivity and phase responses across frequency. The proposed framework provides an adaptive approach for automated quality control in MT data processing. We have applied this new approach to the real field data, when compared with the conventional method, the new results shows an improved S/N ratio.

CRUSTAL SEISMIC IMAGING ALONG JODIA-ANSADOR PROFILE OF SAURASHTRA BASIN USING WIDE-ANGLE SEISMIC DATA

Renuka Kolluru*, Laxmidhar Behera, Prakash Kumar
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500007
* E-mail: renukak.ngri@csir.res.in

ABSTRACT

The Saurashtra basin of western India is considered as an important region of the Deccan Volcanic Province (DVP) having complex tectonic settings with large exposures of Deccan basalts (Trap) due to Late Cretaceous Deccan volcanism. To understand the complex tectonic settings and obtain the crustal structure of the basin along with the Moho configuration, we have employed 2-D ray-trace inversion of wide-angle seismic data along the 180 km long NW-SE trending Jodia-Ansador seismic profile. The 2-D P-wave velocity model (V_P) derived along the seismic profile using both refraction and wide-angle reflection phases show highly heterogeneous and complex geological setting with presence of thick low-velocity-layer (LVL) Mesozoic sediments entrapped by two high-velocity-layers (HVL) as Deccan Traps and older Mesozoic volcanics. Below the Mesozoic volanics, the basement is highly undulated and faulted forming horst and graben structures. In the mid-crust, we have delineated a thick (2-3 km) low-velocity-zone (LVZ) of 6.0 km/s velocity is entrapped with fluids due to metasomatism. The crust is affected by the presence of thick (8-10 km) high-velocity (7.3-7.4 km/s) underplated layer in base forming the lower-crust followed by significant Moho upwarping (36-40 km) near Rajkot in the center of the profile. The crustal velocity model is further constrained and corroborated by density model from the inversion of Bouguer gravity data. The Moho depth and other crustal structural features have been correlated with passive seismic modeling such as receiver-function (RF) studies of this region. The Moho upwarping, magmatic underplating and significant basaltic intrusions forming Deccan Traps with magmatic fluids entrapped in the mid-crust as LVZ indicate complex tectonic activity related to Late Cretaceous (~65 Ma) Deccan volcanism.

Key-words: Wide-angle seismic data, Ray-trace inversion, DVP, Magmatic underplating, Moho, Saurashtra basin

IMAGING THE CRUST AND UPPERMOST MANTLE BENEATH NORTHEAST INDIA AND THE INDO-BURMA SUBDUCTION ZONE USING RAYLEIGH-WAVE TOMOGRAPHY

Ritwik Mandal 1# and Satish Maurya 1
1Applied Seismology Lab, Department of Earth Sciences, Indian Institute of Technology Bombay
23d0466@iitb.ac.in

ABSTRACT

Convergence of the Indian plate with the Eurasian plate and Burma microplate has produced substantial crustal deformation across Northeast India and the Indo-Burma subduction zone. The transition from continental collision along the eastern Himalaya to subduction beneath the Indo-Burma Ranges is characterised by strong lateral variations in crustal thickness, sedimentary architecture and lithospheric geometry. We investigate these variations using nearly 25,000 Rayleigh wave group velocity dispersion curves spanning periods of 5-80 s, with sensitivity to the crust and uppermost mantle. Dense multi-azimuth ray path coverage yields a lateral resolution of approximately 60 km in

well-sampled regions. We employ a two-stage inversion framework. First, path-averaged dispersion measurements are regionalised to estimate isotropic group-velocity distributions and azimuthal anisotropy. Local isotropic dispersion curves are subsequently inverted within a Bayesian framework to obtain a three-dimensional shear-wave velocity (Vs) model. The model resolves pronounced structural contrasts between sedimentary basins and adjoining basement blocks. Beneath the Bengal Basin, low shear-wave velocities delineate an effective sedimentary thickness of approximately 12-18 km overlying comparatively thin crystalline crust. The Shillong Plateau forms a distinct uplifted crustal block, while the Mikir Hills show evidence of strong crustal and upper-mantle deformation. Northward deepening of the high-velocity uppermost mantle indicates crustal thickening associated with Indian plate underthrusting beneath the eastern Himalaya. The Central Myanmar Basin exhibits a laterally narrower low-velocity sedimentary sequence, approximately 10-15 km thick. Beneath the Indo-Burma Ranges, reduced velocities persist into the middle crust and are interpreted to reflect deformed accretionary material, crustal fracturing and possible forearc hydration. A deeper high-velocity body ($Vs > 4.0$ km s^{-1}), dipping eastward beneath the Indo-Burma Ranges and northward beneath the eastern Himalaya, is interpreted as the subducting Indian lithosphere. Near 96°E, between 24°N and 27°N, a low-velocity zone extends to approximately 60-65 km depth and disrupts the lateral continuity of the high-velocity lithosphere. This anomaly is consistent with localised tearing hypothesis, but does not independently demonstrate an open slab window. Earthquake hypocenters concentrate along low-to-high-velocity transitions and within the deeper high-velocity body, supporting an association between active seismic deformation and Indian plate subduction.

AEROMAGNETIC EVIDENCE FOR FAULTS AND SHEAR ZONES IN THE PAMIDI-ANANTAPUR REGION, EASTERN DHARWAR CRATON, SOUTH INDIA

R.K. Kishore*, S. Parveen Begum, K. Satish Kumar, M. Prasanthi Lakshmi, H.V.S. Satyanarayana
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad, India
email: kishore_rayudu.ngri@csir.res.in, kishorerayudu@gmail.com

ABSTRACT

In the present study, aeromagnetic data from the Pamidi-Anantapur region of Archean-Paleoproterozoic Eastern Dharwar Craton (EDC) were analyzed to map faults and shear zones and investigate their association with geological formations and structurally controlled mineralization. Aeromagnetic data are particularly useful for identifying faults and shear zones because these structures may produce linear discontinuities, displaced anomalies, or contrasting magnetic signatures associated with lithological contacts, structural offsets, variations in magnetic mineral content. The interpreted aeromagnetic lineaments predominantly trend NW-SE, ENE-WSW and E-W, are considered to represent major structural discontinuities and localized zones of deformation. The NW-SE trending Ragulapadu, Yeguvapalli, Garladinne, and Chitrachedu faults and their associated shear zones, together with E-W and ENE-WSW trending magnetic lineaments that cross-cut the major NW-SE structures, define the principal structural framework of the study area. Quantitative depth estimates derived from spectral analysis, Euler deconvolution, and 2D and 3D modelling indicate that the magnetic sources associated with these structures predominantly occur at depths of approximately 200–500 m below the surface. The inferred shear zones and faults suggest that the known gabbroic anorthosite bodies at Ramdaspeta and Kotanka are spatially associated with E-W trending splay faults and fracture systems developed

across the major NW-SE trending fault lineaments. These structural relationships suggest that the interpreted fault and shear-zone network may have influenced the emplacement of intrusive bodies and may also have played a role in controlling structurally controlled mineralization in the study area.

Keywords: Aeromagnetic, Eastern Dharwar Craton (EDC), Shear zones and faults

INTEGRATED GEOPHYSICAL CHARACTERIZATION OF THE KOPILI FAULT ZONE AND ADJOINING REGIONS, NORTH-EAST INDIA

Rohit K Jha, Awadhesh K Prasad, Laxminarayana, M., Anand.S.P.
Indian Institute of Geomagnetism, Navi Mumbai
Rohit.jha@iigm.res.in

ABSTRACT

The Kopili Fault zone in northeast India is a major NW-SE trending tectonic feature between the Shilong plateau and the Mikir hills, bounded by the Brahmaputra River to the north and the Barapani Shear Zone (BSZ) to the south. To understand its subsurface structure, ground magnetic surveys were carried out north and south of the Brahmaputra River and across the Kopili fault zone, with about 1,500 stations at an average spacing of 3 km. The resulting magnetic anomaly map clearly delineates the NW–SE trending Kopili Fault and traces the northeastward extension of the BSZ. Distinct magnetic highs between the Brahmaputra River and the BSZ indicate the presence of Archean gneiss beneath alluvial cover, while subdued anomalies north of the river and south of the shear zone suggest lithological variations and/or structural displacement, possibly associated with a downthrown block. Three-dimensional voxel magnetic inversion indicates that magnetic source bodies north of the Brahmaputra River occur at greater depths than those to the south. Gravity inversion gives an average Moho depth of ~36 km, with crustal thickening toward the north and east and a shallower Moho (~32 km) beneath the central Shillong Plateau. Density inversion modeling further highlights subsurface heterogeneities, providing insights into crustal architecture and tectonic segmentation across the Kopili Fault zone and adjoining regions.

GAMMA RAY LOG-BASED ESTIMATION OF SUBSURFACE THERMAL CONDUCTIVITY: VALIDATION USING LABORATORY MEASUREMENTS FROM THE GODAVARI BASIN, INDIA.

Rosemary Sunny *[1], Nishu Chopra[1,2], Labani Ray[1,2], Ankit Singh[3], Manju S[3], B M Nidharshan[1]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
[3]Geological Survey of India, Hyderabad-500068, India
*Presenting author: rosemarysunny62646@gmail.com

ABSTRACT

The transition towards clean and carbon-free energy has increased interest in geothermal energy as a reliable and continuous source of renewable power. Effective assessment of geothermal resources requires a robust understanding of subsurface thermal properties, particularly thermal conductivity, which directly influences heat flow estimation and the evaluation of geothermal potential. It has significant applications in geothermal exploration, basin modelling, geodynamic studies and the characterization of subsurface thermal regime.

Although thermal conductivity is commonly determined through laboratory measurements on core samples, the unavailability of cores or the lack of suitable samples for laboratory measurement can constrain such measurements. In such cases where core samples are scarce, gamma-ray log data can be used as an alternative to estimate thermal conductivity to obtain a continuous subsurface thermal conductivity profile.

In the present study, the gamma-ray log data is used to estimate rock thermal conductivity from the Godavari Basin, India, where the studied formations are predominantly composed of sandstone and shale. Empirical relationships are applied to gamma-ray responses to generate continuous thermal conductivity profiles along the boreholes. The reliability of the log-based estimates is evaluated against independent laboratory measurements of representative core samples using the Optical Scanning method under saturated conditions at ambient temperature. The comparison shows a close correspondence between the estimated and measured thermal conductivity, with differences generally within 10%. This strong agreement falls within the uncertainty limit of any direct measurement method. Such log-based approach can therefore provide a useful means of estimating continuous subsurface thermal conductivity profiles, particularly in sedimentary basins where well-log data are readily available but intact core samples are difficult to obtain.

Keywords: Thermal conductivity; Petrophysical Well log; Gamma-ray log; Volume fraction of shale; Godavari basin.

APPRAISAL OF SHALLOW SUBSURFACE STRUCTURES USING MASW TECHNIQUE ACROSS KANDIVALASA RIVER-ANDHRA PRADESH

S. Trupti*, P. Pavan Kishore, K.N.S.S.S. Srinivas, G. Vasudevan, D. Mysaiah and H.V.S. Satyanarayana
CSIR-National Geophysical Research Institute, Uppal, Hyderabad-39

ABSTRACT

The paper presents an integrated study carried out for the delineation of lineaments in Vizianagaram District of Andhra Pradesh and is characterized by several lineaments and faults identified from available satellite imagery, the Seismotectonic Atlas of India (2000), and other relevant literature. The lineaments/faults may become active or undergo rejuvenation during seismic events, potentially causing secondary hazards such as liquefaction in nearby localities and surrounding areas. These hazards may pose a threat to civil engineering structures, as well as to mechanical, electrical, instrumentation, and control equipment associated with power plants and other industrial facilities. Classification and verification of lineaments based solely on surface geological investigations are not always feasible due to the presence of soil cover, agricultural cultivation, habitation, and other anthropogenic structures. Therefore, investigation of these lineaments in the shallow subsurface using geophysical methods can provide valuable insights into the subsurface geological architecture and help assess their association with structural features. In this study, Multichannel Analysis of Surface Waves (MASW) studies were carried out across one of the lineaments i.e Kandivalasa river to delineate the subsurface geological layers and investigate the presence of any associated structural features. The results of the MASW investigations were presented as two-dimensional (2D) shear-wave velocity images. The shear-wave velocity sections indicate three distinct subsurface layers. The upper layer,

characterized by shear-wave velocities of less than 400 m/s, corresponds to soft to stiff soils and exhibits a variable thickness of approximately 10–20 m. The second layer, with shear-wave velocities ranging from 400 to 600 m/s, is interpreted as compact soil and/or weathered rock and has an approximate thickness of 5 m. The third layer, characterized by shear-wave velocities greater than 1000 m/s, is interpreted as competent rock and occurs at depths of approximately 20–30 m. The MASW sections show a relatively consistent thickness of the upper layer, with no significant abrupt variations. The results do not indicate any shallow subsurface structural features that can be correlated with the mapped structural lineaments or faults along the investigated profiles to depths of approximately 30–40 m.

Key words: lineament, MASW, shear wave velocity, liquefaction

SPATIAL DISTRIBUTION IN THE SURFACE HEAT FLOW FROM THE CHOTANAGPUR GRANITE GNEISS COMPLEX, EASTERN INDIAN SHIELD: IMPLICATIONS FOR GEOTHERMAL ENERGY EXPLORATION IN SONATA GEOTHERMAL PROVINCE

Sandeep Kumar Prajapati[1,2,*], Labani Ray[1,2], Nishu Chopra[1,2], Ayan Dutta[1,2], Eswara Rao Sidagam[1,2], Pragyan Mohapatra[1], Ankita Roy[1], Nagaraju Podugu[1]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
*prajapatisandeep133@gmail.com

ABSTRACT

Surface heat flow is a key parameter to construct the thermal structure and understand the geodynamic evolution of the continental crust. Here, we present first systematic estimates of surface heat flow for the Proterozoic Chotanagpur Granite Gneiss Complex (CGGC), located in the eastern part of the Son-Narmada-Tapi (SONATA) geothermal province of the Eastern Indian Shield. The study is based on the temperature-depth measurements from 37 boreholes and laboratory thermal conductivity measurements of 179 samples, including 166 solid discs and 13 borehole cuttings representing felsic and mafic lithologies in the region. Geothermal gradients are estimated from the linear sections of the temperature depth profiles, with subsequent corrections applied for topographic and paleoclimatic effects. The average surface heat flow values of the CGGC are similar to that of Aravalli and Singhbhum mobile belts. However, the results show significant spatial variability across the CGGC relative to the Damodar Gondwana basin. Relatively higher average values observed in the northwestern and northeastern part of the CGGC, whereas lower values characterize the southeastern part, with intermediate values in the northern and southern regions. This special variation is broadly associated with regional differences in lithology and radiogenic heat production, reflecting the complex metamorphic and magmatic evolution of the CGGC. The observed surface heat flow values are also broadly comparable with those reported from other Proterozoic mobile belts globally, indicating a similar heat flow regime. The present study provides a regional framework to construct the thermal structure of the CGGC and highlights its significance for evaluating geothermal potential within the SONATA geothermal province.

STUDY THE LOCAL SITE EFFECT OF KASHMIR BASIN OF NW HIMALAYA USING FINITE DIFFERENCE METHOD

Sanjay Kumar[1,2], Prakash Kumar[1,2], J.P Narayan[3], Nayeem Ahmad Bhat[2]
[1]CSIR–National Geophysical Research Institute, Uppal Road, Hyderabad-500007, India.
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India
[3] Indian Institute of Technology Roorkee, 247667
Presenting author: skglaniya23@gmail.com

ABSTRACT

The Kashmir Basin is an oval-shaped sedimentary basin with variable sediment thickness reaching depths of over 1300 m, situated at an average altitude of 1800 m above mean sea level. The basin was formed by sediments deposited by rivers originating from the rising Himalaya and is located within the thrust-faulted southern margin of the Himalayan range, between the Pir Panjal and Zaskar thrusts. Intense concentrations of damage parallel to the basin edge have been observed, attributed to the strong generation of surface waves near the basin boundary. To investigate this phenomenon, basin-induced surface waves are simulated using the finite-difference method for the Kashmir Basin. The simulation setup incorporates a uniform grid spacing in both horizontal and vertical directions, and a model domain extending beyond the basin boundaries to minimize edge effects. Absorbing boundary conditions are applied at the model edges to prevent artificial reflections, and a point source represents the seismic excitation. The seismic response is then compared with observed waveforms recorded by ten broadband stations in the North-West Kashmir Himalaya. Assuming a single soil layer within the basin, the fundamental frequency (F_0) is estimated to range from approximately 2 to 12 Hz. The low-frequency response is linked to thick, soft sedimentary deposits and a pronounced impedance contrast between the sediments and underlying bedrock, while higher frequencies are primarily observed near the basin margin and at stations situated in shallow sediment. These parameters provide valuable information for engineers and planners involved in future regional development.

