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Crustal structure along Permanallur-Pallapatti deep seismic reflection/refraction profile and inferred evolutionary history of Palghat-Cauvery Shear System, Southern Granulite Terrain, India

G. Kesava Rao*, B. Rajendra Prasad, A.S.S.S.R.S. Prasad, S. Raju, G.S.P. Rao, M.S. Reddy and Dipankar Sarkar

CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500 007, India
*E-mail: gkrao1950@yahoo.com

ABSTRACT

Deep seismic studies over Permanallur-Dharapuram-Oddanchatram-Pallapatti profile were conducted for better understanding the structure and tectonic frame work of the northern part of Southern Granulite Terrain (SGT), India. The northwest-southeast trending, 140 km long profile over the SGT depicts the basic nature of crustal-scale shear zones like Palghat-Cauvery Shear Zone (PCSZ), Karur-Kambam-Painavu-Trichur Shear Zone (KKPT) and Karur-Oddanchatram Shear Zone (KOSZ). The seismic evidences in the form of opposing reflectivity trends, horst and graben structure and abrupt south dipping mid-lower crustal reflections along transect indicate episodes of crustal extension and stress accumulation. These episodes might have influenced development of weak zones or faults. Subsequent compressional events might have lead to undulations/ uplifting of crustal columns as indicated by five-layered 2D velocity-depth model (Vp 6.0, 6.6, 6.9, 7.3 and 7.5 km/s). A combined interpretation of long range refraction/ wide angle reflection and the vertical reflection data confirms the basic deep seated nature of the crustal scale shear zones. Presence of diffused reflection Moho is noticed at a depth of ~45 km along the profile. The unusually high velocity of 7.5 km/s in the lower crust, presence of diffused Moho and reflections from upper mantle suggest the magmatic underplating in the lower crust during crust-mantle interactions.

INTRODUCTION

In our attempt to fill up the seismic data gap between north-south trending Kuppam-Palani and Vattalkundu-Kanyakumari profiles, along which previous seismic studies (Reddy et al, 2003, Rajendra Prasad et al, 2007) were carried out, the seismic study along 140 km profile in SGT, Permanallur-Dharapuram-Oddanchatram-Pallapatti (NW-SE) has been carried out (Fig-1). Since the present day crustal configuration is a result of various crustal processes over protracted geological periods, the processes that dominate continental crustal evolution can be better understood by studying the inter-relationship of upper, mid and lower crustal layers and the basic nature of intervening shear/ suture zones in the region. The Precambrian crust exposed over large tracts in southern India had resulted due to exhumation of lower crustal rocks during the super-continental assembly of Gondwanaland. Fragments of Gondwanaland are made up of greenstone-granite cratons and gneiss-granulite mobile belts. Most Cratonic nuclei are Archaean in age (>2.5 Ga) and the Mobile Belts are of Proterozoic age (~0.55 Ga). The studies of high-grade crustal provinces, Madurai Block (MB), Kerala Khondalite Belt (KKB) and the regional shear zones of SGT do significantly contribute to our understanding of the structure and evolution of Precambrian crust.

The north south trending, 320 km long deep seismic reflection and refraction profile, Kuppam-Palani (black solid line, Fig-1) has brought out, varied crustal reflectivity characteristics and a four layered velocity structure with a low velocity layer (LVL) at mid-crustal level and crustal thickness of 41-45 km, along the transect. These evidences have great significance in understanding the basic nature of Palghat-Cauvery Shear Zone (PCSZ), sub-surface velocity-depth structure of the region and provided clues to the evolution process of the region (Reddy et al., 2003). Similarly, the seismic studies along Vattalkundu-Kalugumalai-Kanyakumari profile (N-

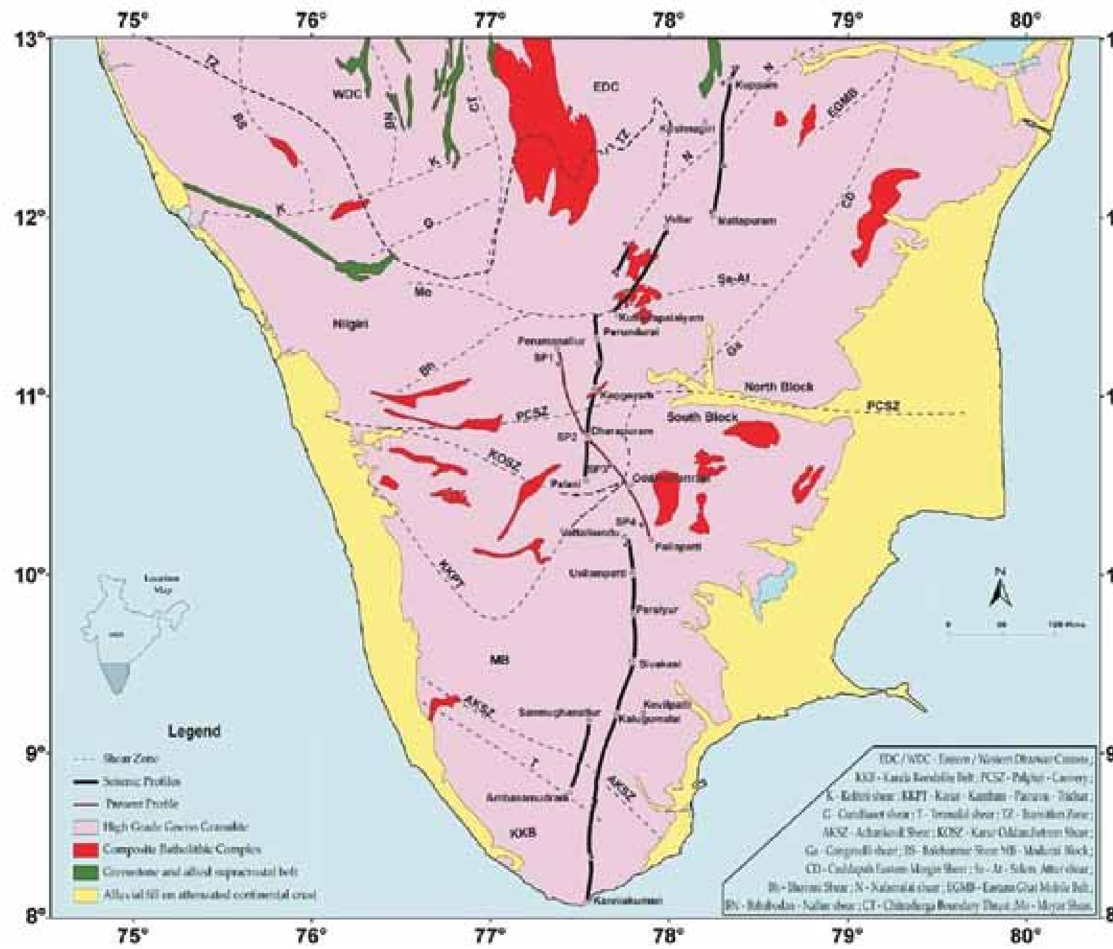

Figure 1. Location of Perumanallur-Oddanchatram-Pallapatti profile on seismotectonic map of India with the present and previously recorded seismic traverse (modified after Cheety and Bhaskara Rao, 2006)

