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A geochemical study on the Lansdowne granite and granite gneiss, Garhwal Lesser Himalaya, Uttarakhand (India)

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ABSTRACT

The Lansdowne klippe in the Lesser Himalaya is a thrust-plunging syncline comprising Precambrian granite and granite gneiss, prominently exposed around Jaiharikhal-Lansdowne in Garhwal region. The study area consists metasedimentary rocks, quartzose-phyllite, mylonite/phyllonite, granitic and augen gneisses. Granites exhibit medium-coarse, hypidiomorphic, and porphyritic textures with minerals Pl-Kfs-Qtz-Bt-Mus-Tour-Mag-Ap-Zr-Ep. Granite gneisses exhibit a mineral composition similar to that of granite, but with a well-developed foliation plane. Near fault zones, mylonitic textures with quartz ribbons and sericite occurrences, indicate NW-SE shearing. Textural features (porphyritic, perthitic) and geochemical characteristics (alkalic-ferroan, peraluminous), suggest slow cooling from a direct magmatic origin within syn-collisional to post-orogenic settings.

Keywords: Garhwal Himalaya, Lansdowne-Jaiharikhal granite and granite gneiss, Lansdowne klippe, Mineral chemistry, Geochemistry, Syn-collisional.

INTRODUCTION

Since ~55 Ma, intense Cenozoic crustal thickening of the crust created the Himalayas due to continental collision between India and Eurasia. Since the Proterozoic era, various granitoids have been emplaced until recent times. The intense pressure and temperature, generated during this process, caused the partial melting of the continental crust leading to the formation of large volumes of granitic magma (Rai and Kumar, 2015). Five significant belts of granite plutons in the Himalaya based on geographical distribution are, Karakoram axial batholith, Trans-Himalayan batholith, Northern Himalayan Granite belt, granitoids of the Higher Himalayan Crystalline belt, and Lesser Himalayan Granite belt (Le Fort, 1988). The occurrences of granites from the Lesser Himalayan sequence, are well exposed in the Himachal and Garhwal-Kumaon regions of the Himalayas (Bhatnagar and Sharma, 1989; Tandon and Bhatt, 1995; Santosh et al., 2003; Islam et al., 2005). These granites were formed by the partial melting of a metasedimentary source rock, possibly a pelitic rock, in a continental crustal setting (Chakraborty et al., 1994; Dasgupta et al.,1996; Upadhyay and Singh, 2000).

The earlier works in the Lansdowne region (Auden,1937; Shanker and Ganesan 1973) proposed that the granite gneiss intruded into underlying metamorphites (chandpurs/ chails) before the formation of the Garhwal thrust (pre-Miocene). Vishnoi (1971) provided detailed information about the geology of the area. Eldson and Gupta (1981) determined petrochemical properties and suggested magmatic origin of granite gneisses, with pronounced gneissosity due to later deformation. This paper focuses on the analysis of geochemical and mineral chemistry data of the area in order to enhance our knowledge to understand the origin, crustal evolution and tectonic setting.

GEOLOGY AND FIELD RELATIONSHIP

The proposed study area lies in the Lansdowne Pauri Garhwal, Lesser Himalaya, Uttarakhand. It lies between latitudes 29°49'0" N and 29°51'30" N and longitudes 78°39'0" E and 78°41'30" E in Geological Survey of India toposheet no. 53K/9. Lesser Himalaya meta-sedimentary rocks and the crystalline nappe/klippe are well exposed (Figure 1) with dominating litho-units Lansdowne granite and granite gneiss. The proximity with thrust, resulted into deformation and transformation of Lansdowne granite to granite gneiss, further follows by augen gneiss and mylonite (Gupta, 1976a,b). The Bijni member rests over sedimentary rock of the Krol nappe and Garhwal thrust consisting quartz, schist and phyllite sequence (Auden, 1937). This phyllite is considered as Amri phyllite, correlated with Chandpur phyllite belonging to Chail nappe (Saklani, 1993). The Lansdowne formation tectonically overlies it and the Amri thrust marks the contact (Valdiya, 1980). Moreover, it has also been described as Lansdowne metamorphic (Gupta, 1976a, b) and Lansdowne crystallines (Valdiya, 1980). The Garhwal nappe comprises deformed phyllite and schist, capped by a small outcrop of Lansdowne granite and granite gneiss (Figure 2). The granite gneiss in the sequence changes from mylonitic gneiss at the base to granite gneiss in the upper sections (Gupta, 1976b). Additionally, there is evidence of granite intrusion above the metasediments in the Lansdowne area (Kumar and Daundhiyal, 1980). The Garhwal thrust is tectonically significant as it delineates major structural units in the lesser Himalaya that facilitated the emplacement of older Precambrian rocks over younger sedimentary sequences.

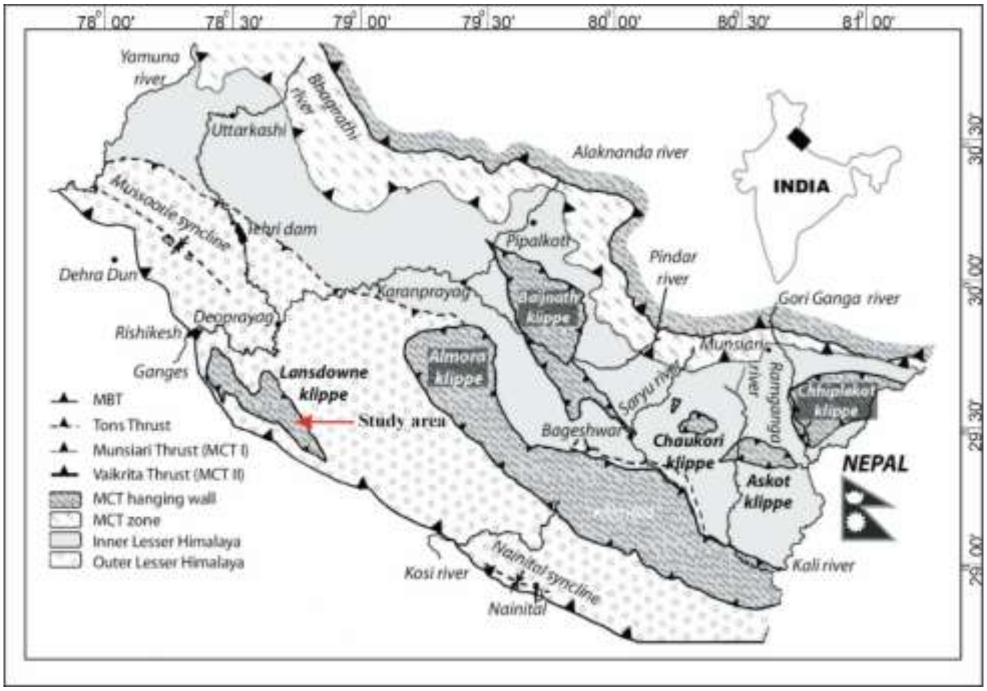


Figure 1. Geological and structural map of the Garhwal-Kumaun Lesser Himalaya (After Fuchs and Sinha, 1978).