Keywords: Kashmir Basin, Basin edge effect, Finite-difference, Local site effects

INTERPRETATION OF AEROMAGNETIC ANOMALIES WITH STRONG REMANENCE USING THE NORMALIZED ANALYTIC SIGNAL APPROACH

V. Pradeep Kumar, D. Seshu*, H.V.S. Satyanarayana
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500007, Telangana, India
Corresponding author: *seshugeo.ngri@csir.res.in

ABSTRACT

Interpreting magnetic anomalies is often complicated by the vectorial nature of Earth's magnetic field and the presence of remanent magnetisation, which distorts anomaly shapes and peak positions around causative bodies. These effects are particularly severe at low magnetic latitudes, where commonly used methods such as Reduction to the Poles (RTP) are mathematically unstable.

An alternative is given by the Analytical Signal (AS) amplitude, whose peak position is independent of both magnetisation direction and magnetic field inclination. Though this peak's theoretical position depends on the inclination, it only moves significantly for highly inclined geometries for most practical cases. The signal's invariance and its dependence on the depth and radius of an isolated body make it particularly useful for quantitative interpretation.

The vertical cylinder is a geologically relevant model that approximates many ore-bearing structures, such as some kimberlite pipes, volcanic plugs, or REE-hosting alkaline carbonatite intrusions with limited areal extent but significant vertical development. Its magnetic signature can be approximated by this ideal shape and the methodology is applicable to such structures.

While the peak of the AS amplitude is generally accepted to lie in the centre of a body, a closer inspection shows that a single-peaked analytical signal (i.e. R/h<1) can have its peak shifted by up to 90% of R for low inclinations (30°), while the shift for a double-peaked signal (R/h>1) is always smaller than 2% of R for any inclination. To account for this systematic shift, a correction is applied to calculate the theoretical peak centre from an estimate of the geometry and to realign the profile.

As a contribution, a full 2D inversion methodology that simultaneously retrieves the radius, top depth, and effective magnetic susceptibility of a vertical cylinder is introduced. It uses a lookup-table-based algorithm that uses ratios of multilevel widths of the normalized AS. The methodology is tested on both synthetic and real-world data and proves successful in practice as an interpretational tool for mineral exploration in low-latitude and complex magnetic environments.

Keywords: aeromagnetic, kimberlite, REE, alkaline carbonatite, analytic signal, vertical cylinder.

EMPIRICAL CHARACTERIZATION OF SEISMIC ENERGY ATTENUATION FROM LANDSLIDE SIGNALS AT MOUNT SPURR, ALASKA

Shelendra Jadon, Sandeep
Department of Geophysics, Institute of Science, Banaras Hindu University
Presenting author: shelendrajadon349@gmail.com

ABSTRACT

Landslides are widespread geological hazards in mountainous regions and can cause substantial disruption to infrastructure and communities. Landslide-generated seismic signals recorded by nearby seismometers provide useful information on their source characteristics and propagation behavior. In this study, we analyze three landslide events occurring at the same geological site near Mount Spurr, Alaska (61.2992°N, 152.2542°W), recorded at multiple stations, including N20K, SPBG, and SPBL, located within approximately 70 km of the source.

We estimate the seismic energy of the recorded signals at different source-to-station distances and investigate its frequency- and distance-dependent attenuation. An empirical energy attenuation relationship incorporating radial distance, geometrical spreading, and frequency-dependent attenuation is developed. The model parameters are estimated by minimizing the root mean square error (RMSE) between observed and predicted seismic energy. The analysis assumes a homogeneous propagation medium, allowing the influence of distance and frequency on energy attenuation to be evaluated independently of complex geological heterogeneity. The estimated parameters provide an empirical characterization of seismic energy decay from landslide sources and may help assess the detectability of landslide-generated signals at different distances. The approach can be extended using a larger dataset, greater source-to-station distances, and spatially variable attenuation parameters to account for geological heterogeneity.

MULTI-GEOPHYSICAL ASSESSMENT FOR IDENTIFICATION OF POTENTIAL MANAGED AQUIFER RECHARGE SITES IN BASALTIC TERRAIN OF RAIGAD, MAHARASHTRA

Shreya Maurya*, Kuldeep Sarkar, Nimatullah, and Anand Singh
Department of Earth Sciences, Indian Institute of Technology Bombay, Powai 40076
E-mail: shreya.m21@iitb.ac.in; shreya.gly@gmail.com

ABSTRACT

Groundwater is an essential resource for domestic water supply, agriculture, and sustaining ecosystems, particularly in regions where surface-water resources are limited or unreliable. Groundwater recharge in crystalline hard-rock terrains is strongly controlled by secondary porosity developed through weathering, fracturing, and faulting. Identifying such structurally controlled recharge zones is essential for sustainable groundwater management and for planning effective Managed Aquifer Recharge (MAR) interventions. This study presents an integrated geophysical investigation to delineate potential groundwater recharge zones in the Ambet region of Raigad District, Maharashtra. The area is mainly comprised of Deccan basaltic flows and lateritic soil. Electrical Resistivity Tomography (ERT), Very Low Frequency Electromagnetic (VLF-EM), magnetic, and Self-Potential (SP) methods were integrated to characterize subsurface lithology, fractures, and groundwater-flow pathways. ERT and VLF-EM data delineated weathered and fractured basaltic zones characterized by distinct resistivity contrasts and steeply dipping conductive features. Magnetic data revealed NE-SW-oriented structural discontinuities and lithological variations extending to greater depths, providing evidence for deep-seated pathways. SP anomalies and current-density distributions further supported the presence of preferential subsurface flow pathways. Integration of the geophysical results with borehole lithology and groundwater-yield information enabled the identification and validation of structurally controlled recharge zones. The study demonstrates the utility of a multi-geophysical approach for characterizing groundwater recharge pathways and assessing potential sites for MAR in fractured basaltic terrains.

Keywords: Groundwater Recharge; Managed Aquifer Recharge; Deccan Basalt; Fractured Hard-rock Aquifer; Geophysical Delineation; Groundwater Flow Pathways

LANDSLIDE MONITORING USING PASSIVE SEISMOLOGY AND SAR INTERFEROMETRY: A CASE STUDY FROM JOSHIMATH, CHAMOLI (UTTARAKHAND)

Shubham Mishra, Satish Maurya
Department of Earth Sciences, IIT Bombay,
mishra.shubham181@gmail.com

ABSTRACT

Landslides are among the most widespread natural hazards in the Himalaya, driven by intense rainfall, steep terrain, and growing anthropogenic pressure. Detection, monitoring, and hazard zonation of slope failures are therefore critical for protecting communities and infrastructure. This study combines Interferometric Synthetic Aperture Radar (InSAR) with Seismic Ambient Noise Interferometry (SANI) to assess landslide-prone terrain around Joshimath, Chamoli. Multi-temporal SAR data acquired between January 2020 and December 2024 were processed using Persistent Scatterer (PS-InSAR) and Small Baseline Subset (SBAS) techniques, implemented with open-source tools including

OpenSARLab, MintPy, LiCSBAS, and StaMPS, to derive surface deformation rates. This enabled the identification of both active and slow-moving landslides across the study area. To examine subsurface behaviour, relative seismic velocity changes (dv/v) were computed for three stations (AULI, CHAD, and KVSJ) between 17 June and 17 July 2024. The KVSJ record shows a marked velocity drop on 5 July 2024, four to five days before landslides occurred on 9–10 July. We attribute this drop to loss of rigidity caused by rainfall-induced increases in subsurface moisture, and interpret it as a potential precursory signal. In contrast, AULI and CHAD show no significant velocity reduction. This may reflect differences in slope aspect, with their downslope areas facing a relatively stable valley floor, as well as the heterogeneous response of the local metasedimentary bedrock to rainwater infiltration; these factors require further investigation. Together, these results show that integrating InSAR with passive seismology strengthens landslide detection and monitoring, supports the development of more effective early warning systems, and contributes to disaster-resilient infrastructure planning in mountainous regions.

STRUCTURE INDUCED ANISOTROPY IN COAL FIELD: A STUDY FROM RANIGANJ, WEST BENGAL

Shubham Rai[1], Joseph Lalngaihawma[1,2], Ajay Malkoti[1,2], Pankaj Kumar[1,2,] Nimisha Vedanti[1,2]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India
srrai1906@gmail.com

ABSTRACT

Seismic imaging has been relatively less explored for coal exploration, which is an unconventional resource since coal-bearing areas yield poor subsurface images. There are many reasons for that, and one important factor is seismic anisotropy, which could be due to the intrinsic nature of coal as well as structure-induced effects, i.e., rapid variations in layer properties. Thin interbedded layers of coal, shale, and sandstone in coal-bearing sequences can behave as a Vertical Transverse Isotropy (VTI) medium at the seismic scale. This study evaluates the effect of this structure-induced anisotropy on seismic sections in the Raniganj coalfield, West Bengal. For that purpose, we have upscaled the geophysical logs (P-wave velocity, S-wave velocity, and density logs) from well ERD-02 to seismic frequencies using the Backus upscaling technique. The upscaled logs were blocked into constant-property layers, and thereafter, the separate seismic response was computed for both isotropic (ISO) and VTI media and compared using CDP gathers. We find that the VTI–ISO differences become increasingly pronounced, particularly at large propagation angles. The near-vertical responses remain relatively similar between the two models. VTI yields progressively different travel times relative to ISO while maintaining substantially higher amplitudes at large angles. The results show that layering-induced anisotropy significantly changes the response of the coal-bearing sequence relative to the isotropic case, and therefore must be considered while processing the seismic data for coalfields where rapid variation in the subsurface is observed.

COSMIC RAY MUON TOMOGRAPHY FOR HIGH-RESOLUTION SUBSURFACE DENSITY IMAGING

Shubhashri S Shenoy [1,2], Prakash Kumar [1,2], Biswajit Mandal [1,2], Akimichi Taketa[3] ,Bijayananda Dalai[1,2]
[1]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
[3] Earthquake Research Institute (ERI), University of Tokyo, Japan
shubhashrisshenoy12@gmail.com

ABSTRACT

Cosmic-ray muon tomography (muography) is a non-invasive imaging technique that utilizes the attenuation of naturally occurring high-energy muons to reconstruct the internal density distribution of large-scale structures. As they pass through matter, muons lose energy due to ionization and radiative processes, and their trajectories are altered by scattering and absorption. As muons propagate through geological media, their energy loss and scattering depend on the integrated density along their trajectory, enabling quantitative subsurface density imaging. With advancements in particle detector technology and computational modeling, muon tomography has demonstrated substantial capability in applications such as volcanic imaging, cavity detection, and structural investigations. In geophysical exploration, muon tomography provides a direct density-sensitive imaging approach that is particularly suitable for large and complex geological targets. In this study, we have explored the feasibility of muon tomography in identifying the density anomalies within the subsurface. We have used synthetic muon data generation as a preliminary step to understand the muon attenuation through various geological structures. With the use of Monte Carlo particle transport algorithms, we have simulated the muon interaction with target structures and obtained the transmission and opacity values respectively. This opacity or density-length information of the target is crucial in the reconstruction of the target structure using geophysical inversion techniques. Also, we have observed the variation of muon flux with increasing depth, and also with zenith and azimuth angles. These synthetic data outputs are important in understanding the capability and limitations of detectors, which is crucial for the real field observations. This research will assess the applicability of muon tomography for mineral exploration, groundwater detection, and identification of fracture zones and density anomalies within complex geological environments.

Keywords: Muon tomography, High-energy muons, Density imaging, Opacity, Synthetic data

MAGNETOTELLURIC IMAGING OF THE BASEMENT ARCHITECTURE AND SEDIMENTARY SUCCESSIONS IN THE CENTRAL VINDHYAN BASIN

S. Srinivasarao*, G. Pavankumar, M. Demudu Babu, M. Suresh, L. Adilakshmi, A. Manglik
CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad – 500007, India
(*Presenting author; Email: srinuongc18@gmail.com)

ABSTRACT

The Vindhyan Basin is a broad, crescent-shaped Proterozoic sedimentary basin belonging to the Purana basins system. It preserves a thick sedimentary succession deposited on a heterogeneous Archaean–Paleoproterozoic basement and is bounded by major tectonic elements, including the Bundelkhand Massif and Indo-Gangetic alluvium to the north, the Narmada – Son Lineament to the south, the Monghyr–Saharsa Ridge to the east, and the Great Boundary Fault – Aravalli–Delhi Fold Belt system

to the west and northwest. Several geophysical studies, especially seismics, have been carried out in the Vindhyan Basin owing to its hydrocarbon potential. However, magnetotelluric (MT) studies in the basin are limited despite their significant role in mapping the basement architecture and the presence and nature of intabasinal fluids. Here, we present the results from a broadband MT study along an about 120 km long, nearly NNW–SSE profile across the central Vindhyan Basin covered by 28 sites. A section of this profile coincides with a previous seismic transect. The integrated MT–seismic analysis suggests sedimentary thickness of ~5–6 km within the basin, but with laterally segmented basement geometry along the profile. The northern block, towards the Bundelkhand Craton, is characterized by relatively shallow basement, whereas the southern block shows deeper basement depth, where the sedimentary succession locally attains ~8 km thickness. The geoelectric model distinguishes conductive Lower Vindhyan group from moderately resistive to resistive Upper Vindhyan group. This resistivity contrast between the Lower and the Upper Vindhyans is indicative of the lithological variations, the Lower Vindhyans representing fine-grained, clay and shale-rich deposits, whereas the Upper Vindhyans are dominated by relatively resistive sandstone–carbonate sequences. Overall, the integrated interpretation suggests an asymmetric, basement-controlled basin development governed by inherited crustal structures.

SEISIMAGE: A PYTHON BASED GUI PACKAGE FOR SEISMIC INVERSION

Sreeja Kalyankar1*, Srishti Singh1,2 , Ajay Malkoti1,2 , Nimisha Vedanti1,2
1CSIR-National Geophysical Research Institute, Hyderabad-500007, India
2Academy of Scientific and Innovative Research, NGRI, Hyderabad-500007
Email: sreejakalyankar@gmail.com

ABSTRACT

Seismic inversion is a crucial process in reservoir characterization as it helps quantify rock properties and improve the accuracy of the reservoir model. The stochastic inversion methods can capture the essence of the inversion, however, they need the correct guiding principles to emulate the realizations. In this work, we have used the Fractal-Based Stochastic Seismic Inversion, which employs fractional Gaussian noise to yield realistic subsurface realizations. This noise is characterized by the Hurst coefficient that we have estimated using the R/S analysis. The best realization is chosen by minimizing a suitable objective function using a very fast simulated annealing (VFSA) algorithm. This inversion technique is computationally cheaper and advantageous over deterministic inversions. It can detect and delineate thin spatial reservoir units, and, to that end, we have demonstrated its application to the F3-block dataset from the Netherlands. The Hurst coefficient for this data was close to 1, indicating strong fractal behavior. The inverted results are assessed by comparing the synthetics generated using this inverted model with those from the inverted model. This shows the method works for most parts, with very small differences, except in some areas where very low frequencies are absent, and the region is structurally very disturbed. This complete inversion procedure is developed as a Python package-SeisImage, containing ~30,000 lines of code. It is based on modern software engineering principles and offers a GUI/CLI package that supports automated workflows with greater process control and fault tolerance.

SPATIAL ANALYSIS AND 2D FORWARD GRAVITY MODELLING OF THE EASTERN CONTINENTAL MARGIN OF INDIA: CONSTRAINTS ON DEEP CRUSTAL ARCHITECTURE

Sreelakshmi PK
CUSAT
sreelakshmipk1410@gmail.com

ABSTRACT

The Eastern Continental Margin of India (ECMI) is a passive continental margin formed during the fragmentation of Eastern Gondwanaland during the Early Cretaceous. It is a geodynamically complex region shaped by rifting, magmatism, sedimentation and tectonic deformation. This study presents a numerically stable workflow for 2D forward gravity modelling and applies it to evaluate the deep 2D crustal architecture of the ECMI. The methodology involves extracting spatial datasets (GEBCO bathymetric, Sandwell free-air gravity and GlobSed sediment thickness) using QGIS. Moho depths computed from the local Airy isostatic assumption are used as the starting model. Forward gravity modelling is done by the modified open-source GRAV_MAG SUITE software.

The modelling results reveals thick continental crust (~30 km) landward of the shelf, significant crustal thinning beneath continental slope, and further oceanward, the Moho stabilizing at depths consistent with oceanic crust. The models from the northern and central segments exhibit a wider OCT zone, while those from the southern segment displays a narrower OCT with a higher Moho gradient.