S, 260 km) in the southern part of SGT provided significant clues in understanding the crustal configuration of the region. The crustal reflectivity pattern along the Vattalkundu-Kalugumalai segment has helped in delineating southward extension of Kodaikanal massif near Vattalkundu, the block uplift of Madurai Block and the metamorphic layering near Ramanathapuram. The reflection Moho along the transect lies at a depth of 39-42 km (Rajendra Prasad et al., 2007). Thus, the seismic studies carried out along ~580 km long transect, as it traverses the entire region of SGT (except for a small portion of 100 km gap between Palani and Vattalkundu) has provided significant crustal velocity and reflectivity details of SGT. The 100 km seismic recording gap was due to the logistic constraints. So as to bridge this gap, the 140 km long, NW-SE trending and logistically difficult seismic traverse (with a minor lateral shift) along Permanallur-Dharapuram-Oddanchatram-Pallapatti (11°15'N-10°15'S, Fig-1) was recorded using state-of-the-art 24-bit Radio Frequency Telemetry Seismic Recording System. The data generated bridged the gap between previous two profiles and provided useful inputs for better understanding of the crustal configuration. The profile passes through one of the major shear zones, the PCSZ and the other shear zones, Karur-Kambam-Painavu-Trichur Shear Zone (KKPT) and Karur-Oddanchatram Shear Zone (KOSZ) of SGT. The seismic traverse and the shear zones, PCSZ, KKPT and KOSZ are marked on the seismotectonic map (Fig-1). The present study aims at a) identifying the basic seismic signatures of regional crustal scale shear zones viz., PCSZ, KKPT and KOSZ, using deep seismic reflection data, b) generating velocity-depth model from the refraction and wide angle reflection data, c) identifying the reflection Moho and its nature along the transect, and d) examining the validity of various data sets such as seismic, gravity, magnetic, magnetotelluric data and their utility/ limitations.

GEOLOGY OF THE REGION

The South Indian shield comprises Dharwar Craton (DC) bounded to the south by Southern Granulite Terrain (SGT), to the east by the Eastern Ghat Mobile Belt (EGMB) and to the north-east by the Karimnagar Granulite Belt (KGB). The DC is separated from the EGMB by the Cuddapah Boundary Shear Zone (CBSZ). In addition, there are numerous intervening shear zones in the shield, and the prominent among them are Moyar Bhavani Shear Zone (MBSZ), Palghat-Cauvery Shear Zone (PCSZ) and Achankovil Shear Zone (AKSZ). The Archaean Dharwar Craton had stabilized after the 2.5 Ga granulite facies metamorphism and wide spread granitic magmatism. After stabilization of the Archaean crust in the DC, a Pan African mobile belt called the SGT had evolved at the southern margin of the craton by collision of another, yet to be identified cratonic terrane from Africa or Antarctica with the DC (Ramakrishnan, 2003). The PCSZ that dips to the south marks this episode of continental collision. The seismic reflection data and seismic tomographic studies have also indicated the south dipping nature of the boundary (Rajendra Prasad et al., 2006; Rai et al., 1993). The aeromagnetic results provide ample evidence of block movements in the region. The Nilgiri region and Kodaikanal massifs are underlain by basement highs, while the Palghat region lies over a basement low (Reddi et al., 1988). These three regions evidently represent distinct crustal blocks uplifted or down faulted against each other along deep crustal breaks; their present elevations being direct consequences of these movements. Also, the gravity results show a prominent low to the south of Palghat region and E-W high to the north of it. The low has been attributed to crustal thickening (Mishra, 1988) and the high to a deep-seated source, considering the associated anorthosite bodies and the well-known Bhavani fault (Mishra and Vyaghreswara Rao, 1993; Singh et al., 2003).

The PCSZ is considered to demarcate the Proterozoic terrane boundary in southern India (Harris et al., 1994). South of PCSZ, charnockitic gneisses are associated with a variety of migmatitic gneisses, intrusive granite gneisses and granite. Further south, the lithological association is dominated by massive to streaky charnockite gneisses all along the Palani-Kodaikanal highland massif. The Palghat Gap is well reflected on Satellite image as a physiographic low and is bounded by hill ranges (>2000 m above MSL) of Nilgiris in the north and Anaimalai and Palani ranges in the massif. At the eastern and southeastern margins of the massif, the charnockites and migmatites are in contact with a metasedimentary association that preserves ultrahigh-temperature sapphirine-bearing Mg-Al rocks (Mohan and Windley, 1993; Raith et al., 1997). These meta-sedimentary rocks have recently been shown to be Neoproterozoic in age, based on their detrital zircon population (Collins and Santosh, 2004). The surface expression of east-west trending PCSZ is 1-2 km wide and located within the crustal-scale Palghat-Cauvery Shear System, which is about 400 km long and 60 km wide, and comprises of number of fault zones. The dominant rock types of PCSZ include migmatitic gneisses and banded charnockites. Meta-sediments, consisting of metapelites, calc-granulites and quartzites, occur as small lenses and strips within the gneisses. The Archaean age for rock suites within the Cauvery Shear Zone has been confirmed by Sm/Nd whole rock isochron age determinations (Bhaskar Rao et al., 1996).

Basically, the SGT is dissected into different granulite blocks by structural discontinuities, lineaments or shear zones. The most conspicuous E-W trending PCSZ was first mapped as Cauvery fault by ONGC and recognized by Grady (1971). Vemban et al., (1977) stated, PCSZ as a boundary between two different geological domains. Drury and Holt (1980) established this boundary from Landsat imagery and named it as Noyil-Cauvery shear zone with Moyar Shear Zone and Bhavani Shear Zone as its branches. On this basis the SGT, south of the Orthopyroxene isograd, is divided into two distinct crustal blocks (Drury et al., 1984; Meissner et al., 2002), viz., the Northern Block and the Southern Block, separated by PCSZ (Sharma, 2010).

The southern block of SGT is broadly divided into two crustal provinces, MB and KKB. The MB is the largest granulite terrain in southern India. The dominant lithology is high grade meta-sedimentary rocks, mafic granulites, highland charnockite massifs and anorthosites. The block was involved in a major Pan-African tectonothermal event as indicated by zircon age data (Santosh et al., 2003). The highest temperature recorded in the surrounding area is in the range of 1000°C (Sajeev et al., 2001), which is very close to closure temperature of U-Pb system in zircon. The block comprises the Anaimalai-Kodaikanal ranges of the Western Ghats on the west, made of high land charnockite massifs rocks.

The AKSZ, the southernmost trans-crustal shear zone, forms boundary between the KKB in the south and the MB in the north. The shear zone has steep dipping NW-SE strike trends, in contrast to a multidirectional open-folded trend in the north. It is defined as a shear zone based on the change in rock types to the north and south, and by sharp change from NE-trending structures within and to the south of it (Drury et al., 1984). The AKSZ is 10-20 km wide and is bounded by Achankovil and Kallada rivers in the Western Ghats. The regional fabric and fold patterns around Kodaikanal and MB are abruptly truncated at this zone. Out crops are rarely observed along AKSZ, but it can be inferred that it comprises a narrow zone of steeply dipping gneissic rocks. The gneissic foliations and lithological banding in other rock types are invariably conformable. In general, the foliations trend NW-SE, while dips vary from 50° to 75° to south-west. Occasional dips to north-east are also observed (Rajesh et al., 1998; Guru Rajesh and Chetty, 2006). Also, the shear zone coincides with a significant change in aeromagnetic pattern traceable across southern India (Reddi et al., 1988). Seismic tomographic study (Rajendra Prasad et al., 2006) depicts that the upper crust (0-8 km) has anomalous high Vp/ Vs ratio (>1.75), large variation of Poisson's ratio (0.25–0.29) representing numerous shear zones cutting across south block with major compositional boundaries.