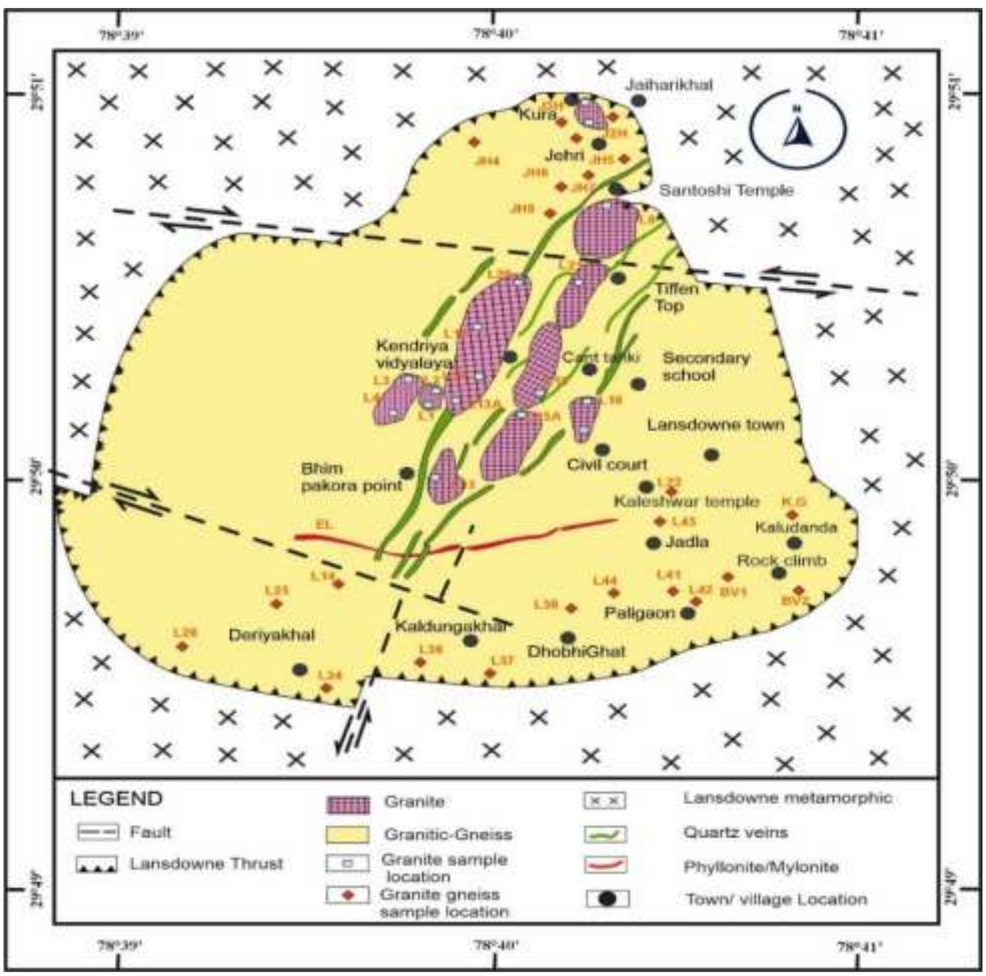


Figure 2. Geological map of the Lansdowne granite (LG) and Lansdowne granite gneiss (LGGn).

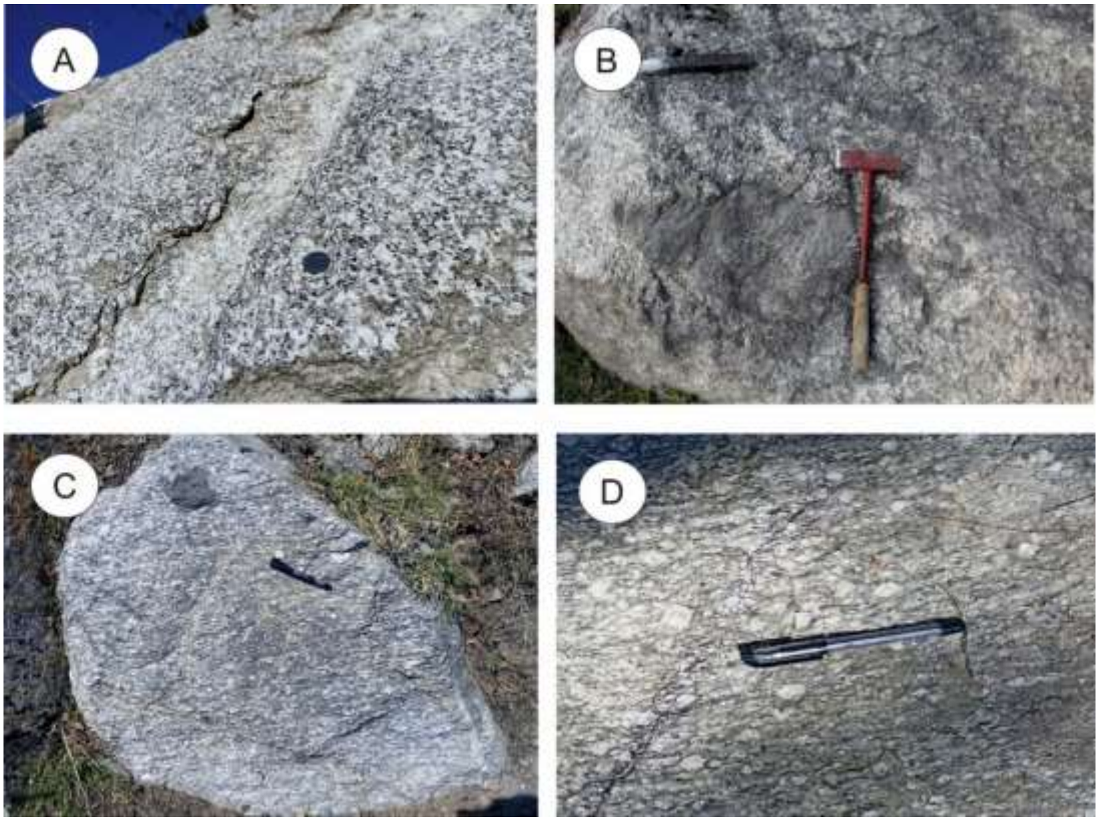


Figure 3. **(A)** Medium to coarse grained leucocratic granite pluton. **(B)** Melanocratic enclave within granite. (**C**) Granite gneiss showing minerals aligned parallel to the foliation plane. (**D**) Porphyroblast of feldspar showing augen structure.