Interpretations from this study are limited by the inherent non-uniqueness of potential field methods, with the models representing a first-order approximation of the deep crustal structure based on uniform-density assumptions for major crustal units. Detailed interpretations with additional independent depth constraints are required for a more precise geodynamic characterization of the margin.

MAGNETIC FABRICS AS INDICATORS OF ACTIVE FAULTING

Sreyashi Bhowmick*[a], Priyeshu Srivastava[a], Mohit Shivane[a], Gaurav D. Chauhan[b], A.P. Dimri[a]
[a]Indian Institute of Geomagnetism, HQ, Panvel, Navi Mumbai
[b]Department of Earth and Environmental Science, KSKV Kachchh University
*Presenting author: sreyashi.b@iigm.res.in/sreyashicu@gmail.com

ABSTRACT

Fault zones preserve rock records of dynamic processes operating within the upper crust and provide valuable insights into the mechanisms of crustal deformation. They comprise high-strain fault cores surrounded by damage zones. Faulting is associated with progressive strain accumulation, abrasion, coseismic frictional heating, and fluid–rock interaction, which can induce brittle-to-plastic deformation, mineral alteration, and reorientation of constituent minerals. Anisotropy of Magnetic Susceptibility (AMS) is a well-established petrofabric technique that can effectively characterize deformation-related fabrics and their spatial variations within fault zones. In addition, magnetic properties of fault rocks can provide valuable constraints on mineralogical transformations associated with frictional heating, fluid–rock interaction, and variations in slip conditions. Consequently, magnetic fabrics and magnetic properties represent promising, yet relatively underutilized proxies for investigating fault-zone processes. Here, we present preliminary results of magnetic fabric characterization from the Kodki Fault in Kachchh, a well-known pericratonic rift basin in western India. We investigate spatial

variations in AMS and magnetic properties across the fault to characterize deformation-related magnetic fabrics and assess their potential relationship with fault-zone architecture and deformation processes. Primarily, a well developed ~N-S trending magnetic fabric characterized by the distribution of K1-K2 AMS axes is identified sub-parallel to the mean orientation of the fault and reflects fault-related deformation fabric. Preliminary observations demonstrate the potential of rock magnetic approaches for deciphering deformation mechanisms and reconstructing the evolution of active fault zones.

AN IMPROVED DETECTION ALGORITHM TO QUANTIFY FRACTURE NETWORK TOPOLOGY AND CONNECTIVITY FROM BOREHOLE CORE IMAGE

Sarkar, Sudipta[1*], Saha, Kuntal[1], Naskar, Ipshita[2], Acharya, Koohinoor[3], Mondal, Tridib Kumar[1], Misra, Surajit[4], Mondal, Sourav[5], C S, Vishnu[6]

[1]GSU, ISI Kolkata, India; sudiptasarkar.malda76@gmail.com, sahakuntal616@gmail.com, tridibkumarmondal@gmail.com
[2]DEC, IISER Pune, India; ipshita.naskar05@gmail.com
[3]Department of Geology & Geophysics, IIT Kharagpur, India; koohinooracharya@gmail.com
[4]Department of Geological Sciences, Gauhati University, India; surajitmisra@gauhati.ac.in
[5]Department of Chemical Engineering, IIT Kharagpur, India; souravmondal2008@gmail.com
[6]MoES, Borehole Geophysics Research Laboratory, India; vishnugeo@gmail.com
Presenting author: Sarkar, Sudipta; sudiptasarkar.malda76@gmail.com *Corresponding author

ABSTRACT

Fracture network are the pathways that control fluid movement. Characterizing this, is essential for understanding, such as managing groundwater, extracting energy, safely storing nuclear waste or carbon and assessing geological hazards like seismicity, landslides.

To characterize a fracture network, generally we measure both of its geometry and its topological properties, which includes digitization of fracture network followed by classifying fractures into different nodes and branches along with its geometrical parameters. Existing methods successfully characterize two-dimensional surface fracture network maps, however in case of subsurface fracture network, information comes from unrolled cylindrical borehole core images, where dipping fracture planes appear as sinuous curves. Consequently, with the help of existing method it is difficult to characterize this sinuous curvature, leading to severe node count discrepancies, fixed boundary and junction snapping errors as well as inability to calculate true branch lengths instead of overall trace or segment lengths. Additionally, these methods cannot directly process SVG vector files exported from any digitizing software and require prior programming knowledge.

To overcome these gaps, we have developed an automated parsing and detection algorithm, specifically designed for unrolled borehole core fracture traces. This algorithm processes any vector files directly, extract depth-wise geometrical as well as topological parameters and capable to build ternary diagrams with accuracy.

Preliminary results from borehole core image of Koyna Warna Seismic Region of Western Maharashtra, India, which is globally recognized for shallow focus reservoir triggered seismicity, active during decades, demonstrate that, this algorithm eliminates false node detections caused by sinuous fracture trace curvature, drastically improving connectivity and topology measurements, which is critical for assessing fault reactivation and earthquake hazards.

INTEGRATED AIRBORNE GEOPHYSICS FOR SUBSURFACE STRUCTURES OVER A SCHIST MINERALIZATION BELT OF SOUTHERN INDIA

Sukant Oraon1* , Akhil Mishra 1,2 , Ved P. Maurya 1,2 Subhash Chandra 1,2 , Joy Choudhury 1,2
1CSIR-National Geophysical Research Institute, Hyderabad 500007, India
2Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
*Presenting Author - sonuoraoniitb10@gmail.com

ABSTRACT

This study presents an integrated interpretation of airborne magnetics complemented with electromagnetic and radiometric data acquired in an area of about 380 sq.km over Kibbanahalli arm of the Chitradurga schist belt of southern India, where the geology is dominated by metamorphic crystalline rocks. The study focuses on identifying the major subsurface structural features associated with major geological contacts with special reference to mineralization and hydrogeology. Total Magnetic Intensity (TMI) data sampled at ~ 150 m is dominated by short wavelength features associated with shallow sources. The power spectral analysis indicates that the major causative magnetic sources occur within ~ 1 km depth. TMI data were inverted using the SimPEG open source code to obtain a 3D magnetic susceptibility model. Total Horizontal Gradient (THG) of inverted susceptibility model was calculated to delineate magnetic contracts and structural trends. Several magnetic lineaments were identified by an amplitude threshold of THG ~ 2.25×10^{-6} having ~ 100 m width and ~500 m length of ridge . This exercise retains the major laterally continuous features of the susceptibility model. The susceptibility depth sections derived from the 3D model are compared with airborne electromagnetic (AEM) resistivity sections that shows good correspondence at several places. Some of the shallow features identified in the resistivity model are found extending down to deeper levels ~ 1 km beyond through the susceptibility model. Additionally, derived lineaments/contacts from airborne magnetic, AEM and radiometric data show correspondence with known geology. The study reveals several concealed subsurface structural trends that follow the regional structural pattern of the Chitradurga Schist Belt and mineralogical domains. These regional structures may have significance to mineral occurrences and hydrogeology aspects of study. Keywords: 3D magnetic inversion, susceptibility, airborne electromagnetics, radiometric, lineaments, subsurface structure.

QUANTUM WAVELET TRANSFORM MACHINE LEARNING SEISMIC IMAGING

Sunjay
Geophysicist, sunjaytellus@gmail.com
Seismic imaging centre, Geophysics,BHU,Varanasi,India

ABSTRACT

Quantum sensing is evolving as a game changer for the oil and gas industry, advancing it to the bleeding edge technology with highly sensitive and precision measurement technologies. Quantum sensing refers to emerging technologies that could significantly advance seismic reflection data acquisition by providing higher sensitivity and resolution than traditional geophones and hydrophones. These sensors leverage quantum mechanical phenomena, such as atomic properties and entanglement, to detect the faint seismic waves reflected from subsurface layers with unprecedented precision. quantum seismic sensing promises to enhance the detailed imaging of geological structures, crucial for resource exploration and understanding Earth's subsurface. Quantum seismic imaging is an emerging field that

uses quantum principles and computing to improve seismic data processing and analysis for subsurface imaging. It involves applying quantum computing techniques like quantum annealing and quantum machine learning to complex seismic problems, leading to higher accuracy and resolution in areas like fault detection and seismic inversion compared to traditional methods. This approach aims to overcome challenges with noisy or complex data to provide more detailed and accurate insights into underground structures. This includes techniques such as quantum annealing, which is used to solve optimization problems like seismic traveltime inversion, and quantum machine learning (QML) for tasks like fault detection. Enhanced seismic inversion: Traditional methods often struggle with uncertainty and noise. Quantum Wavelet Transform- seismic imaging Quantum Computing-wavelets have emerged as a powerful tool for analyzing and processing signals with varying frequencies and resolutions. From image compression to data denoising, wavelet transforms offer versatile techniques for extracting valuable information from signals. As quantum computing continues to make strides in computational capabilitie. Quantum Wavelet Transform (QWT)- Wavelets are mathematical functions that are used to analyze signals in both time and frequency domains. Unlike traditional Fourier analysis, which decomposes signals into sinusoidal components of different frequencies, wavelets decompose signals into localized, transient components. This localization property makes wavelets particularly well-suited for analyzing signals with non-stationary signal seismic data. Quantum Superposition and Entanglement-In QWT, quantum principles such as superposition and entanglement are utilized to perform wavelet analysis on quantum states. Instead of processing signals sequentially as in classical wavelet transforms, QWT can analyze multiple signals simultaneously, the inherent parallelism of quantum computing-parallelism promises significant speedup in processing large datasets and complex signals. Quantum Machine Learning (QML) in geophysics is employed for targeting seismic fault detection. Quantum computing can improve seismic imaging by using quantum algorithms, particularly quantum machine learning (QML), to more accurately and efficiently process seismic data, leading to better subsurface images. This is especially promising for challenging tasks like seismic fault detection and velocity model inversion, where quantum computing can outperform classical methods by handling complex data and large datasets with greater speed and accuracy. Synthetic AI seismic imaging uses artificial intelligence to create synthetic seismic data, which is used to train AI models for seismic interpretation tasks like fault detection, noise reduction, and resolution enhancement. Generative AI is revolutionizing seismic imaging by automating tasks, generating synthetic data, and improving data quality.

Keywords: Quantum sensing, Quantum seismic imaging, wavelet transform, Quantum Machne Learning

PSEUDO-ACOUSTIC FULL-WAVEFORM INVERSION FOR VTI MEDIA: SENSITIVITY, PARAMETERIZATION AND ANISOTROPIC VELOCITY RECONSTRUCTION

Swaraj Ray[1] Shobit Mishra[2] Bharat Shekar[2] Kajaljyoti Borah[1]
[1] Department of Earth Sciences, IISER Kolkata [2] Department of Earth Sciences, IIT Bombay
Presenting author: sr22ms186@iiserkol.ac.in

ABSTRACT

Full-waveform inversion (FWI) provides a high-resolution approach for estimating subsurface seismic properties by exploiting the amplitude and phase information contained in the recorded wavefield.

However, under wide-azimuth and wide-aperture acquisition geometries, neglecting seismic anisotropy can lead to biased velocity models and inaccurate structural positioning. Our study investigates pseudo-acoustic full-waveform inversion (FWI) in vertical transverse isotropic (VTI) media, following an acoustic approximation in which the shear-wave contribution is neglected while the directional dependence of P-wave propagation is retained. The VTI medium is described through anisotropic velocity parameters and Thomsen parameters, allowing the influence of anisotropy on the seismic wavefield to be incorporated without the computational complexity of a full elastic formulation. A central aspect of the study is the analysis of different subsurface parameterizations and their influence on the FWI inverse problem. Radiation and scattering patterns are used to examine the sensitivity of seismic data to individual parameter classes as a function of scattering angle, providing insight into parameter resolution and inter-parameter trade-offs. The analysis indicates that wave-speed parameters generally have stronger and broader sensitivity than the Thomsen parameters, whereas simultaneous inversion of vertical and horizontal velocities can provide complementary information over different scattering-angle ranges. The pseudo-acoustic VTI FWI framework is therefore particularly useful for understanding how acquisition geometry, anisotropic parameterization, and prior model accuracy govern the recoverability of subsurface velocity structure.

CONSTRAINING THE CRUSTAL STRUCTURE OF THE TROODOS OPHIOLITE USING TELESEISMIC RECEIVER FUNCTIONS

U Sreenandana[1] Muhammed Rishal[1], Mohammad Ismaiel[1]
[1]Department of Earth and Climate Science, Indian Institute of Science Education and Research Pune, Pune
Presenting Author mail id: sreenandana440@gmail.com

ABSTRACT

The Troodos Ophiolite in Cyprus represents one of the most extensively exposed fragments of oceanic lithosphere and provides an exceptional natural laboratory for investigating the seismic structure and evolution of oceanic crust. In this study, we investigate the subsurface crustal architecture of the Troodos Ophiolite using teleseismic receiver functions derived from continuous broadband seismic observations recorded at six seismic stations between 2016 and 2019.

The analysis focuses on teleseismic P-wave arrivals and the associated P-to-S converted phases generated at major subsurface seismic discontinuities. Receiver functions are extracted to isolate these converted phases and identify prominent interfaces within the crust and at the crust–mantle boundary. The resulting receiver functions are analyzed using the H–κ stacking technique to estimate crustal thickness and the average crustal Vp/Vs ratio beneath each station. These parameters provide important constraints on the seismic properties, thickness, and structural variability of the crust beneath the ophiolite.

The spatial variation of crustal thickness and Vp/Vs ratios across the six stations is examined to evaluate lateral changes in crustal architecture and seismic properties. Such variations may reflect differences in lithological composition, crustal accretion processes, alteration, fracturing, and the structural organization of the oceanic crust. Particular emphasis is placed on characterizing the Moho and the nature of the crust–mantle transition beneath the Troodos Ophiolite, thereby linking the observed seismic structure with the exposed geological framework.

The results provide seismological constraints on the crustal architecture and internal heterogeneity of the Troodos Ophiolite and contribute to understanding the formation, modification, and preservation of oceanic lithosphere. By integrating receiver-function observations from multiple stations, this study establishes a regional seismic framework for investigating the deeper structure and evolution of this well-preserved fragment of oceanic crust.

Preferred mode of presentation: Poster

INTEGRATED STRUCTURAL AND RESERVOIR CHARACTERIZATION OF THE PALEOCENE–EOCENE SUCCESSION IN THE UPPER ASSAM BASIN.

Kurakula Kalyani[1, 2], Param K. Gautam[1] and Kalachand Sain[3]
[1]Seismic Interpretation Laboratory, Wadia Institute of Himalayan Geology, Dehradun, Uttarakhand-248001, INDIA
[2]Academy of Scientific and Innovative Research, Ghaziabad, Uttar Pradesh- 201002, INDIA
[3]CSIR-National Geophysical Research Institute, Hyderabad, Telengana-500007, INDIA
[*]Presenting authors email: kalyaniau23@gmail.com

ABSTRACT

The Upper Assam Basin is one of the important petroleum-bearing interval in the Paleocene-Eocene succession whose reservoir distribution and hydrocarbon potential are strongly controlled by structural architecture and spatial variation of the reservoir properties. This study presents an integrated seismic interpretation and reservoir characterisation of the Paleocene–Eocene succession using 3D post stack time migrated (PSTM) seismic data and well-log data from the Dibrugarh 3D area, Upper Assam Basin, NE India. This study is concentrated on the structural framework of Lakadong – Therria, Prang and Kopili intervals and its relation to the distribution of reservoir properties. Seismic interpretation was conducted through horizon mapping, time-slice analysis and seismic attributes such as similarity, dip magnitude, dip azimuth and curvature to delineate faults and subtle structural variations. Results reveal a dominant NE–SW to ENE–WSW-oriented fault system with variations in fault geometry and segmentation across the study area, suggesting a structurally complex Paleocene–Eocene succession. An attribute-based analysis further defines zones of discontinuity and localised structural compartments that may influence sediment distribution and hydrocarbon trapping potential. Besides the structural interpretation, a well-to-seismic calibration was performed along with an acoustic impedance inversion to define the relationship between the seismic response and the subsurface lithological variations. An empirical relationship for porosity estimation was developed by combining acoustic impedance information with porosity from well logs. Machine-learning approaches were subsequently tested to extrapolate the well-based porosity information into a 3-D seismic volume. The integrated results provide a spatial understanding of the structural architecture and reservoir-property variations of the Paleocene-Eocene succession. The study demonstrates the value of integrating seismic structural attributes, impedance inversion and quantitative porosity prediction for better reservoir characterisation.