The shear zones, PCSZ and AKSZ, and the tectonic correlation with their equivalent zones in Madagascar, Antarctica and Sri Lanka are carried out by many scientific workers, since all these continents were together in the Gondwana assembly during the Pan-African period (0.55 Ga). PCSZ is the northernmost manifestation of Gondwana orogenies on the Indian Peninsula (Harris et al., 1994). This shear zone has been correlated with the Bongolava-Ranotsara Shear Zone (De Wit et al., 1998), the Madagascar Axial High-Grade Zone (Windley et al., 1994), and the East Antarctic Napier and Rayner Complexes (Harris et al., 1994). Drury et al. (1984) and Meert (2003) have established the PCSZ as a strike-slip zone related to the final assembly of East Gondwana. Also, the lineament correlations as well as topographical features of high lands of Nilgiri in South India and Nuwara hills in Sri Lanka (Adams, 1929; Katz, 1978; Subramanyam and Gopalakrishnan, 1981; Vitanage, 1972 and 1985) have been identified.

DATA ACQUISITION

Deep seismic reflection and refraction data sets were acquired using 24-bit Radio Frequency Telemetry system along the NW-SE trending profile, Perumanallur-Dharapuram–Oddanchatram–Pallapatti. The 2D reflection data using Common Midpoint Technique (CMP), with symmetric split geometry (90 channels on either side of each shot), was acquired along 18 km long spread. At each receiver location of 100 m interval, 10 geophone string of 4.5 Hz natural frequency has been used to record seismic events (P-phase). The system has enough frequency/ dynamic range of 4.5-256 Hz, at 2 ms sampling interval. The nitrate mixture of chemical explosives (50-100 kg, emulsion/ slurry) is loaded in 25 m deep shot-hole or pair of holes, at an interval of 100/200 m constituted the seismic source for deep seismic reflection profiling. Deep seismic reflection TWT data (extending to 24s) to image intra crustal and upper most mantle reflection horizon has been acquired on IBM 3490 tape drives in standard SEG-D format. Logistic constraints and dense population truncated the reflection profile by 15 km north of Perumanallur (Fig-1). Adequate foldage of ~40 could be achieved along the profile. Use of electrical detonators in parallel ensured proper firing of the explosive charges. Recording is usually carried out during late night hours to improve signal to noise ratio. In addition, the seismic refraction data along the line was acquired to derive the velocity-depth model by operating four major shot points along transect with an average interval of 40 km. The shot points SP1 and SP2 are located between Perumanallur and Dharapuram, while SP3 is located between Dharapuram and Oddanchatram. SP4 is located north of Pallapatti (Fig-1). A maximum coverage of 70 km on either side of each shot point could be achieved for recording refracted P-arrivals and wide angle reflections from various sub-surface boundaries. The reverse refraction coverage allowed us to map the dipping layers accurately. For obtaining deep seismic refraction data from near distance to distances of ~100 km nitrate mixture of slurry explosives have been loaded into shot holes drilled to a depth of 25 m. For near distance one/two holes (each loaded with ~50 kg) have been used as seismic energy source. As recording distance increased charge size has been enhanced by making use of more number of shot holes. For covering a distance of 70 to 100 km, a charge size varying between 1000 to 1500 kg has been used, using higher rectangular or circular shot hole patterns (maintaining a shot hole interval of 5 m). The selected charge sizes could provide adequate signal strength to identify first arrivals and subsequent wide angle reflection phases precisely. As seismic energy transmission was poor in the region, refraction coverage was limited to a maximum offset of 70 km with charge of 1500 kg distributed over 30-holes. Reliable radio communication was ensured between Seismic Telemetry System and shot locations even across the hill ranges with wireless repeaters of seismic source synchronizers deployed at regular intervals. Radio repeater experiments were carried out a day in advance to ensure successful long range shot firing.

DATA PROCESSING

Reflection data processing

The reflection data is processed using the ProMAX® software package at NGRI. Data preprocessing consisted of editing noisy traces, correcting of reverse polarity channels. As per requirement dummy traces are introduced to fill the gap. Geometry update was done for all shot gathers with the latitude and longitude coordinates of source and receivers for generating the CDP gathers. Prestack processing included attenuation of ground roll by frequency-wave number (F-K) filtering. Direct and first arrivals are muted by refraction mute. Static corrections are applied using specially surveyed elevation data, while weathered layer velocity is obtained from refraction data. The processing sequence comprised spherical divergence correction, spiking deconvolution, velocity analysis for stacking velocity determination followed by normal move out (NMO) correction, band pass filtering and stacking. Deconvolution and coherency

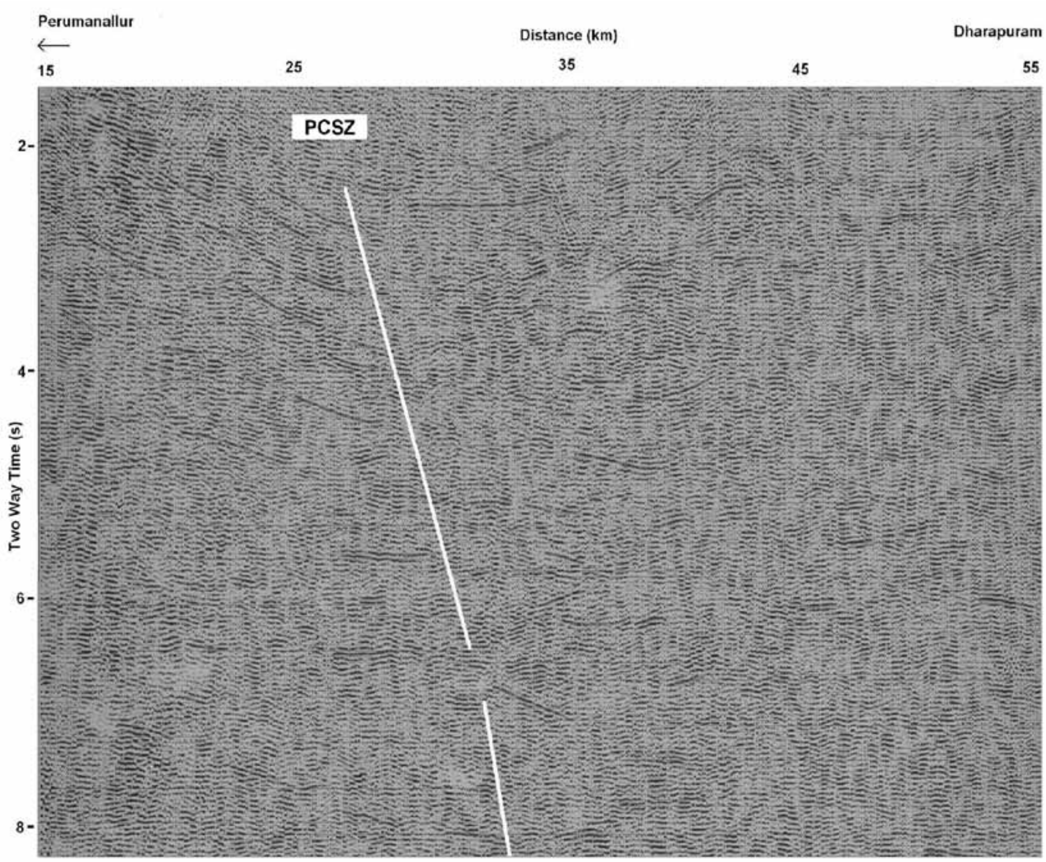

Figure 2a. Seismic stack section (2-8 s) of Perumanallur-Dharapuram segment

enhancement were done as part of post stack processing. Post stack migration on the data set did not yield any improvement in relocation of reflectors. The stack sections are presented in Fig-2a, 2b, 3a, 3b and 4.