The granite forms massive and small plutons. It is medium to coarse-grained, leucocratic, composed of K-feldspar, plagioclase, quartz, muscovite, and biotite, with accessory minerals such as tourmaline, apatite, epidote and zircon. It exhibits hypidiomorphic and porphyritic texture (Figure 3A). It also consists of microgranular enclaves of more or less elliptical shape (Figure 3B). The granitic gneiss exhibits tabular and euhedral feldspar phenocrysts that are aligned parallel to the foliation plane, exhibiting gneissose structure (Figure 3C). Phenocrysts of quartz and feldspars in granitic gneiss are surrounded by a thin mica layer that preserves their original characteristics (Figure 3D).

PETROGRAPHY

Petrographical study of granite and granite gneisses exhibits perthitic and porphyritic texture. Microcline exhibits crosshatch twinning. Sericitization is evident in plagioclase and quartz that show undulose extinction (Figure 4A). Plagioclase feldspar with inclusions of muscovite exhibits albitic twinning (Figure 4B). A single plagioclase crystal displays normal zoning with concentric zones of a calcic core and sodic rims (Figure 4C). Muscovite and biotite demonstrate perfect basal cleavage. Undulose quartz consists of tiny zircon inclusions (Figure 4D). Euhedral to subhedral tourmaline exhibits two sets of cleavage (Figure 4E). K-feldspar with microcline exhibits cross-hatched or tartan twinning. Plagioclase and orthoclase exhibit carlsbad and albite twinning (Figure 4F)

Granite gneisses reveal that quartz and muscovite are aligned as parallel forming gneissic bands due to proximation along the compressional regime. Orthoclase feldspar with Carlsbad twinning exhibits inclusions of muscovite (Figure 5A). Quartz, muscovite, biotite, and K-feldspar crystals show preferred orientation along the foliation plane, exhibiting gneissose structure (Figure 5B). Deformed plagioclase porphyroblasts are aligned parallel to quartz and mica (Figure 5C). In post-deformational structures muscovite is surrounded by biotite, showing preferred orientation (Figure 5D). Deformed quartz wrapped in foliated mica ribbons display augen structure in gneisses (Figure 5E). Feldspar grains show a sigma structure with tails aligned parallel to the foliation plane, indicating shearing in NE-SW direction (Figure 5F). In the modal composition of the QAP diagram (Le Maitre, 2002), the proportions of quartz, alkali feldspar, and plagioclase feldspar falls within the granite field, specifically syeno-granite and monzo-granite (Figure 6)

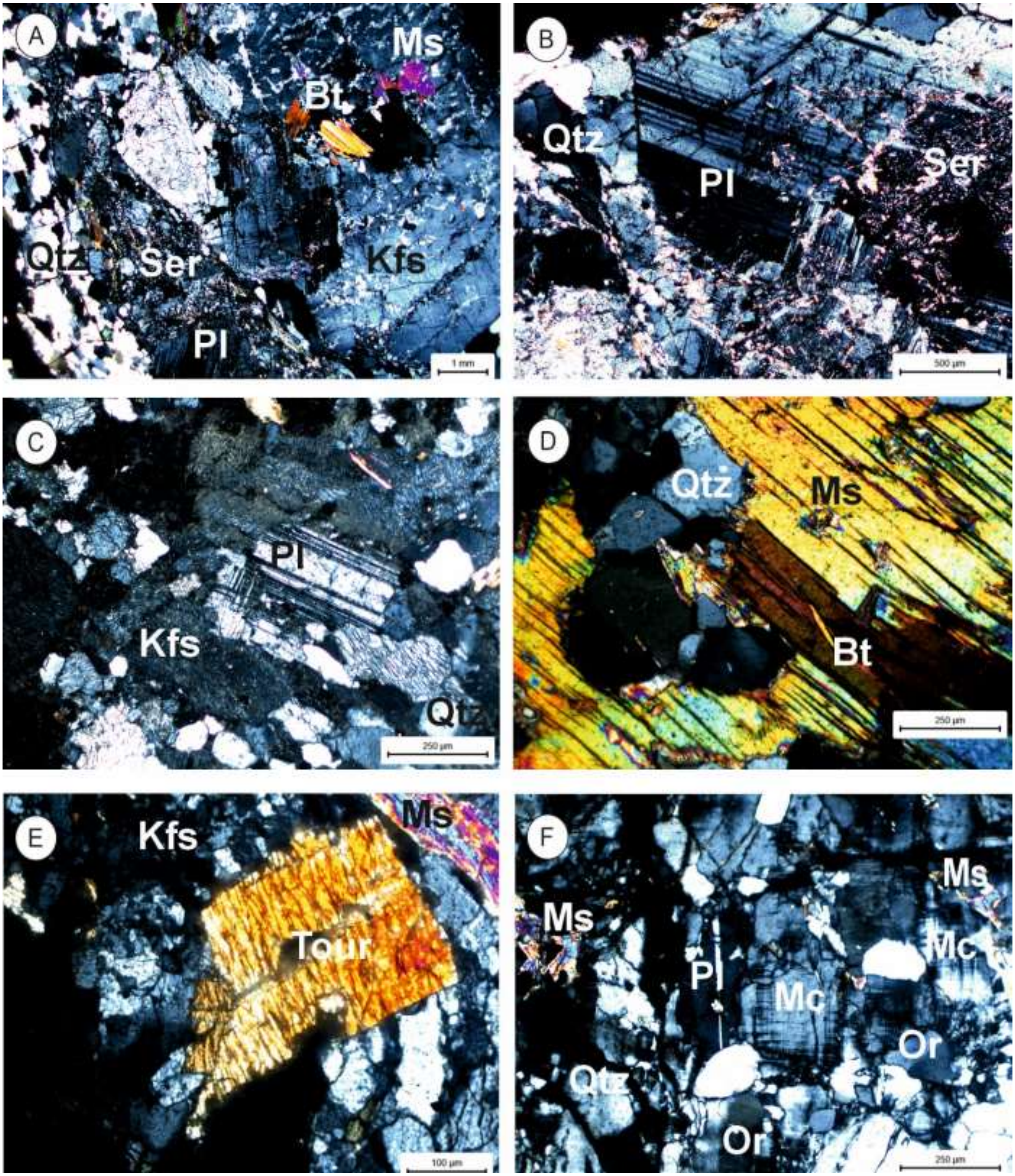


Figure 4. **(A)** Plagioclase and two mica inclusion in perthite. **(B)** Plagioclase phenocryst with sericitized muscovite inclusion. **(C)** Plagioclase normal zoning with sericitization. **(D)** Basal cleavage in two micas. **(E)** Euhedral tourmaline in K- feldspar. **(F)** Ovoid vacuoles in between feldspars. Qtz, Kfs, Pl, Bt, Ms, Mc, Tour, Ser and Or refer to quartz, K-feldspar, plagioclase, biotite, muscovite, microcline, tourmaline, sericitization and orthoclase respectively.