A Hybrid GMPE Framework Integrating Physics-Based Modeling, Transformer Learning, and XGBoost for the Uttarakhand Himalaya

Vikas Singh[1]*, Sandeep[1], A. Raju[2]
[1]Department of Geophysics, Banaras Hindu University, Varanasi
[2]Department of Geology, Banaras Hindu University, Varanasi
Corresponding author: svk199596@gmail.com

ABSTRACT

Accurate prediction of earthquake ground motion is crucial for reliable seismic hazard assessment, especially in tectonically active regions such as the Uttarakhand Himalaya. In this study, we develop a hybrid physics-informed nonlinear machine-learning framework for predicting peak ground acceleration (PGA) in the region. The proposed approach combines a nonlinear parametric ground-motion prediction equation (GMPE) with data-driven modeling of the residuals to improve prediction accuracy and reduce epistemic uncertainty. The base nonlinear parametric GMPE is developed from 12,866 ground-motion records corresponding to earthquakes, covering a moment magnitude range of $2.0 < M_w < 7.0$. The physics-based component accounts for magnitude scaling, nonlinear distance attenuation, focal-depth effects, and site amplification. The coefficients of the base GMPE are estimated using the Simulated Annealing optimization method and independently evaluated for robustness through Bayesian Optimization. The remaining ground-motion variability that is not captured by the base GMPE is subsequently modeled using a Transformer-based deep-learning architecture. An XGBoost (eXtreme Gradient Boosting) ensemble regressor is then incorporated to enhance the generalization capability and stability of the overall prediction framework. The physics-based and data-driven components are finally integrated to construct the hybrid GMPE and improve PGA predictions. The performance of the proposed framework is evaluated through residual-bias analysis, quantile–quantile (Q–Q) analysis, and SHapley Additive exPlanations (SHAP) analysis. The results demonstrate the potential of the proposed hybrid physics-informed framework to provide more accurate and robust ground-motion predictions, supporting improved seismic hazard assessment and earthquake early-warning applications in the Uttarakhand Himalaya.

SEISMOTECTONICS OF NORTHEAST INDIA: CONSTRAINTS FROM RELOCATED SEISMICITY AND FOCAL MECHANISMS

Yashpal Singh Tomar[1,2], Ajay Pratap Singh[1], Sanjit Kumar Pal[2]
National Center for Seismology, New Delhi
Indian Institute of Technology (ISM), Dhanbad
Presenting author: tomaryashpal51@gmail.com

ABSTRACT

Northeast India is one of the most seismically active and complex structures in the world, situated at the convergence of the Indian, Eurasian, and Burmese plates. To understand the seismotectonics of the study region, we analysed a catalogue of 3700 earthquakes (M ≥ 1.5) recorded between January 2010 and July 2024 using data from a 24-station permanent seismic network and 25 temporary stations deployed at different times between 2010 and 2015. To investigate the relationship between seismicity patterns and regional tectonic structures, we used earthquake relocation, focal mechanism and stress inversion methods. The relocated seismicity shows a relationship with the regional tectonic structure. Shallow earthquakes (<60 km) are common in the Shillong Plateau, Tripura Fold Belt, and Himalayan

Belt, while earthquakes at depths greater than 160 km occur mainly toward the Burmese arc. The focal mechanism solutions indicate that the type of faulting varies across the region and at different depths. Thrust and strike-slip faulting are common in compressional areas, whereas normal faulting is locally observed in extensional areas. Stress inversion shows that the region is mainly under N–S to NE–SW compression due to the interaction between the Indian and Eurasian plates. In Northeast India, deformation includes local extension, strike-slip movement, and crustal shortening, all of which are governed by variations in lithospheric strength and pre-existing fault systems. These findings show how lithospheric strength, stress direction, and crustal structure influence deformation in the region. They also improve our understanding of the geodynamic evolution and seismic hazard of the Indo-Burma–Himalayan transition zone.

MARINE GEOSCIENCES

SEISMIC CHARACTERIZATION OF SEDIMENTARY SEQUENCES ALONG THE SOUTHWESTERN CONTINENTAL MARGIN OF INDIA USING MULTI-CHANNEL SEISMIC REFLECTION DATA

Adithya K[1, 2,*], Nisha Nair[1], John Kurian P.[1]
[1]Marine Geosciences and Exploration, National Center of Polar and Ocean Research, Vasco-da-Gama, Goa 403804
[2]School of Earth, Ocean and Atmospheric Sciences, Goa University, Taleigao Plateau, Goa 403206
* E-mail ID: adithyak@ncpor.res.in

ABSTRACT

The present-day architecture of the Southwestern Continental Margin of India (SWCMI) is the result of multiple phases of tectonic and volcanic activity, starting from the rift-drift between India and Madagascar. The offshore region encompasses various tectonic elements, including numerous bathymetric highs, the Laccadive Plateau (LCP), the Cannanore Rift System (CRS), the shelfal horst-graben complexes, the Alleppey-Trivandrum Terrace Complex (ATTC), the shelf-margin basin and/or the Laccadive Basin, and a depocentre such as the Kerala-Konkan Basin. The rifting and drifting of the Indian Plate may have affected sediment deposition in the region, possibly influencing the shelf-edge progradation. Sedimentation, being one of the major driving forces in continental margin subsidence, preserves a record of sea-level changes and the geological evolution of the continental margin through the progradation of the shelf edge. In the present study, an attempt has been made to delineate the different seismic stratigraphic sequences using multi-channel seismic reflection data integrated with litholog data to demarcate the sedimentation pattern during each geologic time interval; the nature and type of deposition; the shelf edge progradation and its associated depositional conditions that might have influenced the sedimentation in the region. The initial interpretation results revealed sediment thicknesses ranging from very thin (~0.15 s TWT) to almost null near certain basement highs, with the thickest sedimentation exceeding ~1.2 s TWT within the basinal region or segments. The interpreted acoustic basement shows signatures of the rift-drift process that led to the evolution of the margin. Mapping of seismic facies revealed the sedimentation history and depositional type.

Keywords: Passive Continental Margin, Rifting, Sedimentation, Stratigraphy, Seismic facies

DYNAMICS OF THE SUBDUCTION ZONE BASED ON THE FLEXURAL MODELLING

Aman Kumar Vishwakarma, M Radhakrishna, G Srinivasa Rao
Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai, India
Presenting author: 23d0454@iitb.ac.in

ABSTRACT

The flexural response of the oceanic lithosphere near subduction zones provides important constraints on its mechanical strength and its characteristics. The key parameters used to characterize this response include the effective elastic thickness (Te), bending moment (M0), and shear force (V0). To understand the influence of each of these parameters on the lithospheric flexure, forward modelling is first carried out by systematically varying the individual flexural parameters and understanding their effects on the resulting trench profiles. Then, a Bayesian inversion framework is developed to estimate the flexure parameters. The methodology is first validated using a series of synthetic experiments performed under different levels of noise. These synthetic tests are used to evaluate the ability of the inversion to recover the prescribed model parameters, quantify the associated uncertainties, and investigate possible trade-

offs among the flexural parameters. The algorithm is subsequently applied to the observed data along selected subduction zones. The estimated flexural parameters are compared with values reported in previous studies and are found to be in excellent agreement with published results. The proposed framework therefore provides a robust approach for investigating lithospheric flexure, spatial variations in mechanical strength, and the tectonic behavior of oceanic plates along subduction margins.

INSIGHTS INTO INTRAPLATE SEISMICITY IN THE CENTRAL INDIAN OCEAN BASIN USING OCEAN BOTTOM SEISMOMETER NETWORK

Athul Ramachandran, Lachit S. Ningthoujam, Sanjay S. Negi, Amit Kumar, Rinku Mahanta, Pasagadgu Sion Kumari, John Kurian P
National Centre for Polar and Ocean Research, Ministry of Earth Sciences, Government of India, Headland Sada, Vasco-da-Gama, Goa 403 804, India
Presenting Author e-mail: athulkr@ncpor.res.in

ABSTRACT

The Indian Ocean hosts one of the world's most prominent zones of diffuse intraplate deformation, expressed by widespread seismicity, large intraplate earthquakes, crustal-scale folding and thrust faulting, and long-wavelength gravity and bathymetric anomalies. This deformation reflects distributed motion within the traditionally defined Indo-Australian Plate and is commonly interpreted as a broad diffuse boundary involving the Indian, Capricorn and Australian plates (Wiens et al., 1986; Royer & Gordon, 1997; Gordon, DeMets & Royer, 1998). However, the spatial distribution and characteristics of offshore seismicity remain poorly constrained due to the sparse coverage of regional or global seismic network. This study investigates seismicity and intraplate deformation across the Central Indian Ocean Basin using data from a temporary Ocean Bottom Seismometer (OBS) network deployed during 2024–2025 under NCPOR's Indian Ocean Geoid Low (IOGL) program. These observations are integrated with existing high-resolution seismic reflection profiles that document the seafloor expressions of deformation.

For the first time we report more than 500 local earthquakes of magnitude Mw~ 1.7 to 4.7, showing seismicity concentration along the pre-existing fracture zones and the diffused plate boundary, particularly around the Afanasy Nikitin Seamount (ANS). A well-constrained subset of these events was further relocated using the HypoDD double-difference algorithm and with bootstrap analysis confirming the stability and reliability of the improved hypocentres. This study highlights the potential of temporary OBS network in resolving low-magnitude offshore seismicity and advancing our understanding of intraplate tectonic processes in remote oceanic settings.

Keywords : Central Indian Ocean Basin, Ocean Bottom Seismometer, Intraplate Seismicity, Diffuse plate boundary, Seismotectonics.

MULTI-PROXY CHARACTERIZATION OF POLYMETALLIC NODULES FROM THE CENTRAL INDIAN OCEAN BASIN.

Kamasani Shiva Kumar[#1], Muralidhar Kocherla [*1] and Prasad Yelicharla[1]
[1]CSIR-National Institute of Oceanography, Goa, India.
*Corresponding author: Muralidhar Kocherla
[#] Presenting author: Kamasani Shiva Kumar

ABSTRACT

This study investigates the microtextural evolution, mineralogical zonation, and rock magnetic characteristics of polymetallic nodules recovered from the Central Indian Ocean Basin (CIOB) across five distinct size classes. Integrated analyses utilizing low-frequency magnetic susceptibility (χ_{lf}), frequency-dependent susceptibility (χ_{fd}), X-ray diffraction (XRD), and scanning electron microscopy in backscattered electron mode (SEM-BSE) reveal pronounced compositional and magnetic heterogeneity from nucleus to outer crust. Magnetic susceptibility is markedly elevated in core regions relative to the outer mantle and crustal domains, signifying a preserved detrital magnetic signature. XRD characterization identifies Todorokite, Vernadite, and Birnessite as the dominant manganese oxide phases within the crust and mantle, associated with subordinate Quartz and Phillipsite; in contrast, the nuclei comprise diverse detrital substrates, including biogenic apatite (shark teeth), indurated clay, and weathered Basaltic fragments. Microstructural examination of polished cross-sections exhibits well-defined concentric, stromatolitic, columnar, botryoidal, mottled, and petaloid fabrics marked by discrete rhythmic laminations, indicative of alternating hydrogenetic accretion and suboxic diagenetic growth pathways. Furthermore, biogenic features manifested as fossilized microbial mats, rod-like morphotypes, micronodule aggregates, and entrained planktic foraminiferal tests indicate biologically mediated nucleation and accretion processes. Synthesizing these microstructural, mineralogical, and magnetic proxies provides refined insights into the growth dynamics, physicochemical fluctuations, and depositional history governing nodule formation in the abyssal CIOB.

Keywords: Polymetallic nodules, Central Indian Ocean Basin (CIOB), Rock magnetic susceptibility, Macrotextures, Todorokite.

A MULTIPROXY INVESTIGATION OF GEOCHEMICAL CYCLING IN A SEDIMENT CORE INFLUENCED BY MASS TRANSPORT DEPOSITS: A CASE STUDY FROM KRISHNA-GODAVARI BASIN.

Maria Hilda João[1], Muralidhar Kocherla [*1], Durbar Ray[1] and Bindiya Velip[1]
[1]CSIR-National Institute of Oceanography, Goa, India.
***Corresponding author**: Maria Hilda João[1]
[#] Presenting author: Bindiya Velip[1]
joao.nio@csir.res.in

ABSTRACT

In this study, we integrate pore-water geochemistry, lithology, grain-size distribution, bulk-sediment geochemistry, mineralogical observations to investigate geochemical cycling within a sediment core affected by mass transport deposits (MTDs). The core represents a methane rich sedimentary environment in which an older sediment interval is emplaced within younger sedimentary sequences. Such stratigraphic juxtaposition provides an opportunity to examine how reworked and contrasting sedimentary units influence pore-water chemistry, redox-sensitive element cycling, and authigenic

mineral formation. The sedimentary sequence shows clear variations in pore-water and sediment geochemical characteristics. We investigated the distribution and enrichment of dissolved iron and other trace metals, their relationship with sedimentary and mineralogical properties, and the processes governing iron mobility and authigenic iron-carbonate formation. The coincidence of metal enrichment, an inconsistent downcore age pattern, and authigenic carbonate formation within the reworked intervals suggest that the MTD-related stratigraphic architecture significantly influence pore-water–sediment interactions and post-depositional geochemical processes. Integrated geochemical, mineralogical and sedimentological investigations provide an overview of the influence of sediment reworking and stratigraphic complexity on elemental cycling and authigenic mineral formation within the study area. Further investigations are in progress for comprehensive understanding of the processes responsible for the observed geochemical and mineralogical variations.

Keywords: Mass transport deposits (MTDs); Pore-water geochemistry; Redox-sensitive elements Authigenic carbonates; Biogeochemical cycling

SPATIAL HETEROGENEITY OF POLYMETALLIC NODULE ABUNDANCE IN THE INDIAN OCEAN NODULE FIELD (IONF): AN EVALUATION OF GEOPHYSICAL, GEOLOGICAL, AND GEOTECHNICAL DRIVERS AND ITS RELATIONSHIP TO SEDIMENT BIOGEOCHEMICAL PROPERTIES.

Muralidhar Kocherla [*1] Prasad Yelicharla[#1], Kamasani Shiva Kumar[1], Durbar Ray[1], Dinesh Ram Ramadoss[1], Maria Hilda João[1], Bharath Subramanyam Ammanabrolu[1]
[1]CSIR-National Institute of Oceanography, Goa, India.
*__Corresponding author__: Muralidhar Kocherla, kocherla.nio@csir.res.in
[#] __Presenting author:__ Prasad Yelicharla[1]

ABSTRACT

In this study we employed suite of physicochemical and geobiological analysis on the sediment cores recovered from a deep-sea environment from poly-metallic nodule field (PMNF) of Central Indian Ocean Basin (CIOB). The aim of this study was to elucidate the relative contribution of physicochemical and geobiological processes on the spatial heterogeneity of polymetallic nodule abundance in the Indian Ocean Nodule Field and its relationship to sediment biogeochemical Properties. The physical properties, mineralogical composition, and chemical component analysis were carried out in sediment samples of three sediment cores from the Central Indian Ocean Basin, having distinctly different abundances of ferromanganese nodules. Based on this comparative assessment between sediments from sampling sites with and without nodule deposits, the possible sediment-based diagenetic controls on nodule formation are discussed. All three cores were water-saturated and mostly composed of fine clays; however, the relatively less abundances of clay and thus sediment porosity were marginally higher in nodule-associated sediment. Moreover, the smectite-dominated sedimentary column at the nodule-free sampling site was found to be depleted in volcanogenic sediments and bulk Fe-oxide content compared to smectite-depleted sediments at nodule-rich sites. Such distinct sedimentary natures at nodule-associated and nodule-free sites suggest that the effectiveness of subsurface processes towards diagenetic nodule development may be controlled by sediment characteristics also. In particular, the variability in the supply of source materials, which could be influenced by the physicochemical nature of the sediment, might play a critical role in nodule formation and abundance on the deep seafloor.

Keywords: Physical properties, geobiology, Sedimentation, Diagenesis, poly-metallic nodules, Central Indian Ocean Basin.