Refraction data processing

The velocity model is developed using the refraction and wide angle reflection data of shot gathers of SP1-SP4 by adopting 2D travel-time inversion approach (Zelt and Smith, 1992; Zelt, 1999). The shot gathers recoded along different spreads are prepared and converted from SEG-D format to SEG-Y. For the purpose of illustration a shot gather each of SP2, SP3 and SP4 with various phases identified are presented as reduced travel time plots (Fig-5). The first arrivals (P_1) and various reflection phases (P^1–P^5) are picked for modeling. The synthetic travel time curves are computed from basic initial sub-surface model and compared with the observed travel time data (Fig-6a, 6b). The basic model is altered till a satisfactory match is obtained between synthetic and observed data for all the shot points. The iterative process continues till the assumed model fits the field data satisfactorily.

This method is based on model parameterization and a method of ray tracing suited to forward step and inverse method. The method uses an efficient numerical solution of the ray tracing equations, an automatic determination of take-off angles, and a simulation of smooth layer boundaries that yields more stable inversion results. The partial derivatives of travel time with respect to velocity and the depth of boundary nodes are calculated analytically during ray tracing. A damped least-squares technique is used to determine the updated parameter values, both velocities and boundary depths simultaneously. The 2D forward and inverse methods serve as a check on the validity of the inversion scheme and provide estimates of parameter uncertainties that account for the bias introduced by the modeling approach.

RESULTS AND DISCUSSION

Imaging Crustal scale faults and shear zones requires quality data in addition to amicable dips of the structures that are to be imaged. Since both Deep reflection profiling (DRP) and deep refraction profiling data have been obtained along logistically crooked profiles, a percentage of subjectivity is unavailable in building structural models (especially the orientation