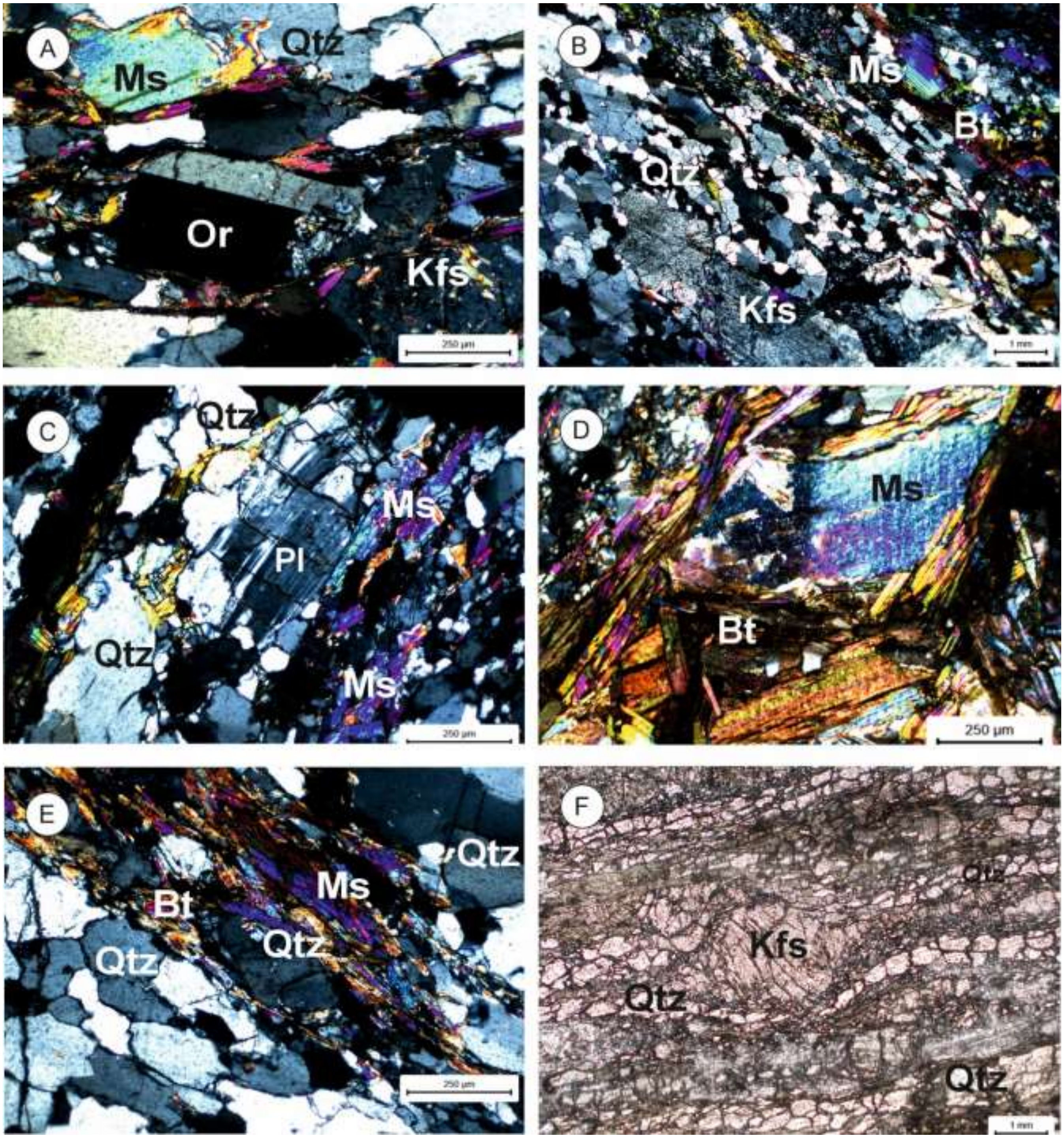


Figure 5. **(A)** Orthoclase, K-feldspar, and muscovite aligned along the foliation plane. **(B)** Alignment of minerals in parallel bands. **(C)** Plagioclase parallel to the foliation plane. **(D)** Biotite muscovite mica in deformed phase. **(E)** Quartz wrapped with mica foliation. **(F)** K-feldspar porphyroblast depicts sigma structure indicating shear sense. Qtz, Kfs, Pl, Bt, Ms, and Or refer to quartz, K-feldspar, plagioclase, biotite, muscovite, and orthoclase respectively.

RESULTS AND DISCUSSION

Whole rock geochemistry

Whole rock geochemical data (major and trace elements) on granite (N = 05) and granite gneiss (N = 05), as obtained from XRF, is given in Table 1. Apparently, there is no major geochemical variation in the granite and granite gneisses. The granite shows limited variation in SiO_2 (69.47-70.19 wt.%), Al_2O_3 (16.76-17.18 wt.%.) and K_2O (4.93-5.38 wt.%), and substantially low range in Fe_2O_3, CaO, MgO, P_2O_5, MnO and TiO_2 (0.99-1.48 wt.%, 0.63-0.69 wt.%, 0.14-0.21 wt.%, 0.28-0.33 wt., 0.03-0.08 wt.% and 0.10-0.14 wt.% respectively). Similarly, the granite exhibits high variations in trace elements Ba, Rb, Cr (147-183 ppm, 364-395 ppm and 59-135 ppm respectively) and moderate variations in Sr, Zr, Pb, Zn, Ni, Ga, Y and Nb (54-69 ppm, 38-54 ppm, 38-59 ppm, 42-61 ppm, 13-16 ppm, 20-24 ppm, 34-37 ppm and 10-16 ppm) apart from considerably low contents in Co, Sc, V, Th, U and Cu (3-5 ppm, 1-3 ppm, 7-10 ppm, 4-7 ppm, 2.0- 2.6 ppm and 8-12 ppm) contents

In comparison, the granite gneiss are characterised by SiO_2 (69.00-70.04 wt.%), Al_2O_3 (16.92-17.45 wt.%), moderately high values of Na_2O (3.94-4.47 wt.%) and K_2O (4.71-5.42 wt.%) and substantially lower values of Fe_2O_3, Cao, MgO, P_2O_5, MnO and TiO_2 (1.21-1.41wt.%, 0.57-0.64 wt.%, 0.16-0.21 wt.%, 0.29-0.38 wt.%, 0.03-0.08 wt.% and 0.11-0.13 wt.% respectively). They exhibit high variations in trace elements Ba, Rb, Cr (109-205 ppm, 379-463 ppm and 21-158 ppm respectively) and moderate variations in Sr, Zr, Pb, Zn, Ni, Ga, Y and Nb (46-67 ppm, 44-51 ppm, 36-53 ppm, 54-61 ppm, 15-19 ppm, 24-27 ppm, 35-41 ppm and 14-17 ppm respectively). They further show low contents in Co, Sc, V, Th, U and Cu (3-7 ppm, 1-3 ppm, 4-9 ppm, 5-7 ppm, 2.0- 2.5 ppm and 4-13 ppm respectively) (Arya, 2024).