PORE PRESSURE AND FRACTURE PRESSURE ESTIMATION IN GAS HYDRATE-BEARING SEDIMENTS OF THE KRISHNA-GODAVARI BASIN

Pradeep Kumar Yadav, Uma Shankar
Department of Geophysics, Banaras Hindu University
Presenting author: pdpbhu@gmail.com

ABSTRACT

Accurate estimation of pore pressure is essential for assessing subsurface geomechanical conditions and designing safe drilling operations. Conventional pore-pressure prediction methods based on sonic velocity and resistivity are primarily developed for shale formations and may become unreliable in gas hydrate-bearing sands, where the abrupt increase in acoustic velocity and resistivity is controlled by hydrate saturation rather than sediment compaction. This study investigates pore pressure and fracture pressure in four wells (NGHP-02-17A, 19A, 22A and 23A) from area B of the Krishna-Godavari Basin, offshore eastern India, using logging-while-drilling (LWD), pressure-core and formation-pressure data. In water-saturated intervals, effective stress and pore pressure were estimated using Bowers' sonic, Eaton's resistivity and Eaton's sonic methods. For gas hydrate-bearing intervals, these conventional approaches substantially overestimate effective stress and consequently underestimate pore pressure. To overcome this limitation, pressure-core data from gas hydrate-bearing sand formations were analyzed to establish a depth-dependent linear relationship between effective stress and depth. The pressure-core data exhibit a strong correlation (0.91), and the resulting linear model provides a coefficient of determination (R^2) of approximately 0.83. Application of the model to the four study wells provides effective-stress and pore-pressure estimates consistent with the available core observations. Independent validation at NGHP-02-23, where formation pressure was measured using a Modular Dynamic Formation Tester (MDT), shows good agreement between the measured pore pressure (28.2 MPa) and the model-derived value (27.8 MPa). Pore pressure remains close to hydrostatic within the gas hydrate-bearing interval and becomes moderately elevated below the base of the gas hydrate zone. Fracture pressures estimated using the Matthew-Kelly method and Eaton's method are also consistent. The reported mud density of 1.3 g/cc remains higher than the estimated pore pressure and lower than the fracture pressure, indicating a suitable drilling window. The study demonstrates that pressure-core-derived effective-stress relationships can provide a practical alternative for pore-pressure estimation in gas hydrate-bearing sand formations where conventional empirical methods are inappropriate.

CHARACTERIZING THE STRESS FIELD OF THE CENTRAL INDIAN OCEAN DIFFUSE PLATE BOUNDARY USING FOCAL MECHANISM INVERSION

Rinku Mahanta[1,*], Sanjay S Negi[1], Lachit S Ningthoujam[1], Amit Kumar[1], Athul Ramachandran[1], Sion Kumari[1], John Kurian P[1].

[1]National Centre for Polar and Ocean Research, Ministry of Earth Sciences, Government of India, Headland Sada, Vasco-da-Gama, Goa 403 804, India

[*]Presenting Author: rinkum@ncpor.res.in

ABSTRACT

The Central Indian Ocean (CIO) hosts a broad zone of diffuse intraplate deformation resulting from the reorganization of the India-Capricorn-Australia plate boundary, expressed through elevated seismicity, folding, and high-angle reverse faulting across the Central Indian Basin and Wharton Basin. Despite decades of study, the present-day stress field across this region has not been systematically characterized using a comprehensive, high-resolution focal mechanism catalogue.

In this study, we compile focal mechanism solutions from the ISC catalogue for the period 1970-2026, supplemented with additional solutions estimated at NCPOR, to build an integrated database for the CIO diffuse deformation zone. An iterative joint stress inversion of the focal mechanisms is performed to determine the principal stress axes, the orientation of maximum horizontal compressive stress (SH_{max}), and the stress shape ratio (R) across five regional domains spanning the 90°E Ridge, Wharton Basin, and Central Indian Basin, as well as on a spatial grid to resolve finer-scale stress heterogeneity within the CIO. Uncertainty in the inverted stress orientations is quantified through bootstrap resampling with angular perturbations applied to the fault-normal and slip vectors. The resulting stress field is compared against independent plate-motion models and prior estimates of intraplate stress in the CIO to evaluate the extent to which the observed deformation reflects far-field compressive stress transmitted from the India-Eurasia collision, combined with ridge-push forces.

This work aims to provide the systematic, high-resolution stress-field characterization for the CIO diffuse deformation zone, offering new constraints on the mechanics of oceanic intraplate deformation for Indian Ocean Geoid Low (IOGL) region.

Keywords: Indian Ocean, Diffuse plate boundary, Intraplate stress, Focal mechanism inversion.

ATMOSPHERIC, PLANETARY & SPACE SCIENCES

IONOSPHERIC VARIABILITY ASSOCIATED WITH EARTHQUAKES AND VOLCANOES: OBSERVATIONS OF COUPLED LITHOSPHERE–ATMOSPHERE–IONOSPHERE

Aastha Rawat [1,2], Anshul Singh [1,2], Qadeer Ahmed [1,2], Ankit Gupta [1,2], Puja Goel [3], A. K. Upadhayaya[1,2]
CSIR-National Physical Laboratory, Dr. K. S. Krishnan Marg, New Delhi 10012, India
Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
G. B. Pant University of Agriculture and Technology, College of Basic Sciences and Humanities, Pantnagar 263145, India
Presenting author: aastharawat28@gmail.com

ABSTRACT

The ionosphere represents a dynamic region and responds to a wide range of geophysical, solar and lithospheric drivers, serving as a critical domain for understanding lithosphere-atmosphere-ionosphere coupling. In this study, we examine ionospheric variability associated with two earthquakes in 2025, the Mw 6.0 Afghanistan earthquake on 31 August and the Mw 5.5 Assam earthquake on 14 September, and the 2022 Hunga Tonga–Hunga Ha'apai volcanic eruption. The observations provide an opportunity to correlate ionospheric responses to distinct sources originating within the lithosphere and atmosphere.

For the 2025 earthquakes, ionosonde observations from New Delhi (CSIR-NPL) and IRNSS-based VTEC observations from New Delhi and Pantnagar were analysed, revealing distinct ionospheric anomalies up to 11 days before the Afghanistan earthquake and 7 days before the Assam earthquake. A prominent precursor signature was detected on 20 August 2025, eleven days prior to the Afghanistan event, characterized by significant maximum ΔVTEC depletions of -26.78 TECU accompanied by a ΔfoF_2 depletion of -5.14 MHz. For the Assam earthquake, notable variability was observed 6 days prior (8 September), including a ΔVTEC enhancement of +23.72 TECU and a corresponding ΔfoF_2 enhancement of +4.36 MHz. Distinct enhancements and depletions were observed during the periods preceding the earthquakes, together with Y-forking features in ionograms. Satellite-derived outgoing longwave radiation was additionally examined to investigate the atmospheric component of the lithosphere–atmosphere–ionosphere coupling framework. The observed ionospheric signatures were evaluated considering concurrent solar and geomagnetic conditions and possible non-seismic sources.

The response to the Hunga Tonga–Hunga Ha'apai eruption, whose massive atmospheric explosion (~50 km plume) generated acoustic gravity waves (AGWs) and Lamb waves, was investigated using ionosonde observations over Japan, GPS-derived VTEC over India, and geomagnetic measurements. At a representative Japanese station, ionospheric anomalies were observed 3.5 to 4 hours post-eruption, exhibiting a maximum electron density variation of more than 500% and a peak ΔfoF_2 of 7.86 MHz. Pronounced perturbations in foF_2 and VTEC, Y-forking structures in ionograms, and a strong afternoon counter-electrojet were observed following the eruption. These observations are consistent with the propagation of atmospheric disturbances generated by the eruption into the ionospheric region.

The combined observations indicate that geophysical events can produce measurable ionospheric variability through atmosphere–ionosphere coupling. The study highlights both common and event-specific ionospheric signatures and demonstrates the value of multi-parameter observations for distinguishing externally driven ionospheric variability from background and solar–geomagnetic influences.

EVALUATION OF DIFFERENT SPECTRAL INDICES FOR ASSESSMENT OF ECOLOGICAL CONDITIONS IN HARIKE WETLAND (RAMSAR SITE) USING REMOTE SENSING AND GEOSPATIAL TECHNIQUES

Alka Kumari[1], Mohit Arora[2], Harpreet Singh Sidhu[2,3]*

[1] Department of Geophysics, Kurukshetra University, Kurukshetra 136119, Haryana, India

[2] Geology, Water Resources and Geoinformatics Division, Punjab Remote Sensing Centre (PRSC), Ludhiana 141004, Punjab, India

[3] Department of Geography, Lovely Professional University, Jalandhar 144411, Punjab, India

Presenting Author E-mail ID**:** alkakumari13oct@gmail

ABSTRACT

Wetlands are highly productive ecosystems that play a vital role in maintaining ecological balance, supporting biodiversity, and regulating water resources. Harike Wetland, a Ramsar site in Punjab, is an important wetland ecosystem whose ecological conditions are influenced by variations in vegetation, surface water, and algal growth. The present study evaluates the applicability of spectral indices and geospatial techniques for characterizing the major ecological components of Harike Wetland using multispectral Landsat and hyperspectral PRISMA satellite data. Six spectral indices, namely Normalized Difference Vegetation Index (NDVI), Normalized Difference Aquatic Vegetation Index (NDAVI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), Floating Algal Index (FAI), and Algal Bloom Detection Index (ABDI), were employed to delineate terrestrial vegetation, aquatic vegetation, open water, and algal-dominated areas. Threshold-based classification of the index outputs was used to assess their spatial distribution within the wetland environment. NDVI and NDAVI effectively characterized terrestrial and aquatic vegetation, respectively, while NDWI and MNDWI enhanced the identification and delineation of surface-water areas. FAI and ABDI provided additional information for detecting floating and algal-dominated regions. In addition, Z-spectral analysis was performed using hyperspectral data to examine and compare the reflectance characteristics of agricultural cropland, open water, algae, and built-up surfaces. The spectral profiles enhanced the discrimination of spectrally similar land-cover classes and provided additional information in heterogeneous and mixed areas. The results demonstrate that integrating multispectral spectral indices with hyperspectral spectral profiling provides a comprehensive approach for assessing the ecological characteristics of Harike Wetland. The study highlights the potential of remote sensing and geospatial techniques for wetland monitoring, ecological assessment, conservation planning, and sustainable water-resource management.

Keywords: Harike Wetland; Ramsar site; hyperspectral remote sensing; PRISMA; Landsat; spectral indices; wetland monitoring; ecological assessment

SPATIAL AND TEMPORAL PATTERNS OF DROUGHT OVER THE INDO-GANGETIC PLAIN: PROJECTIONS AND IMPLICATIONS UNDER CLIMATE CHANGE

Anika Pandey[1] and R.K Mall [1]

[1] DST – Mahamana Centre of Excellence in Climate Change Research, Institute of Environment & Sustainable development, Banaras Hindu University, Varanasi, India

Presenting author: anikapandey.iesd.2025@bhu.ac.in

ABSTRACT

Climate change has increased the occurrence of climatic extremes, posing profound risk for agriculture, water resources, and livelihoods across the most populous and major breadbasket of India, the Indo-

Gangetic Plain (IGP). This study assesses the projected changes in drought characteristics over the IGP using an ensemble of 10 CMIP6 Global Climate Models (GCMs) under two Shared Socioeconomic Pathways (SSP2-4.5 and SSP5-8.5) for mid future (2040-2026) and far future (2070-2099). Drought characteristics in terms of duration, frequency, and severity are analyzed based on the Run theory and using the Standardized Precipitation Evapotranspiration Index (SPEI), which incorporates both precipitation variability and atmospheric evaporative demand, thereby providing a more comprehensive representation of climate-induced drought. Projections indicate more significant increase in number of drying events around 8-15 and rise in frequency up to 23% accounted at SPEI-06, indicating agricultural drought conditions during mid-future under both SSP2-4.5 and SSP5-8.5, with notable differences across various sub-regions of the IGP. Drought prone areas expanded considerably, specifically in the Upper and Middle Gangetic Plains which are expected to experience longer and more severe droughts during future period in comparison to historical period (1980-2009), especially because of the expected increase in evaporative demand driven by rising temperature. The findings provide insights for policymakers in planning region-specific actions for effective drought management in one of South Asia's most agriculturally important regions.

PALEOENVIRONMENT AND HYDRODYNAMICS OF EARLY-MIDDLE HOLOCENE SPITI VALLEY USING PALEOLAKE SEDIMENTS

Anish Varma[1*], Pradnya Mohite[1], K. Deenadayalan[1], B.V. Lakshmi[1], A. Anoop[2] and A. P. Dimri[1]
[1]Indian Institute of Geomagnetism, New Panvel, Navi Mumbai, India
[2]Department of Earth and Environmental Sciences, Indian Institute of Science Education and Research Mohali, Punjab, India
*Presenting author: varmanish.official@gmail.com

ABSTRACT

The Spiti Valley in the Northwest Himalaya lies within a climatically sensitive transition zone influenced by the Indian Summer Monsoon (ISM) and mid-latitude winter westerlies. The Attargu palaeolake, formed by landslide damming of the Spiti River near Mane, preserves a ~41 m thick lacustrine sequence deposited between ca. 8.7 and 6.1 cal ka BP. In this study, Anisotropy of Magnetic Susceptibility (AMS), Natural Remanent Magnetization (NRM), and concentration-dependent magnetic parameters were used to investigate variations in sediment provenance, magnetic mineral concentration, and depositional processes. The AMS results reveal systematic changes in the orientation and distribution of the principal susceptibility axes, defining four distinct magnetic fabric zones within the sequence. These variations indicate changes in the organization of magnetic grains and sediment transport conditions through time. The magnetic record is broadly concordant with the previous study, particularly toward the upper part of the sequence, where increased sediment influx reflects the transition to intensified monsoonal conditions after ca. 6.8 cal ka BP. The integrated magnetic record provides valuable information for reconstructing changes in sediment dynamics, depositional conditions, and hydroclimatic variability in the Spiti Valley during the early–mid Holocene. Further magnetic mineralogical and grain/domain-state analyses will help to constrain the relative contributions of detrital and authigenic magnetic minerals and strengthen the paleoenvironmental interpretation.

ASSESSMENT OF DIFFERENT SOIL DIELECTRIC MIXING MODELS SUITABLE FOR L BAND SOIL MOISTURE RETRIEVAL OVER WHEAT CROP

Anjali[1, *], Prashant K Srivastava[1]
[1]Remote Sensing Laboratory, Institute of Environment and Sustainable Development,
Banaras Hindu University, Varanasi, Uttar Pradesh, India
Presenting author: *anjalim214@bhu.ac.in*

ABSTRACT

Soil moisture plays a vital role in the hydrological cycle, influencing water resource management, agricultural productivity, and climate modelling. Accurate estimation of soil moisture hinges on precise determination of the soil dielectric constant, which varies nonlinearly with soil water content, texture, and temperature. This study evaluates four prominent soil dielectric mixing models namely, the Dobson, Hallikainen, Mironov, and Wang and Schmugge to characterize soil dielectric behavior across varying crop growth stages. The study was conducted over wheat-growing agricultural fields in the Varanasi region, representing typical alluvial soil conditions. In-situ measurements were collected on three separate dates across four different locations using field sensors and satellite-based microwave observations (SMAP brightness temperature) were used to support the estimation. The model-derived dielectric constants were analyzed based on agreement, variability, and consistency across different sites and dates and compared with field observations and evaluated using statistical metrics such as root mean square error (RMSE), coefficient of determination (R^2), and Bias. The graphical analysis along with performance statistics indicate that the Wang & Schmugge and Mironov models with low RMSE values ranging from 0.545–2.49 and 1.80–3.86 respectively and Bias values range from -0.105 to -3.54 & −1.71 to −3.54 across all sites and dates respectively demonstrates the highest reliability and precision, followed by the Hallikainen and Dobson models which tend to consistently underestimate the dielectric constant across all sites and crop stages.

Keywords: Soil Dielectric Mixing Model, Crop Stages, L band, Soil Moisture

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY CONSTRAINTS ON THE EVOLUTION OF THE KIOTO PALEOLAKE, SPITI VALLEY, NW HIMALAYA.

Ankita P. Sarangi, Neha Goswami, Pratikshya Behera, V. Priyanka, Manan Singh, B.V. Lakshmi, K. Deenadayalan, A.P. Dimri
Indian institute of Geomagnetism, Navi Mumbai
Presenting author: prachipriyadarshini209@gmail.com

ABSTRACT

The evolution of the Kioto paleolake succession in the Spiti Valley, NW Himalaya, reflects the interplay between Himalayan tectonics and changing depositional conditions. The succession comprises ~25 m of lacustrine clay overlain by ~2–3 m of fluvial sediments, with basal coarse sand covered by landslide debris, indicating a multiphase evolution of the paleolake. In this study, anisotropy of magnetic susceptibility (AMS) was used to determine the magnetic fabric and to assess the changes in depositional energy and potential post-depositional deformation within the lake sediments. The lower part of the section (0–4.9 m) is characterized by predominantly vertical Kmin axes with a NE–SW trend and sub-horizontal Kmax axes with a preferred NW-SE orientation. The near-perpendicular relationship between Kmin and Kmax, together with dominantly oblate AMS ellipsoids, indicates a planar depositional fabric formed in relatively high-energy conditions of current flow. The middle

interval (4.9–10.6 m) is defined by mostly vertical to sub-vertical Kmin axes, whereas Kmax axes predominantly sub-horizontal with a dominant NE–SW orientation and a subordinate NW–SE trend. The fabric suggests a transition to lower-energy, low-velocity lacustrine depositional conditions, consistent with the dominance of oblate ellipsoids. The upper part (10.6-26 m) is dominated by vertical to sub-vertical Kmin axes and mostly horizontal Kmax axes clustered along N-S. More than 90% of the AMS ellipsoids are oblate, implying predominantly planar fabric associated with low-energy lacustrine conditions, whereas the minor prolate fraction might be the result of local fluvial interaction. The mean P′ value of ~1.09 indicates a weakly developed magnetic fabric. Overall, the vertical variations in AMS fabrics records changes in depositional energy and lake dynamics, providing clues for multiphase evolution of the Kioto paleolake in relation to the regional Himalayan tectonic activities.