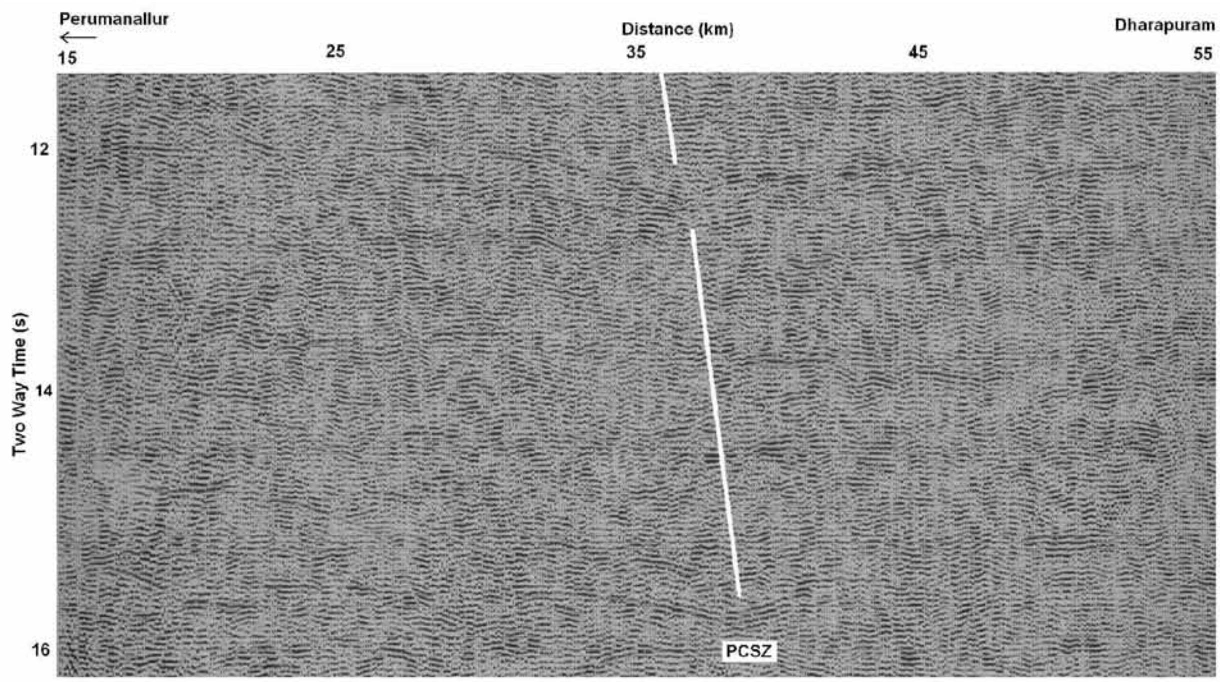

Figure 2b. Seismic stack section (12-16s) of Perumanallur-Dharapuram segment

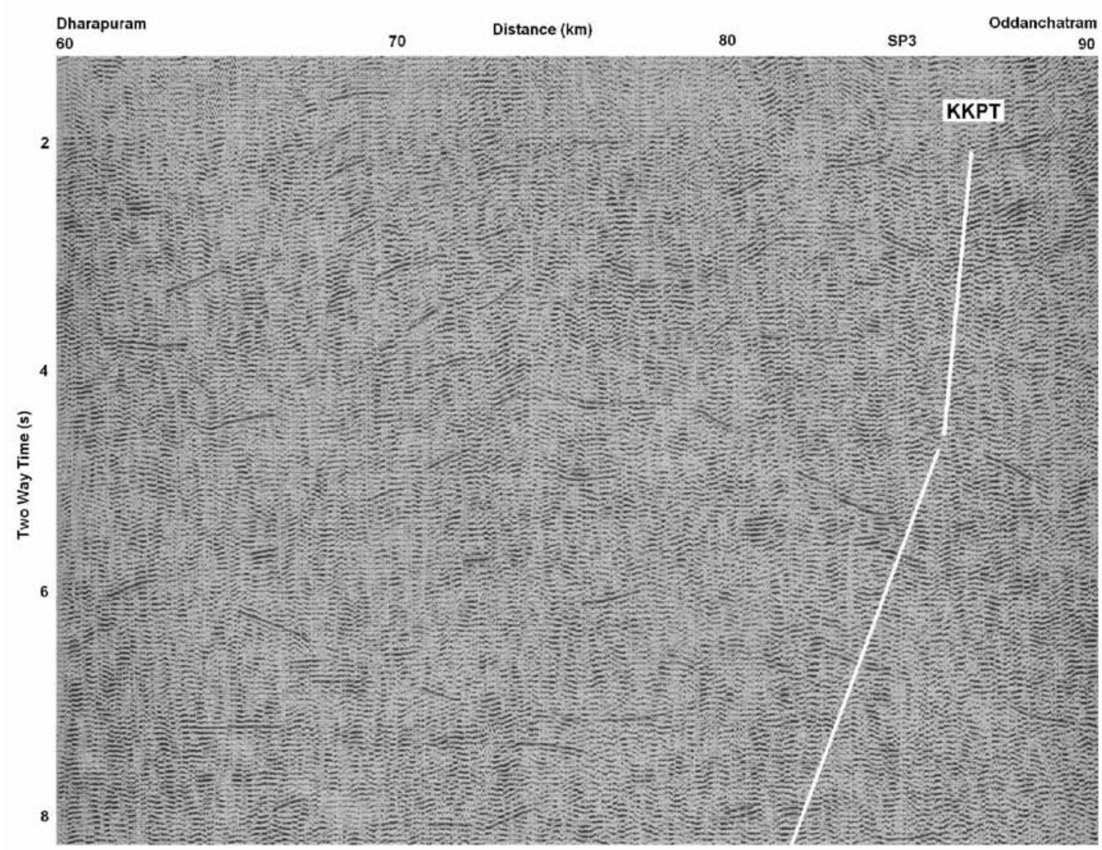

Figure 3a. Seismic stack section (2-8s) of Dharapuram-Oddanchatram segment

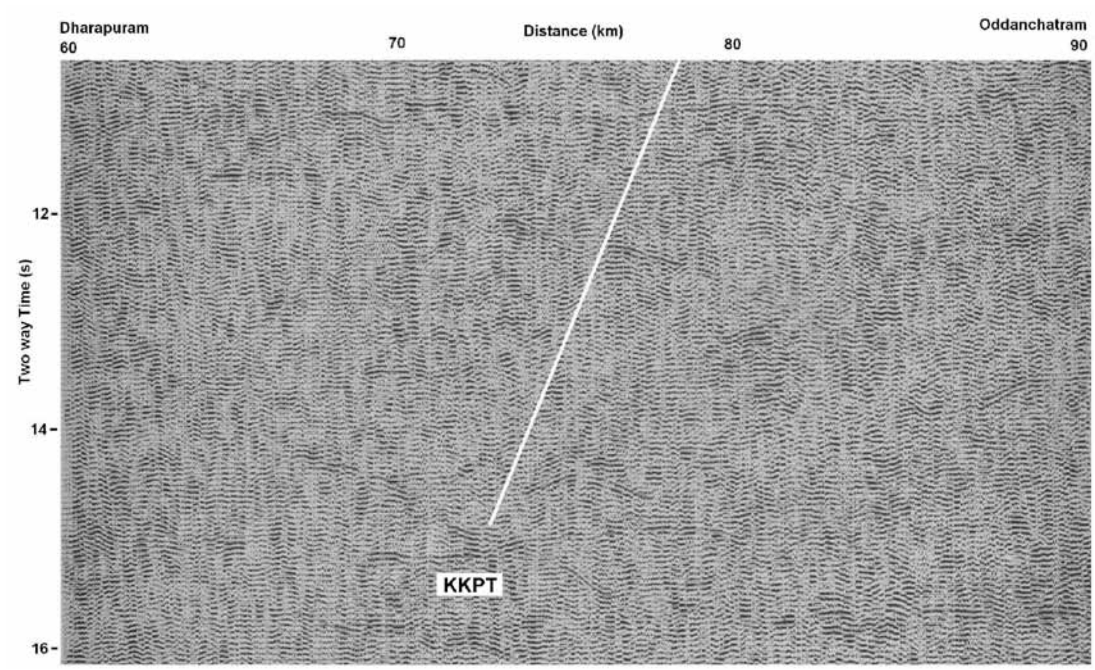

Figure 3b. Seismic stack section (11-16s) of Dharapuram-Oddanchatram segment

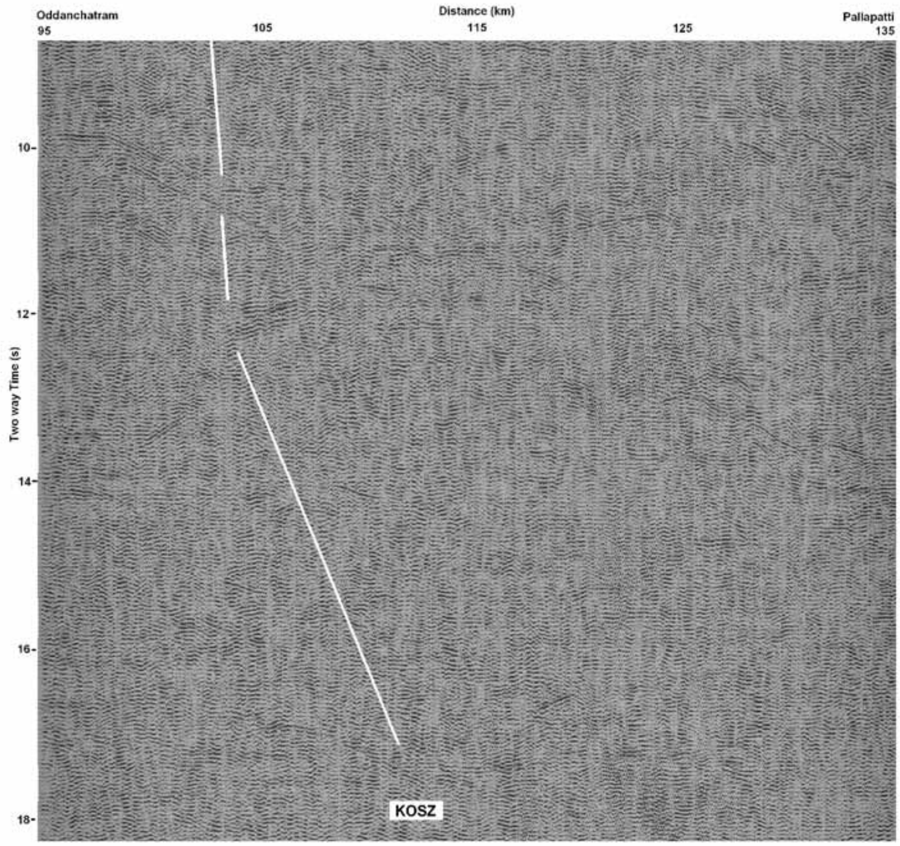

Figure 4. Seismic stack section (9-18s) of Oddanchatram-Pallapatti segment

and depth extension of shear zones). Keeping this in view, needed steps have been taken in bringing out images of shear zones, using direct and indirect methods.

The seismic stack sections from reflection data along Perumanallur-Dharapuram-Pallapatti transect are shown as three segments, Perumanallur-Dharapuram, Dharapuram- Oddanchatram and Oddanchatram-Pallapatti. In Perumanallur-Dharapuram segment (40 km, Fig-2a), 15 km south of Perumanallur, the south dipping reflectivity pattern is observed at upper and mid crustal level, up to 8 s TWT, to a distance of 30 km. Further south, the pattern direction changes towards north and the reflectivity is continuous up to 10 km south of Dharapuram (Fig-3a). The change of dip direction from south to north is observed even at mid-lower crust with less prominence at 11.5, 12.5 and 15.5 s TWT (Fig-2b). This observed synclinal feature between Perumanallur and Dharapuram indicates the faulted nature of Palghat Cauvery Shear Zone (PCSZ) in the region. In addition, a five layered velocity-depth model derived from refraction and wide-angle reflection data confirms the presence of PCSZ (Fig-6c). The top three layers (Vp 6.0, 6.6 and 6.9 km/s) of the velocity model are relatively thin with varying thickness of 4 to 10 km, and having a gentle southerly dip, south of Perumanallur/ SP1. These observations led us to infer the presence of the crustal scale shear zone, PCSZ and it is marked on the stack sections and velocity depth model (Fig-2a, 2b & 6c). The PCSZ is considered as the terrain boundary by many researchers. The seismic study by Reddy et al. (2003) depicts 4 km upwarp near Chennimalai and graben type configuration in shallow part of velocity structure of Kolattur-Palani in the same region on a parallel profile. Theses features are indicative of deep crustal tectonics in the study area with intense crust-mantle interaction which might have resulted in large amount of mantle-derived fluids trapped at upper crustal depths. This is consistent with the formations of extensive granulites exposed near surface. The region of PCSZ is characterized by gravity high (~20 m Gal) and fluctuating magnetic anomaly (Singh et al., 2003). They inferred that the high density body (2.80 g/cm^3) at shallow depth