Mineral chemistry, composition, and classification of feldspar

K-feldspar

The general formula of feldspar is XZ_4O_8 (where X = Ca, Na, K, and Z = Si, Al). The feldspar group of end members are $NaAlSi_3O_8$ (albite, Ab), $KAlSi_3O_8$ (orthoclase, Or), and $CaAl_2Si_2O_8$ (anorthite, An). Micro probe analysis data and calculated structural formulas for feldspar group of minerals are provided in Tables 2-9.

Compositions of K-feldspars in granite vary in a narrow range (Ab=2.57-7.15, Or=92.55-95.87, An=0.00-0.001), except few samples. The K-feldspar in granite gneiss reveals almost similar composition to granite (Ab=4.43-6.64, Or=92.86-99.60, An=0.00). The K-feldspar from both litho-units is equal to sanidine composition (Figure 7A).

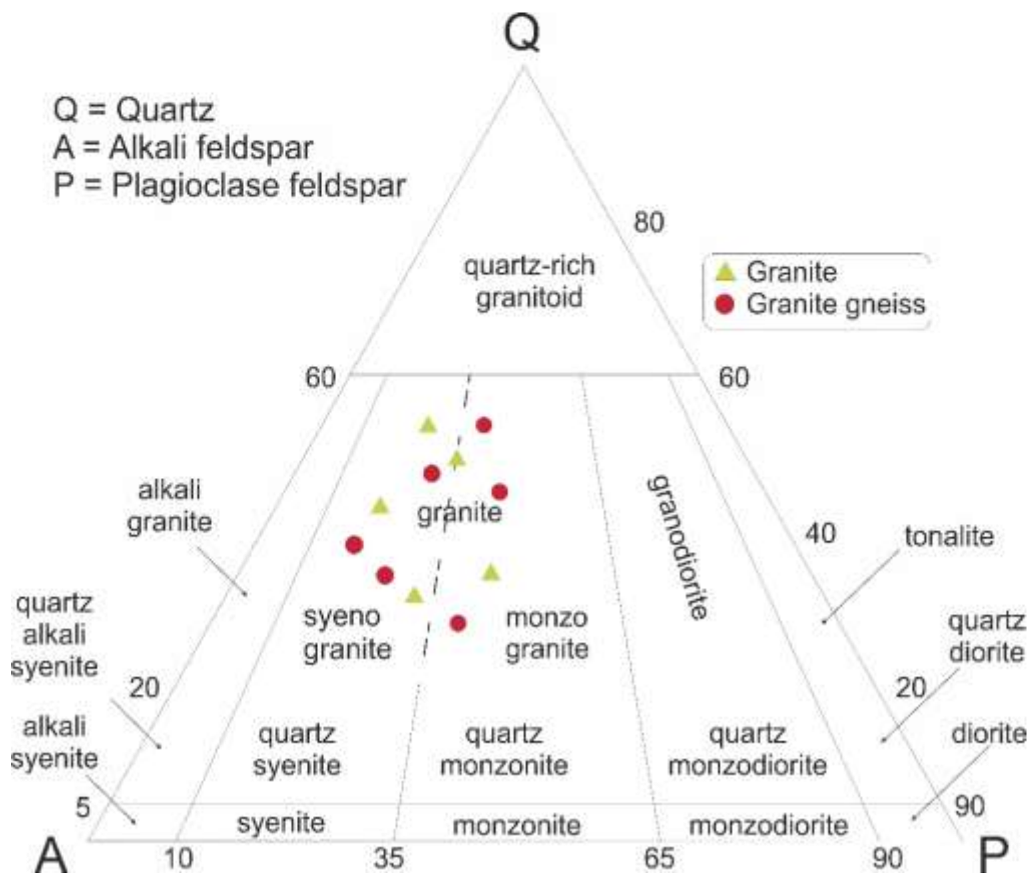


Figure 6. Modal composition of the Lansdowne granite and granite gneiss rocks plotted in the QAP diagram. Granite reveals two fields syenogranite and monzogranite (after Le Maitre, 2002).

Table 1. Major oxides (wt.%), trace, and rare earth elemental composition (in ppm) of Lansdowne granite (LG) and Lansdowne granite gneiss (LGGn) samples from Garhwal Lesser Himalaya.

Sample No.	L13 (LG)	L16 (LG)	L19 (LG)	L21 (LG)	L45 (LG)	JH1 (LGGn)	BV1 (LGGn)	L6 (LGGn)	L23 (LGGn)	L35 (LGGn)
SiO_2	69.5	70.19	69.47	70.15	69.79	70.04	69.47	69	69.28	68.99
TiO_2	0.12	0.1	0.13	0.14	0.12	0.11	0.13	0.12	0.12	0.12
Al_2O_3	17.18	16.98	16.98	16.76	16.96	16.92	17.07	17.34	17.45	17.22
Fe_2O_3	1.27	0.99	1.38	1.48	1.31	1.21	1.41	1.32	1.28	1.33
MnO	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
MgO	0.19	0.14	0.2	0.21	0.18	0.16	0.21	0.18	0.18	0.19
CaO	0.69	0.63	0.65	0.63	0.63	0.61	0.64	0.61	0.57	0.61
Na_2O	4.17	4.32	3.81	3.82	4.28	4.47	3.94	3.99	3.96	4.12
K_2O	5.15	5.38	5.02	5.18	4.93	4.71	4.96	4.94	5.42	4.8
P_2O_5	0.33	0.28	0.33	0.33	0.32	0.38	0.32	0.34	0.29	0.34
LOI	1.48	1.46	1.6	1.65	1.35	1.49	1.65	1.92	2.05	1.66
TOTAL	98.63	99.04	98	98.73	98.55	98.64	98.18	97.87	98.58	97.76
Ba	167	171	178	183	147	109	160	159	205	140
Rb	365	364	368	377	395	463	388	401	379	393
Sr	69	68	61	63	54	46	59	55	67	50
Y	35	34	35	36	37	41	37	38	35	37
Zr	50	38	51	54	49	44	51	51	46	48
Nb	14	10	15	16	16	17	16	17	14	16
Cr	135	59	89	94	60	26	21	23	158	55
Ni	13	16	14	15	16	17	16	16	15	19
Co	5	3	5	3	4	6	3	3	7	7
Sc	2	2	3	1	2	2.3	1.4	1.2	3	2.7
V	9	7	8	10	7	7	9	8	4	8
Cu	8	12	9	8	8	4	10	9	10	13
Pb	48	59	42	42	38	36	44	41	53	36
Zn	52	42	57	61	60	59	61	58	54	59
Ga	23	20	22	22	24	27	26	26	24	25
Th	6	4	7	7	6	6	7	7	5	5
U	2.3	2	2.3	2.6	2.5	2.5	2	2.4	2.3	2.1
La	13.72	7.58	9.69	13.72	11.32	9.33	13.91	17.27	8	12.22
Ce	27.53	16.13	22.4	30.06	24.82	16.98	31.43	36.71	15.35	27.61
Pr	3.18	1.71	2.26	3.24	2.71	2.26	3.31	4.05	1.85	2.97
Nd	10.49	5.87	7.85	10.81	9.21	7.11	11.5	13.6	5.97	10.02
Sm	2.98	1.52	2.19	3.15	2.6	2.25	3.21	3.8	1.67	2.74
Eu	0.56	0.46	0.38	0.47	0.33	0.28	0.44	0.52	0.4	0.39
Gd	2.84	1.5	2.22	3.19	2.48	2.11	3.08	3.61	1.62	2.72
Tb	0.49	0.25	0.4	0.55	0.41	0.38	0.53	0.61	0.29	0.47
Dy	2.43	1.27	1.93	2.6	1.93	1.82	2.56	3.02	1.45	2.28
Ho	0.3	0.16	0.24	0.31	0.25	0.22	0.31	0.36	0.18	0.28
Er	0.7	0.35	0.58	0.71	0.53	0.5	0.73	0.83	0.46	0.64
Tm	0.08	0.04	0.07	0.08	0.07	0.07	0.08	0.1	0.05	0.08
Yb	0.5	0.26	0.4	0.52	0.42	0.38	0.52	0.57	0.32	0.5
Lu	0.07	0.04	0.05	0.07	0.05	0.05	0.07	0.08	0.04	0.07