INSIGHTS INTO PAST CLIMATE CHANGE FROM BOREHOLE TEMPERATURE PROFILES IN THE CHHOTANAGPUR GRANITE GNEISS COMPLEX, INDIA

Ankita Roy[*1], Sandeep Kumar Prajapati[1,2], Labani Ray[1,2], Nishu Chopra[1,2]
[1]CSIR-National Geophysical Research Institute, Hyderabad-500007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India
Presenting author (email- ankitakgp12@gmail.com)

ABSTRACT

Climate change is one of the major challenges affecting human societies and natural systems. Understanding past climate change is important for assessing recent climatic changes, particularly in regions where long-term instrumental records are limited. Changes in surface temperature propagate downward into the subsurface by heat conduction and disturb the background thermal regime. These disturbances are mainly preserved in the shallower part of temperature–depth (T-z) profiles as positive or negative temperature anomalies, which provide a record of past surface-temperature changes. In this study, T-z profiles from 19 boreholes, with depths ranging from 150 to 450 m, distributed across different parts of the Chotanagpur Granite Gneiss Complex (CGGC), Eastern Indian Shield, are analysed to investigate past changes in surface-ground temperature. To reconstruct the temperature history, the geothermal gradient was estimated from the deeper, approximately linear and relatively undisturbed portion of each temperature-depth profile. The background temperature profile was then removed from the observed profile to obtain the reduced temperature profile representing the transient temperature signal. The reduced temperature profiles were subsequently analysed using the solution of the one-dimensional heat-diffusion equation, with inversion approach to estimate the magnitude and timing of past surface-temperature changes. The results indicate recent surface warming in the CGGC, consistent with the average warming reported for the Indian Shield, with an estimated temperature increase of approximately 1°C over the last century. However, the reconstructed temperature histories from some boreholes also reveal earlier cooling phases, which may reflect local or site-specific influences. These findings demonstrate that borehole temperature profiles can preserve evidence of both warming and cooling phases, providing insights into climate variability beyond the period covered by instrumental observations. The reconstructed temperature histories thus offer new evidence of past surface-temperature variability in the CGGC and highlight the potential of borehole temperature profiles for extending the regional climate record.

Keywords: Temperature; Heat conduction; Surface-ground temperature; Past climate; Chotanagpur Granite Gneiss Complex**.**

BROADBAND GROUND MOTION MODELLING OF MARSQUAKES AT HESPERIA PLANUM USING HYBRID SIMULATION TECHNIQUES

Arghya Kusum Dey[1,2]*, Rahul Biswas[1,2], Prakash Kumar[1,2]
[1] CSIR–National Geophysical Research Institute (CSIR-NGRI), Hyderabad, Telangana, India
[2] AcSIR – Academy of Scientific and Innovative Research, Ghaziabad, India
*Corresponding author: Arghya Kusum Dey (arghyakusumdey@gmail.com)

ABSTRACT

Deep-learning-based polarization analysis of InSight data has identified a new clustered seismicity zone at Hesperia Planum, comprising seven low-frequency-family marsquakes (M_w 2.7–3.6) at epicentral distances of ~30° from InSight. Unlike Cerberus Fossae, where seismicity is tied to extensional dike-induced grabens, Hesperia Planum is a wrinkle-ridge-dominated volcanic plain, with seismicity tentatively linked to compressional rupturing from planetary thermal contraction. Ground motion characterization for this source region remains unexplored, and fault geometry, rupture kinematics, and site response are presently unconstrained.

This study estimates attenuation-corrected source parameters and develops a probabilistic ground motion model for the Hesperia Planum cluster. A kinematic rupture model is designed for a representative thrust-style fault geometry consistent with the wrinkle-ridge setting, incorporating spatial variation in slip, rupture velocity, and rise time along strike, combined with a 1D Martian velocity model for the local crust. A hybrid broadband approach couples deterministic low-frequency ($f < 1$ Hz) 3D wave propagation with stochastic high-frequency ($f > 1$ Hz) synthesis to generate synthetic seismograms for comparison against the relocated events. Synthetics are validated against SEIS data via spectral fitting, corner frequency estimation, and PGA/PGV comparison, and evaluated within a Ground Motion Prediction Equation (GMPE) framework, with attention to whether this cluster's lower moment release and compressional style yield attenuation and scaling behavior distinct from Cerberus Fossae.

Virtual seismic stations proposed around the Hesperia Planum epicentral region are used to generate PGA/PGV contour maps, offering a first hazard characterization for a Martian tectonic setting not previously modelled. Contrasting an extensional and a compressional source region clarifies how tectonic style modulates Martian ground motion, informing future network deployment and landing-site risk assessment.

Keywords: Ground motion simulation, Hesperia Planum, Marsquake cluster, Compressional tectonics, Seismic hazard

MAGNETIC CHARACTERIZATION OF AIRBORNE POLLUTANTS DERIVED FROM URBAN ROAD DUST AND THEIR POTENTIAL HEALTH IMPLICATIONS

Durga Prasad Tripathi[1*], Arvind Kumar Nema[2], Rajesh Singh[3], A. P. Dimri[4]**
[1]Dr. KSK Geomagnetic Research Laboratory, Indian Institute of Geomagnetism (IIG), Prayagraj, India 22505
[2]Indian Institute of Technology (IIT) Delhi, Hauz Khas, New Delhi, India 110016
[*]Email Id: durgaprasadtripathi@gmail.com, [**]Email Id: rajesh.singh@iigm.res.in

ABSTRACT

Airborne and settled road dust in megacities such as Delhi, India, contains fine particulate matter associated with potentially neurotoxic metals (e.g., Pb) and magnetic pollutants (e.g., magnetite), a

growing concern in highly- traffic loaded urban environments. This study examined road dust from four locations across Delhi including IIT Delhi (IITD), Padmini Enclave, All India Institute of Medical Sciences (AIIMS), and South Extension-1 (South Ex-1), characterized using mass- specific low-frequency (χ_{LF}) and high-frequency (χ_{HF}) magnetic susceptibility, anhysteretic remanent magnetization (χ_{ARM}), saturation isothermal remanent magnetization (SIRM), and elemental composition. A pronounced spatial variation in magnetic characteristics was observed across the sampling sites. South Ex-1 exhibited the strongest magnetic enhancement, with χ_{LF} reaching 503×10^{-8} m^3/kg and SIRM values of up to 6175×10^{-5} Am^2/kg. χ_{ARM} ranged from 30.98×10^{-7} $m^3\ kg^{-1}$ (Padmini Enclave) to 69.04×10^{-7} $m^3\ kg^{-1}$ (South Ex-1). AIIMS showed the next highest magnetic response, with χ_{LF} ranging from 288 to 378×10^{-8} m^3/kg and SIRM from 3216 to 4396×10^{-5} Am^2/kg. In contrast, IITD and Padmini Enclave exhibited comparatively lower and more variable magnetic responses, with χ_{LF} at Padmini Enclave reaching as low as 165×10^{-8} m^3/kg. Elemental analysis further supported the observed magnetic variation. Fe content ranged from 5.88% at South Ex-1 to 6.26% at AIIMS, with AIIMS also showing the highest concentrations of Mn (0.157%) and Pb (0.023%). The parallel behaviour of χ_{LF} and χ_{HF} across all locations indicated dominance of coarse ferrimagnetic grains from vehicular combustion and mechanical abrasion, while co- enrichment of Fe, Mn, and Pb at AIIMS and South Ex- 1 strengthened the magnetic- geochemical linkage. These magnetic, Fe- rich particulates are increasingly recognized as an emerging environmental concern in rapidly urbanizing megacities, where their fine, respirable nature and capacity to carry neurotoxic trace metals raise the possibility of translocation into biological tissue via inhalation.

Keywords: Magnetic pollutants, Magnetic susceptibility, Ferrimagnetic grains, Neurotoxic trace metals

INVESTIGATING THE ANCIENT GEOMAGNETIC FIELD INTENSITY USING ARCHAEOLOGICAL ARTEFACTS FROM WESTERN INDIA

Juili Raut, Pradnya Mohite, K. Deenadayalan, B.V. Lakshmi, and A.P. Dimri
Indian Institute of Geomagnetism, New Panvel, Navi Mumbai
Presenting Author Email: juileeraut25@gmail.com

ABSTRACT

Earth's magnetic field is governed by both high-frequency external forcing, such as space weather, and long-term internal core dynamics known as secular variation. Investigating these variations requires tracking the absolute strength of the ancient field; however, the necessary archaeointensity data points remain critically sparse for the Indian subcontinent. The present study focuses on determining the ancient geomagnetic field intensity from archaeological artefacts collected from three sites in Maharashtra: Korlai Fort and Nizam Shahi Mosque (both 16th century CE), and Phupgaon (7th–4th century BCE). Prior to the intensity experiments, detailed rock-magnetic measurements were executed to systematically characterise the magnetic mineralogy, grain-size distribution, and thermal behaviour of 37 selected specimens. The laboratory results demonstrate that magnetite operates as the primary magnetic remanence carrier across the majority of the samples, while specific specimens contain coexisting ferrimagnetic magnetite and antiferromagnetic hematite minerals in varying proportions. Remanence ratios indicate that the magnetic grain sizes reside within stable single-domain (SD) to pseudo-single-domain (PSD) states. Furthermore, continuous temperature-dependent magnetic

susceptibility (χ–T) analyses reveal distinct Curie temperatures falling between 580 °C and 590 °C. The high degree of reversibility observed in these thermomagnetic curves confirms the presence of thermally stable magnetite and the complete absence of mineralogical transformations or chemical alteration during laboratory heating. These diagnostic rock-magnetic characteristics confirm that the selected artefacts are exceptionally suited for reliable intensity determination. Absolute archaeointensity measurements were performed using the classical Thellier-Thellier method. The resulting experimental datasets were evaluated using ThellierTool 4.0 software to analyse the linear relationship between the progressive loss of natural remanent magnetisation (NRM) and the laboratory acquisition of thermoremanent magnetisation (TRM). Corrections for the anisotropy of TRM (ATRM) and laboratory cooling-rate effects were strictly incorporated. These outcomes provide precise new archaeointensity data points for Maharashtra, significantly expanding the limited database available for the Indian subcontinent.

PARTICLE-SIZE SPECIFIC MAGNETIC PROPERTIES OF A LARGE OXBOW LAKE SURFACE SEDIMENTS: EVIDENCE FOR HYDRODYNAMIC SORTING

Mohit Shivane[1*], Priyeshu Srivastava[1], A.P. Dimri[1]
[1]Indian Institute of Geomagnetism, Navi Mumbai 410218, India
Presenting author: shivanemohit@gmail.com

ABSTRACT

Lakes are a crucial element of the Earth's hydrosphere and can accurately document regional climate changes over decadal to millennial time scales. Lake sediments preserve integrated records of catchment erosion, sediment transport, aquatic productivity and post-depositional processes, and are therefore widely used to reconstruct environmental and climatic change. This work integrates environmental magnetic measurements, grain size distributions and organic matter content of surface sediments of a large monsoon-fed oxbow lake from the Ganga Plain, to understand links between magnetic mineral concentrations, grain-size distributions, and modern environmental parameters. Environmental magnetic measurements, including magnetic susceptibility (χ), anhysteretic remanent magnetization (ARM) and saturation isothermal remanent magnetization (SIRM), on bulk samples reveal spatial heterogeneity in magnetic mineral abundance across the lake basin reflecting variable sediment inputs from the catchment. Particle-size specific magnetic measurement demonstrate that magnetic minerals, are preferentially concentrated in finer fractions (<20 μm). Our findings underscore the utility of environmental magnetism as a rapid and non-destructive proxy for tracing modern sedimentary processes and anthropogenic impacts.

Keywords: Surha Lake; Ganga Plain; environmental magnetism, grain size-specific magnetism

STATISTICAL CHARACTERISTICS AND SPATIAL DISTRIBUTION OF ELECTROMAGNETIC ION CYCLOTRON (EMIC) WAVES IN THE EARTH'S MAGNETOSPHERE

Neetu Singh*(1), Bharati Kakad (1), Amar Kakad(1)
Indian Institute of Geomagnetism, New Panvel, Navi Mumbai, India – 410218
e-mail: neetusingh7948@gmail.com

ABSTRACT

Electromagnetic Ion Cyclotron waves are low frequency plasma waves that play an important role in magnetospheric dynamics through wave-particle interactions, particularly in the scattering and precipitation of energetic electrons into the Earth's upper atmosphere. Although EMIC waves have been extensively investigated in the Earth's inner magnetosphere using both ground-based and satellite observations. Nevertheless, their occurrence and characteristics in the outer magnetosphere at large Lshells is not well explored. In this study, we examined the statistical characteristics and spatial distribution of EMIC waves in the inner and outer magnetosphere using magnetic field observations from Magnetospheric Multiscale Spacecraft (MMS) satellites during the ascending phase of solar cycle 25. A total of 536 EMIC wave events were identified from high-resolution Fluxgate Magnetometer (FGM) observations through spectral analysis of magnetic field fluctuations. For each wave event, parameters including wave frequency range, central frequency, polarization, ellipticity, periodicity, duration, magnetic latitude (MLAT), magnetic local time (MLT), and spacecraft altitude have been determined. Later this compiled information is quantified statistically to get the trends in their occurrence pattern. The detailed statistical results will be presented. These results provide insights on the spatial distribution of EMIC waves covering inner and outer magnetosphere in the ascending phase of solar cycle 25.

MINERAL MAGNETIC SIGNATURES OF SEDIMENT PROVENANCE: INSIGHTS FROM THE MANE PALEOLAKE, LOWER SPITI, NW HIMALAYA

Neha Goswami, Ankita.P.Sarangi, Pratikshya Behera, V.Priyanka, Manan Singh,
B.V. Lakshmi, K. Deenadayalan, A.P. Dimri
Indian Institute of Geomagnetism, Mumbai
Presenting Author: nehagoswami9539@gmail.com

ABSTRACT

Environmental magnetism provides a rapid, sensitive, and non-destructive approach for investigating sediment provenance, transport processes, and environmental changes preserved in lacustrine sequences. In this study, mineral magnetic properties of a~15-m-thick sedimentary sequence from the Mane paleolake, Lower Spiti region, northwestern Himalaya, were investigated.This region lies within a climatically sensitive zone influenced by the Indian Summer Monsoon and mid-latitude westerlies within the Trans-Himalayan rain-shadow region, which preserves valuable sedimentary archives. Magnetic concentration, grain size, and mineralogy were determined using a wide range of magnetic parameters, including low-frequency magnetic susceptibility (χlf), saturation isothermal remanent magnetization (SIRM), anhysteretic remanent magnetization (ARM), frequency-dependent susceptibility(χ_{fd}%), ARM/χ_{lf}, SIRM/χ_{lf}, S-ratio, HIRM, and IRM acquisition.The sedimentary sequence has been divided into four magnetic zones. Zone 1 has comparatively coarse magnetic grains and a low magnetic concentration, suggesting a low magnetic mineral input. Zone 2 shows an

increasing trend in magnetic concentration and a significant contribution of low-coercivity, fine-grained minerals, indicating a higher influx of detrital or pedogenic magnetic material from the catchment area.Zone 3 exhibits fluctuating magnetic concentration and grain size, which depicts presence of mixed magnetic population from different sediment source, while elevated χ_{fd}% indicate a significant presence of superparamagnetic particles. Zone 4 exhibits a moderate magnetic concentration with slight variations, indicating a comparatively steady influx of sediment. A substantial contribution of high coercivity minerals like hematite is indicated by high HIRM and low S-ratio values.Since a most samples are unsaturated at 2T, IRM acquisition curves further support the presence of a hard-magnetic component.However some sample showing low coercivity ferrimagnetic mineral behaviour,like magnetite/maghemite.Overall, variations in magnetic concentration, particle size, and mineralogy provide important insights into variations in sediment sources and catchment erosion, illustrating how mineral magnetic proxies can be used to reconstruct sediment source-to-sink dynamics in Himalayan lake systems.