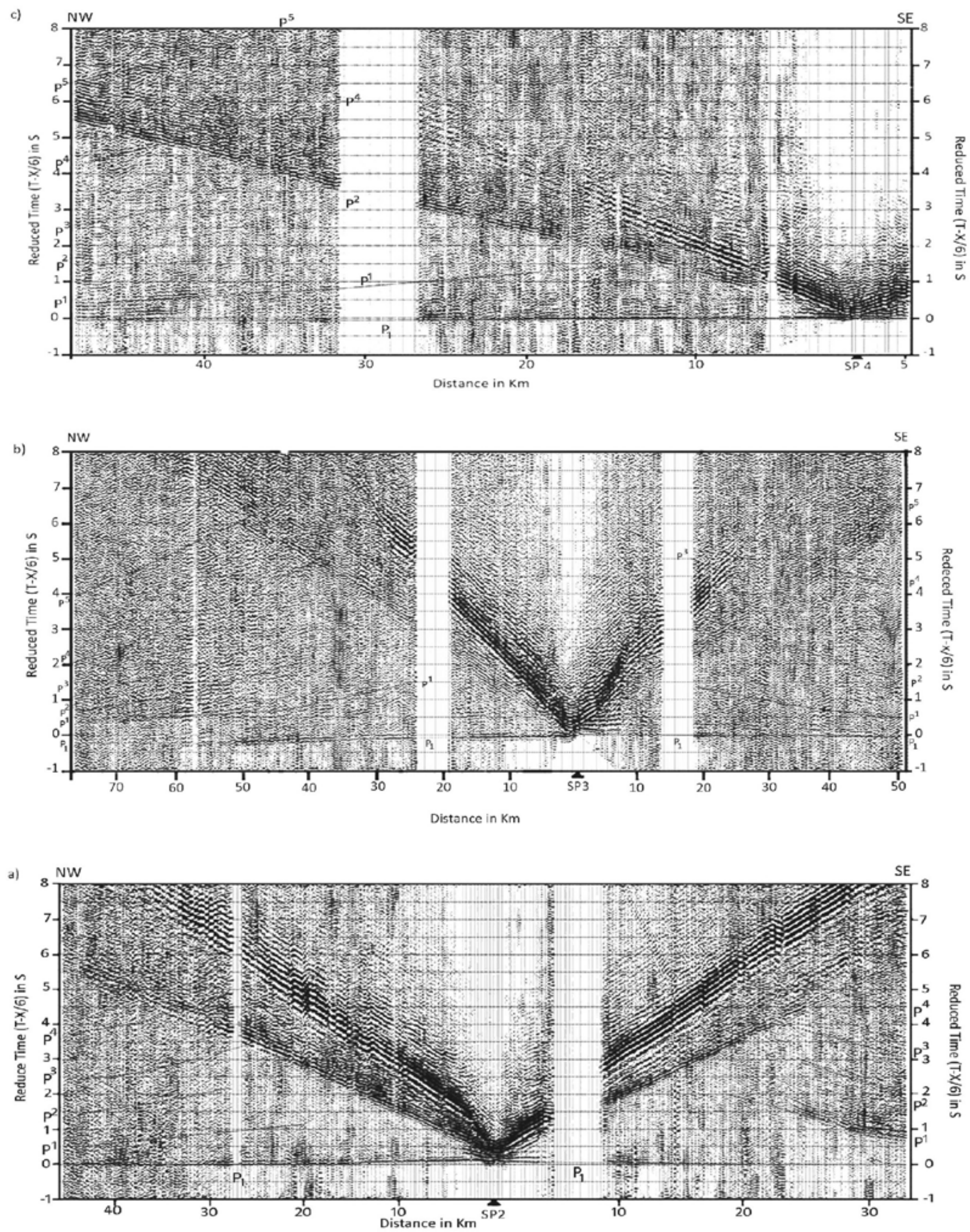

Figure 5. Shot gathers showing the first arrivals (P1) and various reflection phases (P1-P5) for (a) of SP2 (b) SP3 (c) SP4.

in the region is responsible for gravity high. They stated, post tectonic underplating of mafic material and exposed iron ore deposits and anorthosite bodies were considered as proxies to the possible presence of high density body. Similar intrusion of mafic mantle material at shallow crustal level and upwelling of Moho by about 10 km was demonstrated beneath a major shear zone in the Madagascar (Pili et al., 1997). The magnetic high in the region suggests the association of mafic intrusive rocks with the shear zone, PCSZ. The magnetic anomaly and the 2D gravity model of the region depict Moho up-warp from the depth of 44 km on either side of Palghat gap, to 38 km beneath PCSZ (Singh et al., 2003). The magneto telluric study exhibited high resistivity character in the upper and lower crust north of PCSZ, while towards south, upper crust is resistive and lower crust is anomalously conductive

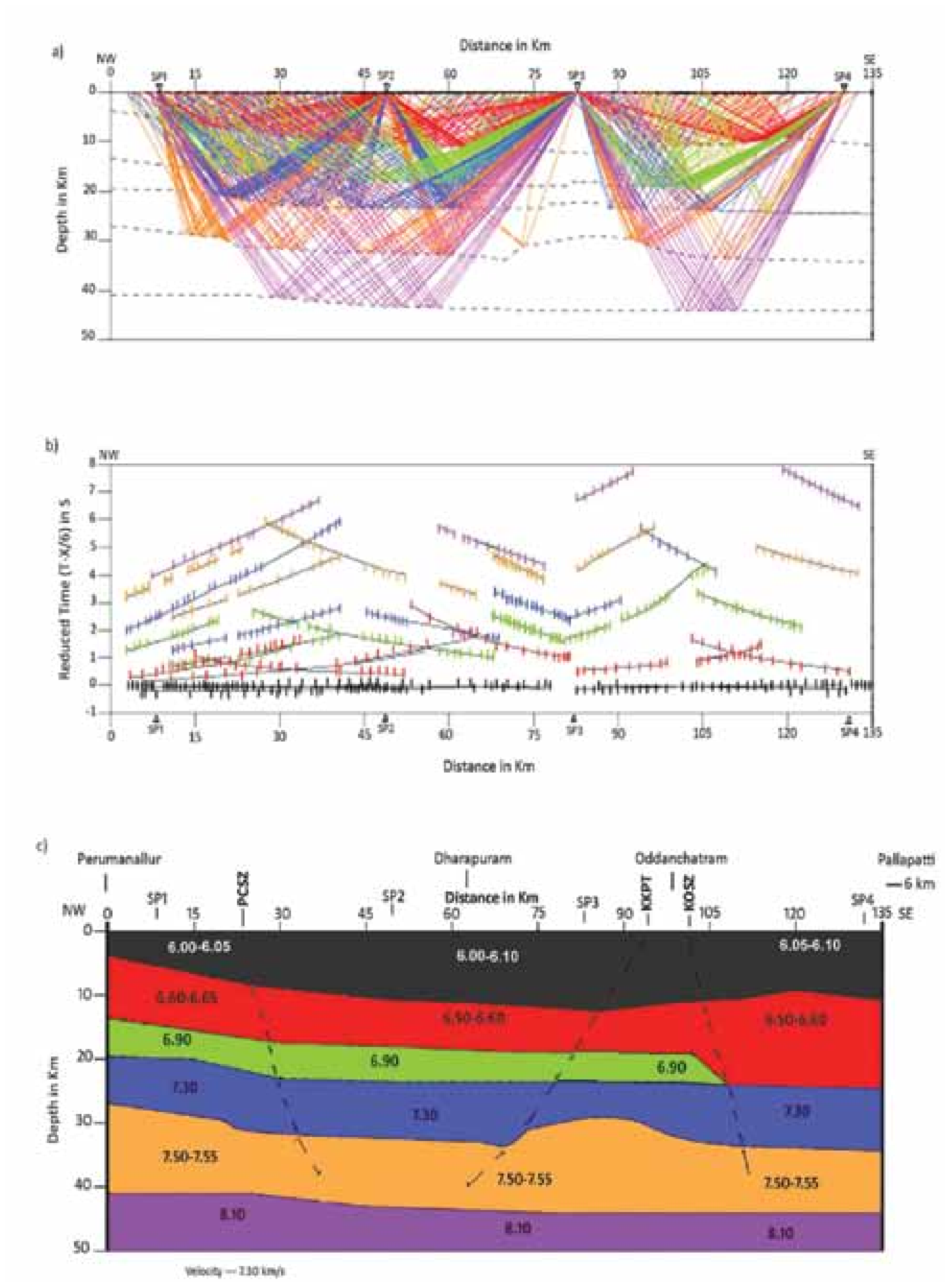

Figure 6. (a) Ray diagram generated for the shot points along Perumanallur-Pallapatti profile, (b) Reduced travel time plot for the shot points, (c) 2-D velocity depth section of Perumanallur-Pallapatti profile. The layer velocities in km/s are indicated.