Table 2. Microprobe analysis of K-feldspar (K-Fsp) from the Lansdowne granite sample L16, Garhwal Lesser Himalaya. Oxides are in wt%.

	Lansdowne Granite																	
Sample No.	L16	L16	L16	L16	L16	L16	L16	L16	L16	L16	L16	L16	L16	L16	L16	L16	L16	L16
Mineral	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp
SiO_2	63.7	63.16	64.24	63.36	63.96	63.93	63.98	64.42	63.92	63.85	63.43	63.57	65.07	63.62	63.63	63.99	63.29	63.30
TiO_2	0.035	0.011	0.03	0	0	0.03	0	0.021	0.009	0.015	0.017	0.004	0	0	0.003	0.006	0.032	0
Al_2O_3	18.01	18.46	18.29	18.74	18.49	18.63	18.27	18.44	17.74	18.32	17.81	17.79	18.13	17.94	17.74	17.77	17.81	18.02
FeO	0.058	0.095	0	0	0.168	0	0.036	0	0	0	0.013	0.003	0.074	0.076	0.001	0.073	0	0
CaO	0.095	0	0	0.003	0	0	0	0.064	0.213	0	0	0.021	0.25	0.036	0.03	0.032	0.04	0.032
Na_2O	0.277	0.553	0.689	0.663	0.583	0.632	0.724	0.709	0.713	0.798	0.564	0.399	4.239	0.337	0.327	0.562	0.324	0.676
K_2O	15.89	16.05	16.03	15.96	16.61	16.07	15.91	16.11	15.68	15.82	16.34	16.77	11.35	16.26	16.72	16.31	16.72	16.02
P_2O_5	0.319	0.526	0.26	0.744	0.247	0.331	0.336	0.336	0.433	0.255	0.345	0.165	0	0.164	0.014	0	0.223	0.283
TOTAL	98.39	98.87	99.55	99.48	100.0	99.64	99.27	100.1	98.73	99.07	98.54	98.73	99.12	98.44	98.48	98.76	98.45	98.34
Tot.oxy	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Cation																		
Si	11.77	11.67	11.87	11.71	11.82	11.82	11.83	11.91	11.81	11.80	11.72	11.75	12.03	11.76	11.76	11.83	11.70	11.70
Ti	0.005	0.001	0.004	0	0	0.004	0	0.003	0.001	0.002	0.002	0	0	0	0	0.001	0.005	0
Al	3.925	4.023	3.986	4.085	4.03	4.061	3.983	4.018	3.867	3.993	3.882	3.878	3.951	3.91	3.867	3.873	3.882	3.927
Fe	0.009	0.015	0	0	0.026	0	0.006	0	0	0	0.002	0	0.011	0.012	0	0.011	0	0
Ca	0.019	0	0	0.001	0	0	0	0.013	0.042	0	0	0.004	0.049	0.007	0.006	0.006	0.008	0.006
Na	0.099	0.198	0.247	0.237	0.209	0.226	0.259	0.254	0.256	0.286	0.202	0.143	1.52	0.121	0.117	0.201	0.116	0.242
K	3.749	3.787	3.781	3.764	3.919	3.791	3.754	3.801	3.7	3.733	3.855	3.956	2.678	3.837	3.944	3.848	3.943	3.779
Ba	0.025	0.041	0.02	0.058	0.019	0.026	0.026	0.026	0.034	0.02	0.027	0.013	0	0.013	0.001	0	0.017	0.022
TOTAL	19.60	19.74	19.91	19.86	20.02	19.92	19.85	20.02	19.71	19.84	19.7	19.74	20.24	19.66	19.70	19.77	19.67	19.68
An	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ab	2.571	4.969	6.133	5.933	5.063	5.636	6.465	6.244	6.395	7.115	4.982	3.484	35.78	3.042	2.878	4.964	2.859	6.017
Or	96.94	95.03	93.86	94.05	94.93	94.36	93.53	93.44	92.55	92.88	95.01	96.41	63.05	96.77	96.97	94.87	96.94	93.82

Table 3. Microprobe analysis of K-feldspar (K-Fsp) from the Lansdowne granite sample L21, Garhwal Lesser Himalaya. Oxides are in wt%.