GEOMAGNETIC STORM-INDUCED VARIABILITY OF IONOSPHERIC TEC: A MULTI-STATION ASSESSMENT USING GNSS OBSERVATIONS AND ANN MODELING

[1,2]Nitin Dubey, [1]Gurpinder Singh, &[2,3,4]Devbrat Pundhir

[1]Department of Chemistry, School of Chemical Engineering and Physical Sciences, Lovely Professional University, Phagwara, Punjab 14441, India

[2]Seismo-electromagnetics & Space Research Laboratory, Department of Physics, Raja Balwant Singh Engineering Technical Campus, Bichpuri, Agra, India

[3]Kuala Lumpur University of Science & Technology, Selangor Darul Ehsan 43000, Malaysia [4]Visiting Faculty, SR University, Ananthasagar, Hasanparthy, Warangal, Telangana 506371, India

Presenting author e-mail: dubeyn380@gmail.com

ABSTRACT

Geomagnetic storms can produce substantial and spatially variable disturbances in the ionosphere, with important implications for satellite-based communication and navigation. This study investigates the response of ionospheric total electron content (TEC) to the severe G5 geomagnetic storm of 10–11 May 2024 using observations from 46 International GNSS Service (IGS) stations distributed across low-latitude regions. TEC observations for 9–14 May 2024 were examined to distinguish storm-time disturbances from the quiet-time background, while geomagnetic parameters including Bx, By, Bz, Dst, AE and ΣKp were used to characterize the intensity and evolution of the storm. The observed TEC was further compared with International Reference Ionosphere (IRI-2020) estimates to assess the performance of an empirical climatological model under disturbed conditions. In addition, an Artificial Neural Network (ANN)-based nonlinear autoregressive network with exogenous inputs (NARX) model was employed to predict TEC variations. The results reveal pronounced latitudinal, longitudinal and local-time dependence of the storm response. During the main phase, equatorial stations generally exhibited TEC enhancements of up to about 50 TECU, whereas most stations outside the equatorial region experienced depletions reaching about 45 TECU. Strong longitudinal contrasts were also observed, with daytime sectors showing enhancements of approximately 20–50 TECU and dusk-to-night sectors exhibiting dominant depletions of about 30–60 TECU. The ANN predictions reproduced the observed TEC variations more accurately than IRI-2020, with ANN-derived RMSD generally below 3 TECU compared with values exceeding 4 TECU for IRI-2020 at most stations. The findings demonstrate that storm-driven ionospheric variability is highly non-uniform and highlight the potential

of GNSS observations combined with data-driven modeling for improved monitoring and prediction of ionospheric disturbances during severe space-weather events.

TRACKING AEOLIAN SAND MIGRATION AND EMERGING DESERTIFICATION IN THE SEMI-ARID RAYALASEEMA LANDSCAPE OF INDIA: A MULTI-TEMPORAL REMOTE SENSING ASSESSMENT OF ANANTAPUR

Badapalli Pradeep Kumar1* ; Anusha Boya Nakkala2 , Sakram Gugulothu3
1 Dept of Geography & Geoinformatics, Central University of Andhra Pradesh, Anantapur, India – 515701
2 Dept of Geology, Government College (A), Anantapur, Andhra Pradesh, India – 515001
3CSIR – National Geophysical Research Institute, Uppal, Hyderabad, Telangana, India – 500007 *
Presenting & Corresponding Author: badapallipradeep@gmail.com

ABSTRACT

Aeolian sediment mobilisation is an important yet comparatively under-investigated driver of land degradation in the semi-arid landscapes of peninsular India. Anantapur district of Andhra Pradesh, within the drought-prone Rayalaseema region, is particularly vulnerable because of low and variable rainfall, high temperatures, sparse vegetation, soil-moisture deficits, and strong seasonal winds. This study investigates the spatial distribution and temporal dynamics of aeolian sand migration and their association with emerging desertification using multi-temporal satellite remote sensing and geospatial analysis. Satellite observations were integrated with rainfall variability, land-surface temperature, vegetation dynamics, surface characteristics, and hydrological conditions to identify areas exhibiting persistent surface exposure, sand mobilisation, and land-degradation signatures. The analysis identifies approximately 192 km² of land as concentrated hotspots of aeolian activity and associated land degradation within Anantapur. The spatial patterns indicate that recurrent surface drying and vegetation degradation increase sediment availability and susceptibility to winddriven transport, particularly under strong seasonal wind conditions. Annual rainfall of approximately 550 mm, combined with summer temperatures frequently reaching 42°C and occasionally exceeding 46°C, intensifies evaporative demand, soil-moisture stress, and surface instability. The predominance of non-perennial drainage further increases dependence on seasonal rainfall and places additional pressure on surface- and groundwater resources. Aeolian sand migration is therefore interpreted as a potential positive feedback mechanism of desertification, in which vegetation loss and declining soil moisture enhance sediment mobilisation, further accelerating land degradation. The findings identify Anantapur as a significant emerging desertification-risk landscape in southern India, rather than implying inevitable desert formation. The study demonstrates the value of remote sensing for monitoring aeolian processes and provides a scientific basis for targeted wind-erosion control, vegetation restoration, soil-moisture conservation, rainwater harvesting, and sustainable groundwater management under increasing climatic variability. Keywords: Aeolian sand migration; desertification; land degradation; semi-arid environment; Rayalaseema; Anantapur; remote sensing; wind erosion; land-surface temperature; vegetation dynamics.

DIGITAL SOIL MAPPING OF SOIL ORGANIC CARBON STOCKS IN WEST BENGAL: IMPLICATIONS OF FUTURE CLIMATE CHANGE

Progya Mukherjee[1*] and R.K Mall [1]
[1] DST – Mahamana Centre of Excellence in Climate Change Research, Institute of Environment & Sustainable development, Banaras Hindu University, Varanasi, India
Presenting author - mukherjeeprogya@gmail.com

ABSTRACT

Soil organic Carbon (SOC) is an indicator of soil health contributes significantly in the sequestration of carbon that might otherwise contribute to the global warming leading to climate change consequences. Climate change leading to increased temperature conditions and erratic precipitation patterns have significant impact on the soil organic carbon. There is significant knowledge gap regarding the changing Carbon stock in the top soil(0-30cm) with changing climatic conditions. In the present study we have used ISRIC SoilGrids SOC data in a Digital Soil Mapping framework to predict future SOC stocks across the state of West Bengal. We have used multiple linear regression (MLR), random forest (RF) and Support Vector Regression(SVR) method for training the dataset. Based on the model evaluation matrix, SVR (R-squared = 0.61, rmse = 3.65, LCCC= 0.74) was found to be the best performing model. Further, we projected the SOC stocks for the mid-future (2040-2069) and far-future (2070-2099) under two Shared Socio-economic Pathways (SSPs) scenarios SSP2-4.5 and SSP5-8.5 based on global climate models (GCMs) from the Coupled Model Inter- comparison Project Phase 6 (CMIP6) using SVR. Further the change from the baseline time period (1980-2009) was calculated. The results show a percentage decrease in most regions under all the scenarios. However, the maximum decrease of about 5% was observed mainly in the central and southern parts of the study area, in SSP5-8.5 scenario during the far-future. The findings can be used to support decision-making in land management and climate change mitigation strategies in West Bengal.

SPATIO-TEMPORAL CHARACTERISTICS OF MARINE HEATWAVES ALONG THE MALABAR COAST

Rama Pandey#, B Mandal and R Bhatla
Department of Geophysics, Banaras Hindu University, Varanasi.
#Presenting author: ramapandey@bhu.ac.in

ABSTRACT

Marine heatwaves (MHWs) are prolonged periods of anomalously high sea surface temperatures that have profound impacts on marine ecosystems and regional climate. This study analyzes the spatio-temporal characteristics of marine heatwaves (MHWs) along the Malabar Coast using NOAA OISST v2.1 Sea Surface Temperature (SST) data from 1982 to 2025. The spatial distribution of six MHW metrics averaged over the Malabar region yielded mean MHW intensity, duration and frequency of 1.11 °C, 12.7 days and 2.91 events per year, respectively. A simple linear regression analysis of daily area-weighted SST against time showed a significant positive warming trend (~0.20 °C per decade) over the Malabar region, corresponding to a total fitted SST increase of 0.88 °C over the study period (R^2 = 0.0966, p< 0.001). Because long-term warming is not solely responsible for these extreme heat events, the fitted linear trend was removed to obtain a detrended SST series used for regional MHW detection. Notably, intense events occurred in years such as 2015 and 2023/24, with heatwave days

increasing at a rate of roughly 10–15 days per decade in the southeastern Arabian Sea, which influences the Malabar Coast area. The Malabar Coast's role as a major upwelling zone makes it crucial for monitoring these changes. This study underscores an urgent need for enhanced monitoring and adaptation strategies to mitigate the ecological and socio-economic impacts of marine heatwaves along the Malabar Coast. These findings reflect current scientific understanding and research trends on MHWs in the region, emphasizing the interannual variability and their increasing frequency and duration.

Keywords: Marine heatwaves, Malabar Coast, NOAA OISSTv2.1, Interannual variability, Upwelling.

LINKING GREEN SPACE CONNECTIVITY AND URBAN HEAT MITIGATION: A DECADAL ASSESSMENT OF BENGALURU

Rupam Singh[1*], R.K. Mall[1]
[1]DST – Mahamana Centre of Excellence in Climate Change Research, Institute of Environment & Sustainable Development, Banaras Hindu University, Varanasi, UP, 221005, India
Presenting author: rupamsingh1895@gmail.com, rkmall@bhu.ac.in

ABSTRACT

Indian cities undergoing rapid urban growth are experiencing major shifts in land cover, with green areas becoming increasingly fragmented and surface temperatures steadily rising. Bengaluru, among the fastest-developing urban centers in South Asia, has witnessed a marked intensification of the urban heat island (UHI) effect due to dense construction and reduced vegetation cover. This research investigates the evolving relationship between green space patterns and urban thermal environments over the period 2014–2024. Using multi-source datasets, Landsat 8 OLI/TIRS, Resourcesat-2 LISS-IV, and high-resolution Google Earth imagery, we mapped changes in vegetation extent, impervious surface cover, and land surface temperature (LST). The Coupling Coordination Degree Model (CCDM) was applied to evaluate how effectively green infrastructure supports thermal regulation at the city scale. Results show a mean LST increase of nearly 3.9 °C over the decade, accompanied by a decline in average NDVI from 0.18 to 0.13. While vegetation maintained a strong inverse relationship with surface temperature, the coordination between them deteriorated, particularly in high-density built-up areas after 2019. Thermal hotspots were consistently linked to zones with sparse, poorly connected greenery, and built-up intensity showed a negative correlation with thermal coordination. By integrating high-resolution, manually digitized green space mapping with landscape metrics and remote sensing indices, this study demonstrates a transferable framework for urban climate analysis. Findings emphasize the urgent need for strategically connected green infrastructure and micro-scale greening solutions to mitigate UHI impacts in rapidly urbanizing cities.

Keywords: Urban Heat Island, Urban Green Space, LST, Coupling Coordination Degree Model (CCDM), NDVI

EXPLORING SIGNATURES OF VOLCANIC ACTIVITY ON VENUS THROUGH MULTI-MISSION OBSERVATIONS

Satyamesh H. Tiwari[1*] & Mala S. Bagiya[1]
[1]Indian Institute of Geomagnetism (DST), Navi Mumbai, India
*satyameshtiwari@gmail.com

ABSTRACT

Observations of Venus reveal evidence of recent surface changes in synthetic aperture radar (SAR) data, along with significant variability in atmospheric sulfur dioxide (SO_2), raising the possibility of ongoing volcanic activity on the planet. However, distinguishing potential volcanic signatures from atmospheric dynamical processes remains a challenge. This study explores potential signatures of present-day volcanic activity using observations from Magellan, Pioneer Venus Orbiter, Venus Express, and Akatsuki. Variations in atmospheric trace gases, particularly SO_2 and H_2O, are examined alongside available SAR observations of surface changes to identify signatures that may be associated with volcanic activity.

LITHOSPHERE-ATMOSPHERE-IONOSPHERE COUPLING FOLLOWING LARGE VOLCANIC ERUPTION: CASE STUDY OF 13 JULY 2003 SOUFRIÈRE HILLS ERUPTION

Satyamesh H. Tiwari[1*]& Mala S. Bagiya[1]
[1]Indian Institute of Geomagnetism (DST), Navi Mumbai, India
*satyameshtiwari@gmail.com

ABSTRACT

The 13 July 2003 VEI 3 explosive eruption of Soufrière Hills, Montserrat, produced an ash column reaching approximately 15 km. AIRS 4.3 μm observations acquired ~1.5 h after the eruption revealed concentric, ripple-like brightness-temperature perturbations propagating outward from the volcanic source, indicating stratospheric gravity waves. Corresponding GNSS-TEC observations from GPS PRNs 2, 11, 27, and 31 showed clear wave-like ionospheric oscillations, with enhanced wavelet power below 2 mHz, supporting a gravity wave origin. Rapid TEC perturbations associated with acoustic wave propagation were also detected, revealing the simultaneous presence of gravity- and acoustic-wave signatures. These observations demonstrate that volcanic energy was transferred from the eruption into the atmosphere and ionosphere through multiple wave modes. The coexistence of acoustic and gravity wave signatures makes this event a distinctive example of volcanic lithosphere-atmosphere-ionosphere (LAI) coupling.

SPATIO-TEMPORAL HETEROGENEITY OF LAND SURFACE TEMPERATURE AND SURFACE URBAN HEAT ISLAND CHARACTERISTICS IN LUCKNOW, INDIA

Shreya Rai1*, R.K. Mall1
1DST - Mahamana Centre of Excellence in Climate Change Research, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, UP, 221005, India
Presenting author: raishreya.4769@gmail.com, rkmall@bhu.ac.in Abstract

ABSTRACT

Urbanization-induced land surface modifications have intensified thermal imbalances in cities, leading to the emergence of Urban Heat Island (UHI) effects. This study examines the spatial and seasonal

variability of Land Surface Temperature (LST) and Surface Urban Heat Island (SUHI) characteristics in Lucknow, India, using multi-temporal satellite data for the period 2000–2020, covering both summer and winter seasons. Urban extents were delineated using the Global Human Settlement Layer (GHS-SMOD), and a buffer-based zonation approach was employed to classify urban core, peri-urban, and rural regions. Zonal statistics within a GIS framework were used to quantify temperature variations and assess thermal gradients across these zones. The results indicate a consistent urban–rural thermal contrast, with the urban core generally exhibiting higher surface temperatures than the surrounding rural areas. The estimated SUHI intensity generally ranges between approximately 1–2°C, with comparatively higher intensities observed during winter than summer. A clear spatial gradient is evident, showing a systematic decline in temperature from the urban core towards rural zones, while peri-urban areas exhibit transitional thermal characteristics influenced by heterogeneous land-use patterns. The findings emphasize the importance of considering both seasonal variability and peri-urban dynamics in UHI assessments. This study provides critical insights for urban planning and climate adaptation strategies, highlighting the need for integrated approaches to mitigate heat stress in rapidly urbanizing regions.