(400-500 Ωm). The anomalous high conductivity at lower crustal depths could be due to the presence of fluids or partial melts (Harinarayana et al., 2003). The geo-electrical study along Savakaundanur-Palani exhibits very high resistivity of the order of 10^4 Ωm in the north, to a distance of 25 km, while the southern side the resistivity falls to 10^3 Ωm to a distance of 40 km. The low resistivity is continuous to a depth of 2.5 km and further, and the region falls under the influence of PCSZ. Though this resistivity transition is not clear at greater depths, the extension of low resistivity zones has been well manifested (Singh et al., 2003).

The second segment Dharapuram–Oddanchatram (30 km, Fig-3a) has different reflectivity characteristics in the upper crust of 2-7 s TWT. A domal shaped pattern is visualized (2-6 s TWT), between 5-25 km south of Dharapuram, where the north dipping pattern abruptly switches to south at 15 km south of Dharapuram. Further, a graben shaped reflectivity pattern is observed (6-7 s TWT), in the same region, where the pattern direction changes from south to north. The domal feature coupled with graben structure (2-7s TWT) observed, has great significance. This feature can be attributed to geologically mapped Karur-Kambam-Painavu-Trichur (KKPT) shear zone. The deep seated nature of KKPT could be interpreted considering the horst and graben formation at upper crust, and mutually opposing dipping reflectivity at 15 s TWT, above Moho (Fig-3b). The sudden upwarp observed near Dharapuram, in the layer-4 (Vp 7.3 km/s and 12-36 km thick) of velocity structure, confirms the deep seated KKPT shear zone (Fig-6c).

The third segment Oddanchatram-Pallapatti (40 km, Fig-4), is characterized by gentle south dipping reflections in the upper crust, near Oddanchatram. Furthermore, at 10 s TWT, abrupt steep dipping reflections ($\sim 20^0$) are observed. Similar trend is noticed even at lower crust and upper mantle (15-17 s TWT). This trend might indicate south dipping Karur-Oddanchatram Shear Zone (KOSZ). The merging of the Layer-2 (velocity 6.50-6.60 km/s) with Layer-3 (velocity 6.90km/s) led to inferred identification of KOSZ (Fig-6c). According to Bhaskara Rao et al., (2004), the regions south of the KOSZ are distinct from those north of it in terms of regional scale ~0.55 Ga due to the ultra high temperature metamorphism. Archaean-Proterozoic terrane boundary in the SGT may coincide with the shear zone decollement that runs between Karur-Oddanchatram and the northern foothills of Kodaikanal massif rather than the PCSZ, as opined by earlier workers.

Many of the Precambrian reflectivity patterns appear to preserve structures that date from ancient collisional events, which imply that this reflectivity is not due to post-orogenic ductile shear, igneous intrusions, or fluids. Rather reflectivity is due to primary lithologic and metamorphic layering, and Precambrian shear zones that were formed during ancient compressional orogenies. In the extended crust, the origin of crustal reflectivity is probably depth dependent, with ductile shear-enhancing reflectivity that has its primary origin in lithologic and metamorphic layering in the lower crust, and igneous layering with in 3-5 km thick Moho transition zone (Mooney, 2002).

The PCSZ was interpreted by Drury et al., (1984) as a Proterozoic dextral shear zone with strong planar fabrics enclosing less deformed granulite massifs and large blocks and small pods of granulites, metasediments and layered anorthosites-gabbro-ultramafic complexes. Naha and Srinivas (1996) pointed out that the Archaean structural style continues further south of PCSZ. The ultrahigh-temperature ($>1000^0$ C) and high-pressure (20 k bar) eclogites in Sittampundi complex confirm the concept that the Palghat Cauvery Shear System represents a major suture zone between Archaean crustal blocks to the north and the Madurai block in the south. The general southerly dip of rocks in the suture zone suggests the subduction was towards the south. This would inturn suggests that the older block to the north was in the footwall, and the younger southerly block in the hanging wall (Sajeev et al., 2009). Gosh (1997) and Gosh et al., (1998) obtained new U-Pb zircon and monazite ages in support of this argument and proposed that another shear KKPT, defines the Archaean-Neo Proterozoic boundary in the SGT. Between Karur and the Palani–Kodaikanal hill ranges, the northern part of the KOSZ matches well with the KKPT shear zone (Bhaskar Rao et al., 2003) and the presumed Archaean–Neo Proterozoic terrane boundary of Gosh et al. (1998). In the present study, it is observed that the northern part of KKPT and KOSZ are merging near Oddanchatram, which concurs with the observations by Bhaskar Rao et al., (2003). From these observations one could conclude that the KOSZ could mark the Archaean-Neo Proterozoic terrane boundary in the SGT, thus extending the Archaean crust further south of PCSZ (Bhaskar Rao et al., 2003). However, further geochronological evidence is needed to prove/ disapprove the observation.

Near Pallapatti most reflections dip towards south, whereas near Vattalkundu of Vattalkundu-Kalugumalai profile (Rajendra Prasad et al., 2007), the reflections dip towards north. These observed northerly dips are consistent with the reflectivity pattern observed in the southern most part of Kuppam-Palani profile (Reddy et al., 2003). The continuation of north dipping nature near Vattalkundu with respect to Kuppam-Palani profile is interpreted as the extension of Kodaikanal massif, 5 km south of Vattalkundu. However, 5 km south of Vattalkundu, the seismic reflectors dip towards south, consistent with the reflectivity pattern near Perumanallur of the present study.

The characteristic reflection Moho is observed clearly at ~15.5 s TWT in the northern part of Perumanallur-Dharapuram (Fig-2b) and it is horizontal in Dharapuram-Oddanchatram segment (Fig-3b). However, in Oddanchatram-Pallapatti segment, the Moho is diffused but observable at 15 s TWT (Fig-4). Thus, the crustal thickness of ~45 km is noticed along transect. The lack of distinct Moho reflections appear to be consistent with a transition Moho beneath Precambrian crust, possibly due to a gradual transition from mafic lower crust to an ultra mafic upper mantle (Pavlenkova, 1987 and 1988). Precambrian lower crust, like Phenerozoic crust, appears to possess the full range of seismic reflectivity response, ranging from transparent to highly reflective laminae (Mooney and Meissner, 1992). The high reflectivity observed for some deeply penetrating fault zones can be caused either by the juxtaposition of different rock types across the fault or by the physical characteristics within the fault zones (Smithson et al., 1979; Brewer et al., 1983). In the present study, strong and diffused south dipping, upper mantle reflectors can be seen along transect. The observed, diffused reflection Moho and the strong south dipping upper mantle reflections confirm the magmatic underplating in the region.

The previous seismic study along Kuppam-Palani transect (Reddy et al., 2003), revealed a four-layered velocity model, with an LVL at mid crustal level and varying crustal thickness of 41-45 km. The presence of LVL was attributed to granite intrusions, metasomatic activity, presence of fluids, or 750 Ma alkaline activities related to intra-plate rifts. Though an average 10-15 km thick LVL is observed along north-south trending Kuppam-Palani transect, near the intersection of the previous and present profile, near Dharapuram, the layer thickness is less than 5 km. In contrast, the reflection phases associated with LVL are not traced in the present study. The possibility of not finding the thin LVL near Dharapuram is quite high, as the profile is in NW-SE direction. The discrepancy in the velocity structure could also be due to the anisotropy. It is to be mentioned, the crustal anisotropy can be regarded as an indicator of the crustal stress/ strain regime (Rai Abhishek et al., 2008). Assuming that crustal anisotropy is uniformly distributed in whole of the crust and a mean crustal thickness of about 40 km, ~2% anisotropy may be assigned to both the Dharwar craton and the Granulite terranes. However, good correlation of the azimuth of anisotropy with the structural grains of these terranes which are expected to fade at depth, suggests that most of the inferred anisotropy is confined to the upper-most few kilometers of the crust. In case, all of the anisotropy is confined in the upper crust up to a depth of 15 km, the degree of anisotropy would be ~5–6% (Rai Abhishek et al., 2008).