	Lansdowne Granite													
Sample No.	L21	L21	L21	L21	L21	L21	L21	L21	L21	L21	L21	L21	L21	L21
Mineral	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp
SiO_2	63.066	64.286	63.62	63.639	63.304	63.066	63.57	65.077	64.628	65.016	63.924	63.397	63.711	64.037
TiO2	0	0.006	0	0.003	0	0	0.004	0	0	0.002	0.021	0.022	0	0.021
Al_2O_3	17.945	17.946	17.945	17.748	18.025	17.945	17.797	18.132	17.946	18.065	17.918	17.889	18.072	17.817
FeO	0	0.031	0.076	0.001	0	0	0.003	0.074	0.017	0	0	0.015	0.043	0.058
CaO	0.036	0.02	0.036	0.03	0.032	0.036	0.021	0.25	1.537	0.027	0	0	0.1	0.005
Na_2O	0.313	0.658	0.337	0.327	0.676	0.313	0.399	4.239	7.539	0.318	0.318	0.581	0.076	0.099
K_2O	16.475	15.944	16.269	16.723	16.024	16.475	16.774	11.354	6.183	15.79	16.715	16.184	15.825	16.273
P_2O_5	0.136	0.001	0.164	0.014	0.283	0.136	0.165	0	1.437	0.007	0	0.02	0.193	0.01
TOTAL	97.97	98.89	98.445	98.483	98.343	97.97	98.732	99.126	99.287	99.223	98.895	98.109	98.02	98.32
Tot.oxy	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Cation														
Si	11.66	11.885	11.762	11.766	11.704	11.66	11.753	12.032	11.949	12.02	11.818	11.721	11.779	11.839
Ti	0	0.001	0	0	0	0	0	0	0	0	0.003	0.003	0	0.003
Al	3.91	3.91	3.91	3.867	3.927	3.91	3.878	3.951	3.91	3.936	3.904	3.898	3.938	3.882
Fe	0	0.005	0.012	0	0	0	0	0.011	0.003	0	0	0.002	0.007	0.009
Ca	0.007	0.004	0.007	0.006	0.006	0.007	0.004	0.049	0.304	0.005	0	0	0.02	0.001
Na	0.112	0.236	0.121	0.117	0.242	0.112	0.143	1.52	2.702	0.114	0.114	0.208	0.027	0.035
K	3.885	3.76	3.837	3.944	3.779	3.885	3.956	2.678	1.458	3.724	3.942	3.817	3.732	3.838
Ba	0.011	0	0.013	0.001	0.022	0.011	0.013	0	0.112	0.001	0	0.002	0.015	0.001
TOTAL	19.585	19.801	19.661	19.701	19.681	19.585	19.748	20.241	20.439	19.8	19.781	19.651	19.518	19.608
An	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0
Ab	2.799	5.899	3.042	2.878	6.017	2.799	3.484	35.781	60.521	2.961	2.806	5.176	0.721	0.914
Or	97.024	94.004	96.777	96.978	93.826	97.024	96.416	63.054	32.659	96.901	97.194	94.824	98.755	99.059

Table 4. Microprobe analysis of K-feldspar (K-Fsp) from the Lansdowne granite gneiss samples L 42 and L44, Garhwal Lesser Himalaya. Oxides are in wt%.

	Lansdowne Granite Gneiss									
Sample No.	L42	L42	L42	L42	L42	L44	L44	L44	L44	L44
Mineral	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp	K-Fsp
SiO_2	63.304	63.066	63.57	65.077	64.628	65.016	63.924	63.397	63.711	64.037
TiO_2	0	0	0.004	0	0	0.002	0.021	0.022	0	0.021
Al_2O_3	18.025	17.945	17.797	18.132	17.946	18.065	17.918	17.889	18.072	17.817
FeO	0	0	0.003	0.074	0.017	0	0	0.015	0.043	0.058
CaO	0.032	0.036	0.021	0.25	1.537	0.027	0	0	0.1	0.005
Na_2O	0.676	0.313	0.399	4.239	7.539	0.318	0.318	0.581	0.076	0.099
K_2O	16.024	16.475	16.774	11.354	6.183	15.79	16.715	16.184	15.825	16.273
P_2O_5	0.283	0.136	0.165	0	1.437	0.007	0	0.02	0.193	0.01
TOTAL	98.343	97.97	98.732	99.126	99.287	99.223	98.895	98.109	98.02	98.32
Tot.oxy	8	8	8	8	8	8	8	8	8	8
Cation										
Si	11.704	11.66	11.753	12.032	11.949	12.02	11.818	11.721	11.779	11.839
Ti	0	0	0	0	0	0	0.003	0.003	0	0.003
Al	3.927	3.91	3.878	3.951	3.91	3.936	3.904	3.898	3.938	3.882
Fe	0	0	0	0.011	0.003	0	0	0.002	0.007	0.009
Ca	0.006	0.007	0.004	0.049	0.304	0.005	0	0	0.02	0.001
Na	0.242	0.112	0.143	1.52	2.702	0.114	0.114	0.208	0.027	0.035
K	3.779	3.885	3.956	2.678	1.458	3.724	3.942	3.817	3.732	3.838
Ba	0.022	0.011	0.013	0	0.112	0.001	0	0.002	0.015	0.001
TOTAL	19.681	19.585	19.748	20.241	20.439	19.8	19.781	19.651	19.518	19.608
An	0	0	0	0	0.001	0	0	0	0	0
Ab	6.017	2.799	3.484	35.781	60.521	2.961	2.806	5.176	0.721	0.914
Or	93.826	97.024	96.416	63.054	32.659	96.901	97.194	94.824	98.755	99.059

Table 5. Microprobe analysis of plagioclase (Plag) from the Lansdowne granite sample L27, Garhwal Lesser Himalaya. Oxides are in wt%.

	Lansdowne Granite											
Sample No.	L27	L27	L27	L27	L27	L27	L27	L27	L27	L27	L27	L27
Mineral	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag
SiO_2	66.65	66.35	64.16	63.53	63.96	67.25	68.18	66.22	63.87	63.94	65.71	64.48
TiO_2	0.02	0	0	0	0	0	0	0	0	0	0	0
Al_2O_3	19.47	20	21.18	21.18	21.79	19.37	19.65	19.77	19.73	20.11	20.07	18.34
FeO	0	0	0	0	0	0.04	0.03	0	0	0	0	0
CaO	0.65	1.36	2.69	2.88	3.21	0.79	0.3	1.36	1.55	1.79	1.43	2.62
Na_2O	10.95	11.26	10.44	10.51	10.34	11.43	11.64	11.33	11.28	10.95	11.31	11.38
K_2O	0.17	0	0.08	0.05	0.13	0.12	0.09	0.04	0.02	0.05	0.08	0.15
P_2O5	0.3	0.14	0.28	0.25	0.3	0.01	0.27	0.22	0.23	0.26	0	2.3
TOTAL	98.22	99.11	98.84	98.4	99.74	99.02	100.16	98.94	96.67	97.09	98.6	99.29
Tot.oxy	8	8	8	8	8	8	8	8	8	8	8	8
Cation												
Si	12.186	12.13	11.73	11.615	11.693	12.296	12.465	12.106	11.676	11.69	12.013	11.789
Ti	0.003	0	0	0	0	0	0.001	0	0	0	0	0
Al	4.196	4.309	4.563	4.563	4.696	4.172	4.234	4.259	4.25	4.334	4.324	3.952
Fe	0	0	0	0	0	0.007	0.004	0	0	0	0	0
Ca	0.127	0.266	0.527	0.564	0.629	0.155	0.058	0.267	0.303	0.35	0.281	0.514
Na	3.88	3.991	3.7	3.726	3.666	4.051	4.127	4.016	3.997	3.88	4.01	4.035
K	0.041	0	0.019	0.012	0.03	0.027	0.021	0.008	0.004	0.011	0.018	0.035
P	0.023	0.011	0.022	0.019	0.023	0.001	0.021	0.017	0.018	0.02	0	0.178
TOTAL	20.43	20.7	20.54	20.48	20.71	20.71	20.91	20.66	20.23	20.26	20.64	20.32
An	3.14	6.26	12.42	13.11	14.55	3.67	1.38	6.23	7.04	8.26	6.52	11.21
Ab	95.86	93.74	87.13	86.61	84.75	95.69	98.13	93.58	92.87	91.49	93.06	88.03
Or	1	0	0.45	0.29	0.7	0.64	0.49	0.19	0.1	0.25	0.42	0.75

Table 6. Microprobe analysis of plagioclase (Plag) from the Lansdowne granite sample L13, Garhwal Lesser Himalaya. Oxides are in wt%.