Keywords: Surface Urban Heat Island, Land Surface Temperature, Urban Thermal Gradient, Seasonal Variability, Peri-urban Dynamics, Lucknow

REMOTE SENSING-BASED QUANTIFICATION OF GLACIER DYNAMICS AND CLIMATE DRIVERS IN THE ZANSKAR VALLEY, LADAKH

Tania Basu[1,2], Manish Mehta[1]
[1] Wadia Institute of Himalayan Geology, 33, GMS Road, Dehradun 248001, India.
[2] Academic of Scientific and Innovative Research, Ghaziabad, 201002, India.
*Presenting author: tania@wihg.res.in

ABSTRACT

This study quantifies snow-cover and glacier dynamics and their climatic controls in the Zanskar Valley glaciers over ~2015–2025 by integrating satellite-derived Normalized Difference Snow Index (NDSI) maps with daily reanalysis and model products. Using multi-temporal Landsat imagery (2019–2025), annual and seasonal snow-cover extent was mapped via NDSI, which exploits snow's high green-band reflectance and strong SWIR absorption to minimize atmospheric and illumination effects and enable consistent, large-area monitoring. Daily ERA5-Land mean temperature, CHIRPS precipitation, and GLDAS snow-depth fields were compiled and correlated with NDSI-derived snow-cover variability to assess the strength and seasonality of temperature, precipitation, and snow-pack controls on observed changes. Results show marked intra-annual and inter-annual variability, where mean annual snow cover is seen to be ~67%, with a seasonal maximum in March (~96%) and minimum in August (~32%), consistent with strong accumulation during winter–spring and extensive ablation and meltwater production during the monsoon and late summer. Drang Drung Glacier (33.76°N, 76.30°E), one of the largest and most accessible glaciers of the Zanskar Range (area ~69.6 km²; length ~24 km; average elevation ~4,780 m; maximum ~6,573 m), exhibits recent negative mass balance (-0.74 ± 0.43 m w. e. a^{-1}, 2021–2023), an equilibrium-line altitude near 5,134 m asl (2021–2023), frontal retreat of ~1 m a^{-1} (2021–2023), and long-term area loss of ~10.73% since the 1970s. Concurrent pro-glacial lake growth (0.28 km² in 2020; ~0.18×10^6 m³ volume in 2021) underscores emerging hazards, including potential

glacial lake outburst floods. Using multi-temporal Sentinel-2 imagery (2019–2025), this study applies the Normalized Difference Snow Index (NDSI) to generate annual and seasonal snow-cover maps and quantify inter-annual variability in snow extent across the Zanskar Valley. Leveraging decadal records of daily ERA5-Land mean temperature, CHIRPS precipitation, and GLDAS snow depth, the analysis elucidates hydroclimatic controls on snow-cover dynamics and recent climate variability in the region. The integrated results provide actionable evidence for hydrological response assessment and inform water-resources planning and risk management strategies in Zanskar. The glacier's runoff sustains the Doda and Zanskar rivers, linking cryospheric change to downstream water security.

Keywords: Remote sensing, NDSI, Drang Drung Glacier, Zanskar Valley, snow cover, glacier dynamics, climate change

THE EARLY HOLOCENE NORTH-EAST MONSOON VARIABILITY: A MULTI-PROXY RECONSTRUCTION USING LAKE SEDIMENTS

Vireswar Samanta[1,2*], Monalisa Mallick[1,2], Barnita Banerjee[1,2], E.V.S.S.K Babu[1,2], T. Vijaya Kumar[1,2]
[1]CSIR – National Geophysical Research Institute, Hyderabad-500 007, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, 201002, India
Presenting author: Vireswar Samanta (vireswar.geology@gmail.com)

ABSTRACT

The North-east monsoon (NEM) is very important for rain-fed agriculture in the dry zones of southern India. It provides ~17–49% of the annual rainfall in the southern part. Despite its importance, the past variability of NEM remains poorly understood due to the limited number of studies. Here, we present a multi-proxy work to reconstruct the Holocene NEM variability using sediment samples from the Pulicat lagoon, India. AMS radiocarbon dating shows the deposition at the site ranges from ~6.4 to ~10.7 cal kyr. BP. Proxies, including grain size variation, low-frequency magnetic susceptibility (χ_{lf}), stable isotopes ($\delta^{13}C$ and $\delta^{15}N$), total organic carbon to nitrogen ratio (TOC/TN), trace elemental abundances, and Rock-Eval pyrolysis, are used to understand the climatic variability as well as the depositional condition. The early interval (before ~10 cal kyr BP) is characterised by relatively strong monsoonal activity along with enhanced land-ocean interactions, which is followed by a terrestrial dominated interval marked by a very high sedimentation rate and high sand fraction. The monsoon intensification is likely linked to the early Holocene thermal minima, which enhanced the land-ocean temperature contrast, leading to intensified NE winds. A significant intensification of NEM is also observed during ~8.2 cal kyr. BP, associated with the slowdown of Atlantic Meridional Overturning Circulation (AMOC) and the westward shift of the subtropical westerly jet. During the mid-Holocene (post ~8.1 cal kyr. BP), the proxies are showing a clear shift to a marine-dominated depositional environment, driven by the sea level rise. This interval highlights the formation of the Pulicat lagoon. Although the multiproxy data indicate a weakening of monsoonal activity during this interval, the records appear to be strongly overprinted by the effects of rapid sea-level rise and lagoon formation.

ON THE RESPONSE OF THE MESOPAUSE REGION OVER AN INDIAN ANTARCTIC STATION BHARATI TO THE GEOMAGNETIC STORM OF 23–24 MARCH 2023

Vishal Virapouttirassamy *(1), Navin Parihar(1), Anand Kumar Singh(2), Rahul Rawat(1), Shailendra Saini(2) and Ashok Priyadarshan Dimri(1)

(1)Indian Institute of Geomagnetism, Navi Mumbai, India, (2)National Centre for Polar and Ocean Research, Ministry of Earth Sciences, Goa, India,

E-mail: vishal.v.res@gmail.com

ABSTRACT

We report, in this work, the changes in the thermal structure of the mesosphere-lower thermosphere (MLT) region over an Indian Antarctic station Bharati (69.4° S, 76.2° E, CGM coordinates 75° S, 97° E) brought about by an intense geomagnetic storm of 23–24 March 2023 (Dst ~ −155 nT). We use the temperature and OH airglow measurements of the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument onboard NASA's Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) mission satellite to compare the thermal field of the MLT region on these disturbed days with the neighbouring quietest days of 27–28 March. Such comparison reveals both warming and cooling in the MLT region associated with the storm. An extension of this comparative study in the latitude region located poleward of Bharati also shows similar behavior of the MLT region during this geomagnetic storm. Overall, this study reveals the maximum temperature enhancement of ~39–43 K to occur at around 99 km, a significant warming of ~4–43 K in 95–105 km, and a decrease of ~12–16 K in 80–87 km. While the enhancement of temperature in 95–105 km appears to be a consequence of the auroral heating associated with this storm; we are unable to account for the cooling below based on existing theories. Present observation of the development of cooling underneath the region of temperature enhancement during the geomagnetic storm is rare and demands further investigation.

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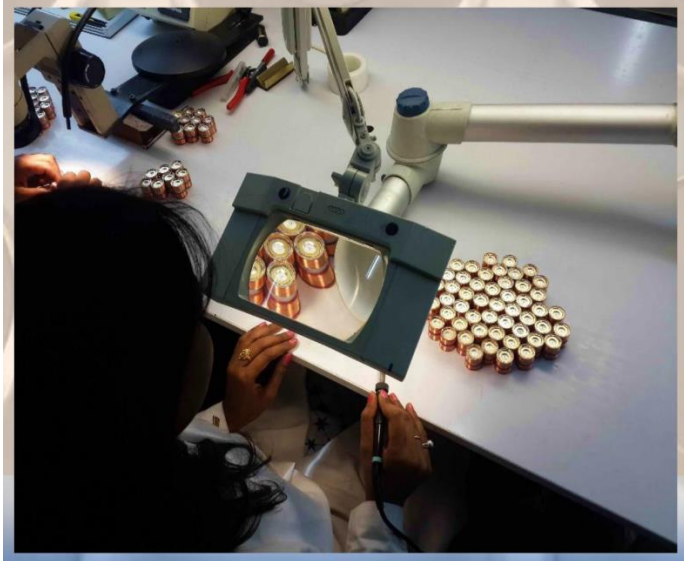
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Journey of IITM from Research and Academic Interest to Mission Mode Project and its Deliverables in Weather and Climate

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The need to study fundamental atmospheric problems and to understand the mechanisms of monsoons, weather systems, and climate-related processes in tropical regions, particularly over the monsoon area, prompted the World Meteorological Organization (WMO) to recommend the establishment of meteorological research and training institutes in tropical countries during its Third Congress. This proposal was formally approved by the Government of India in February 1962 as part of its Third Five-Year Plan, leading to the founding of the Institute of Tropical Meteorology (ITM) on November 17, 1962, in Pune (then known as Poona) as a distinct unit of the India Meteorological Department (IMD). On April 1, 1971, the Institute was transformed into an autonomous organization and renamed the Indian Institute of Tropical Meteorology (IITM). In July 2006, IITM came under the administrative control of the newly formed Ministry of Earth Sciences (MoES).

Vision of the Institute

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months), and decadal scales (2-10 years). Additionally, IITM has developed an indigenous Earth System Model (ESM) capable of predicting climate conditions up to 100 years into the future and has participated in the global IPCC climate assessments. In May 2025, India unveiled its indigenous Bharat Forecasting System.

The state-of-the-art observational program initiated at IITM has significantly contributed to national scientific projects, including the Cloud-Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX), the Centre for High Altitude Cloud Physics Laboratory (HACPL), the Atmospheric Research Testbed (ART), weather radars, lightning networks, and air quality measurements and forecasts. The institute also plays a crucial role in capacity building for the next generation of scientists and academicians through its dedicated training programs. IITM boasts the top rank in the country for its high-performance supercomputer facility, featuring 13 petaflops of computational speed and 30 petabytes of storage capacity.

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To understand the oceanic processes several instruments such as floats, buoys, gliders, etc are deployed as round-the-clock watchers of the ocean and provide real /near real time data for operational and forecast services.

Climate Services

El Niño-Southern Oscillation (ENSO) is an atmosphere-ocean phenomenon of the tropical Pacific. In the positive phase, also known as El Niño, the eastern Pacific warms, and the western Pacific cools. During El Niño, the Indian Ocean becomes warmer than normal and causes prolonged marine heat waves. It can also weaken the Indian summer monsoon.

Indian Ocean Dipole (IOD) is an El Niño like oceanic phenomenon in the Tropical Indian Ocean. During its positive phase, the eastern Indian Ocean cools and the western Arabian Sea warms.

INCOIS provides global and regional climate outlooks on its portal by regularly updating prevailing El Niño & La Niña (the two phases of ENSO) and IOD conditions.

Information, Communication & Technology Services

State-of-the-art facilities including high performance computing and communications facilities are adopted to provide round-the-clock services to the nation.

Ocean Data & Information Services

Heterogeneous data from various in-situ and satellite platforms as well as numerical modeling are made available at the fingertips of the researchers, students, and industry.

International Training Centre for Operational Oceanography (ITCOOcean)

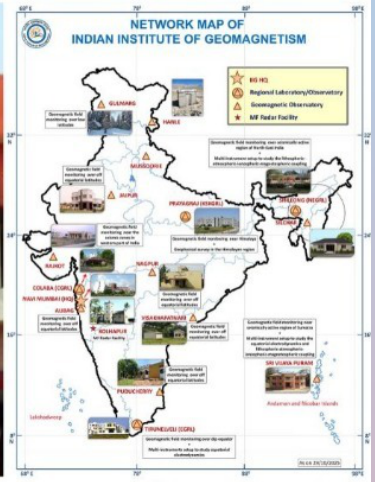
A Category-II Training Centre, recognised by IOC-UNESCO, provides advanced training in operational oceanography that would help the trainees in translating the results and findings in ocean science to real-time use by end users.

/INCOISofficial/ /ESSO_INCOIS /INCOISofficial Hyderabad/ www.incois.gov.in

INDIAN INSTITUTE OF GEOMAGNETISM (IIG)

Autonomous Institution under Department of Science & Technology





IIG has an enviable antiquity of over 181 years, which was instrumental in spawning geomagnetism in the Indian subcontinent region. It has evolved from being a data-gathering organization to using long series of geomagnetic data to tackle applied aspects that benefit society in an obvious and abstruse way. The Indian Institute of Geomagnetism (IIG) was given a full-scale mandate to pursue geomagnetic and allied field research in 1971. It has been an autonomous institution since its inception and is now functioning directly under the Department of Science & Technology, Government of India. The evolution of geomagnetism in the country has been interminably linked with the growth of this institution.

OUR RESEARCH

~ Solid Earth Geomagnetism

Earth's magnetic field, Geomagnetic variations, Lithospheric magnetic anomalies, Paleomagnetism & Geophysical processes

~ Upper Atmosphere & Space Weather

Solar Wind - Magnetosphere - Ionosphere-Atmosphere interactions, Geomagnetic storms & Space Weather

WHAT WE OFFER

Junior Research Fellowship (JRF) & Ph.D. Programs

Integrated MS(R) - Ph.D. Programme

Nanabhoy Moos Research Fellowship (NMRF)

Research Associates (RA) & Postdoctoral Fellowships

OUR INFRASTRUCTURE & EXPERTISE

~ Observatory & Data Analysis

Sustained geomagnetic observations across India to investigate magnetic field variations & geospace processes

~ Historic Colaba - Alibag Observatory

A globally significant legacy of long-term geomagnetic observations dating back to 1841

~ World Data Center for Geomagnetism, Mumbai

An important resource for geomagnetic data, supporting scientific research & international collaboration

~ Polar Research

Participation in Indian scientific expeditions to the Arctic & Antarctic

~ Instrumentation & Laboratory Facilities

Expertise in the development, calibration & application of instruments for geomagnetic & allied research

Indian Institute of Geomagnetism
Headquarter (Panvel Campus) Plot 5,
Sector 18, New Panvel Navi Mumbai
India

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CSIR-National Geophysical Research Institute

Exploring Earth for 60 Eventful Years

CSIR-NGRI



Unique Geophysical Research institute of the country for Near Surface to Deep Earth Exploration

CSIR- National Geophysical Research (CSIR-NGRI) established in 1961, with a vision for the pursuit of earth science research, which strives for global impact and its application for optimizing sustainable societal, environmental, economic benefits for the Nation. CSIR-NGRI carries basic and applied research in the fields of Geophysics, Geology, Geochemistry and Geochronology

Overview

Research : From academic to field stations, research is lifeline of CSIR-NGRI. Excellent laboratory and infrastructure to carryout cutting-edge research in Hazard, Water, Energy, Geodynamics, Minerals. It is supported by High Computing facility.

Academic : A large number of PhD programs are running with vibrant campus life. It has two hostels with canteen facility.

Campus– Performances, events, fitness center, Club, gym facility and dispensary within the campus.

Knowledge Center : One of the largest libraries in India in Geosciences. It subscribes to 102 research journals and holds more than 20000 books.

Publications : ~ 5000 SCI research papers, ~ 1260 technical reports, more than 100 books, 31 patents.

Significant Achievements

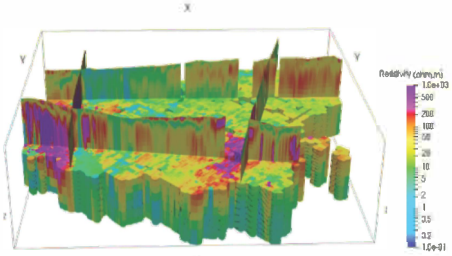
- Pioneer in Airborne Geophysical Research in India
- Gravity Map Series of India (GMSI)
- First indigenous airborne geophysical instruments
- Largest Seismological Network across the country
- Expertise of sub-Basalt imaging for oil and gas exploration
- Simulation of deep Earth processes and magnetic field

Future R&D

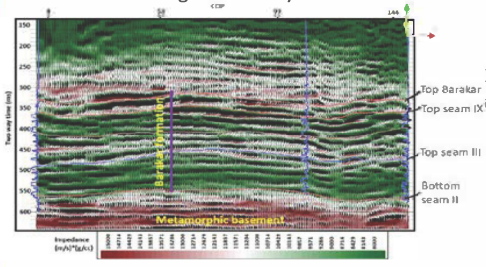
- ✓ Geological Hazard Assessment – Early Warning System
- ✓ Water Security – Sustainable Groundwater Resources Management
- ✓ Energy Security- Hydrocarbon, Uranium, Geothermal
- ✓ Minerals – Lithium and REEs
- ✓ AI/ML for Geosciences



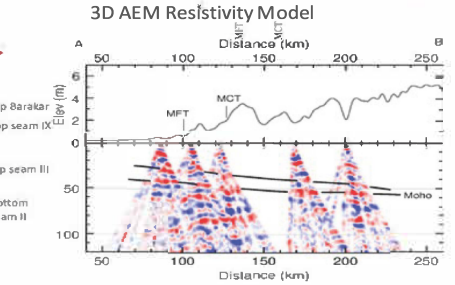
Drone based Magnetic Survey in Ladakh



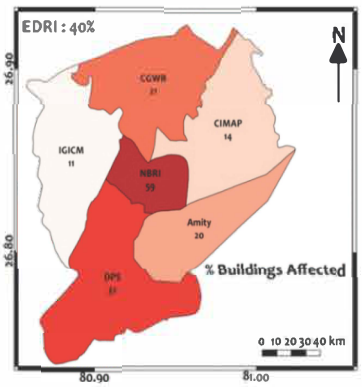
3D AEM Resistivity Model



3D Seismic Data for CBM Exploration



Seismic image of the Moho in Kashmir Himalaya



Earthquake Risk Map – Lucknow

Contact:

+91-40-23434600 +91-40-27171564 director.ngri@csir.res.in www.ngri.res.in

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