The layer-5 of the velocity structure, with a high velocity of 7.5 km/s in the lower crust can be attributed to magmatic underplating at the base of the crust. The reflection Moho is identified at a depth of 45 km all along transect with upper mantle velocity of 8.1 km/s. The 8.1 km/s is presumed for the upper mantle velocity as inferred from receiver function and wide angle refraction studies in the SGT (Rai et al., 2003; Reddy et al., 2003). The process of magmatic underplating in the region between MBSZ and KOSZ is also indicated by high velocity at lower-crust through the previous seismic study (Vijaya Rao and Rajendra Prasad, 2006). The Magnetotelluric study suggests a high conductivity zone in this region (Harinarayana et al., 2003). They pointed out that high conductivity is due to the presence of volatiles (low velocity/ low density/ high conductivity fluids) released during magmatic underplating. In addition, the process of magmatic underplating in this area is reflected as Bouguer gravity high in the region between MBSZ and KOSZ, with a minimum value of -60 mGal on either side and maximum of -30 m Gal at the centre location (Singh et al., 2003). Seismic data consistently indicate crustal thickening and the existence of high velocity layers at the base of the crust in large igneous provinces. These high velocity layers are commonly interpreted as a result of magmatic underplating (Kelemen and Holbrook, 1995; Farnetani et al., 1996; Trumbull et al., 2002).

A major process of continental accretion is magmatic underplating. Fyfe (1993) outlines several aspects of this process and its possible importance in the turbulent Archaean mantle. Related to the process of underplating and thickening of the crust is the process of delamination of the underplated denser crust. The extent of such delamination may be depending on the thickness and composition of the underplated material and the nature of mantle material flux underlying the thickened crust. Delamination as a process attains great importance as it exposes the overlying crust to the hot mantle and starts a new cycle of interactions that changes the whole course of geological evolution (Black and Liegeois, 1993). These aspects of underplating and delamination and their possible role in determining

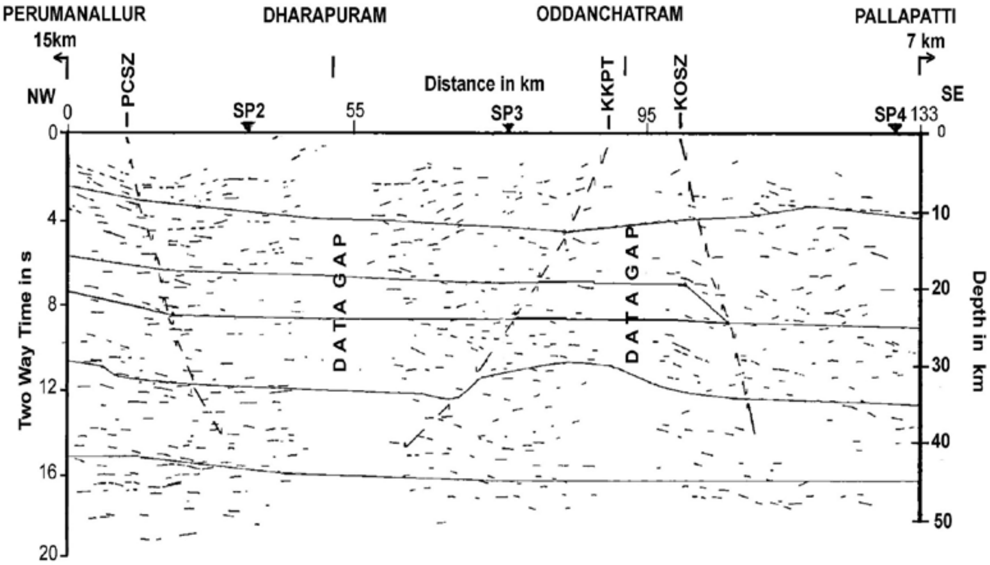

Figure 7. The combined line drawing of the stack sections of all the three segments with superimposed velocity structure. The shear zones: PCSZ: Palghat Cauvery Shear Zone, KKPT: Karur Kambam Painavu Trichur Shear Zone and KOSZ: Karur Oddanchatram Shear Zone is marked.

the course of evolution of the intracontinental high grade domains need to be further studied (Mahadevan, 1999).

Durrheim and Mooney (1991), on the basis of refraction studies in different continents, have suggested a thinner crust for the Archaean regions and a thicker crust for the Proterozoic areas. The crustal thickness of SGT is identified, more than that of Archaean terrains. The reason could be due the Proterozoic crustal reworking mainly at the MBSZ, PCSZ and other shear zones (Reddy et al., 2003). Drury et al., (1984) opined that the shear zones of this region were developed during Meso/ Neo-proterozoic period.

The 2D velocity-depth section plotted against the composite line drawing of seismic stack sections is shown in Fig-7, which provides the results of the present study at a glance. The south dipping reflectors, and subsequent nature of flat and gradual up dips towards south and, the south dipping nature of top three layers in velocity structure depicts clear indication of PCSZ between Perumanallur and Dharapuram. The host and graben reflectivity structure between Dharapuram and Oaddanchatram and, upwarp in the layer-4 of velocity-depth model can be correlated to the presence of KKPT. The abrupt south dipping reflectivity feature, south of Oddanchatram and merging of layer-2 with layer-3 in velocity structure, confirm the presence of KOSZ. The diffused Moho between 15.5-15.0 s TWT along transect confirms the crustal thickness of ~45 km.

It may be concluded that the process of collision, crustal thickening, de-lamination of the lower crust followed by magnetic under-plating has led to the evolution of a network of shear zones between MBSZ and KOSZ, popularly referred as Palghat Cauvery Shear System.

CONCLUSIONS

The present study based on deep seismic reflection, refraction/WAR data, has clearly brought out the basic nature of crustal scale regional shear zones of SGT and the velocity structure along Perumanallur-Dharapuram-Oddanchatram–Pallapatti (NW-SE) transect.

a) The south-west dipping PCSZ, located 25 km south of Perumanallur is identified (Fig-2a). It extends to lower crustal levels through reflectivity pattern (Fig-2b). The velocity structure confirms through the gentle south dipping nature of top three layers, south of Perumanallur (Fig-6c).

b) The northwest dipping shear, KKPT located 88 km south-west of Perumanallur is identified by horst-graben structure in the stack section (Fig-3a) and, the up-warp of layer-4 (Vp 7.3 km/s), near Dharapuram in the velocity structure (Fig-6c).

c) The south-west dipping KOSZ located 100 km south-west of Perumanallur is inferred by gentle and abrupt steepening of reflectivity at 10 s TWT (Fig-4). Also, the merging of Layer-2 (Vp 6.60-6.65 km/s) with Layer-3 (Vp 6.90 km/s), south of Oddanchatram led to inference of KOSZ as marked on Fig-6c.

d) The diffused Moho at 15.0 s TWT (~45 km thick crust), the reflectivity deeper than Moho and, the high velocity layer of 7.5 km/s in the lower crust, above upper mantle, may be due to injected mantle material. These higher velocities in the lower crust can be attributed to magmatic underplating at the base of the crust.

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