	Lansdowne Granite											
Sample No.	L13	L13	L13	L13	L13	L13	L13	L13	L13	L13	L13	L13
Mineral	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag
SiO_2	63.9	64.29	63.96	68.17	67.9	68.39	66.87	68.39	68.99	67.81	67.58	67.74
TiO_2	0.03	0.05	0.03	0.05	0	0	0	0	0	0	0.01	0
Al_2O_3	20.94	21.42	20.91	19.83	18.92	18.64	18.82	18.64	19.02	19.19	19.21	19.03
FeO	0.16	0.01	0.11	0	0.03	0.05	0.12	0.05	0.03	0.13	0.03	0
CaO	2.87	2.87	2.86	0.51	0.01	0.01	0.57	0.01	0.12	0	0.05	0.15
Na_2O	9.7	10.28	10.29	10.85	11.85	10.78	11.94	10.78	11.41	12.01	11.47	11.25
K_2O	0.24	0.28	0.19	0.08	0.14	1.62	0.09	1.62	0.14	0.11	0.18	0.08
P_2O_5	0.3	0.25	0.32	0.57	0.01	0.09	0.13	0.09	0	0	0	0.02
TOTAL	98.14	99.45	98.68	100.06	98.85	99.58	98.54	99.58	99.71	99.25	98.51	98.27
Tot.oxy	8	8	8	8	8	8	8	8	8	8	8	8
Cation												
Si	11.683	11.754	11.693	12.463	12.414	12.504	12.225	12.504	12.613	12.397	12.354	12.385
Ti	0.004	0.007	0.005	0.007	0	0	0	0	0	0	0.001	0
Al	4.512	4.615	4.505	4.272	4.076	4.016	4.055	4.016	4.098	4.134	4.138	4.1
Fe	0.024	0.002	0.017	0	0.004	0.007	0.018	0.007	0.005	0.02	0.004	0
Ca	0.562	0.562	0.56	0.099	0.001	0.003	0.112	0.003	0.024	0	0.009	0.029
Na	3.438	3.643	3.647	3.844	4.199	3.82	4.232	3.82	4.043	4.256	4.064	3.986
K	0.055	0.064	0.045	0.02	0.032	0.377	0.021	0.377	0.033	0.026	0.042	0.019
P	0.023	0.019	0.025	0.044	0.001	0.007	0.01	0.007	0	0	0	0.002
TOTAL	20.28	20.65	20.47	20.71	20.73	20.73	20.66	20.73	20.82	20.83	20.61	20.52
An	13.85	13.17	13.17	2.51	0.02	0.06	2.57	0.06	0.58	0	0.23	0.73
Ab	84.79	85.32	85.76	97	99.21	90.95	96.95	90.95	98.61	99.4	98.76	98.81
Or	1.36	1.51	1.06	0.5	0.77	8.99	0.48	8.99	0.81	0.6	1.01	0.46

Table 7. Microprobe analysis of plagioclase (Plag) from the Lansdowne granite sample L20, Garhwal Lesser Himalaya. Oxides are in wt%.

	Lansdowne Granite											
Sample No.	L20	L20	L20	L20	L20	L20	L20	L20	L20	L20	L20	L20
Mineral	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag
SiO_2	68.07	67.54	68.01	68.43	68.73	67.37	67.96	68.08	68.14	66.96	67.75	68.99
TiO_2	0	0	0	0	0	0	0	0	0	0	0	0
Al_2O_3	19.19	19.24	19.03	19.31	19.53	19.47	18.86	18.86	18.85	18.97	18.76	19.02
FeO	0.18	0.07	0	0	0.07	0.07	0	0	0	0.07	0.06	0.03
CaO	0.07	0.19	0	0.12	0	0	0.1	0.09	0.15	0.23	0.14	0.12
Na_2O	11.77	11.35	11.79	10.99	11.65	11.83	11.42	11.62	11.4	11.57	11.71	11.41
K_2O	0.11	0.12	0.06	0.07	0.1	0.25	0.15	0.15	0.13	0.18	0.11	0.14
P_2O_5	0.02	0.03	0	0	0	0	0.01	0	0	0.03	0.03	0
TOTAL	99.4	98.54	98.89	98.92	100.09	98.98	98.5	98.8	98.68	98.02	98.56	99.71
Tot.oxy	8	8	8	8	8	8	8	8	8	8	8	8
Cation												
Si	12.445	12.348	12.434	12.511	12.565	12.316	12.425	12.446	12.457	12.241	12.387	12.613
Ti	0	0	0	0	0	0	0	0	0	0	0	0
Al	4.134	4.146	4.099	4.16	4.209	4.195	4.064	4.063	4.061	4.088	4.043	4.098
Fe	0.027	0.011	0	0	0.011	0.011	0	0	0	0.011	0.009	0.005
Ca	0.013	0.037	0	0.024	0	0	0.019	0.018	0.03	0.045	0.027	0.024
Na	4.173	4.024	4.179	3.894	4.128	4.192	4.048	4.118	4.042	4.102	4.149	4.043
K	0.024	0.027	0.014	0.017	0.023	0.058	0.035	0.034	0.031	0.042	0.026	0.033
P	0.002	0.002	0	0	0	0	0.001	0	0	0.002	0.002	0
TOTAL	20.82	20.59	20.73	20.61	20.94	20.77	20.59	20.68	20.62	20.53	20.64	20.82
An	0.32	0.89	0	0.6	0	0	0.46	0.44	0.73	1.08	0.64	0.58
Ab	99.1	98.43	99.67	98.97	99.45	98.65	98.68	98.74	98.51	97.91	98.75	98.61
Or	0.58	0.67	0.33	0.42	0.55	1.35	0.86	0.82	0.76	1	0.61	0.81

Table 8. Microprobe analysis of plagioclase (Plag) from the Lansdowne granite gneiss sample BV1, Garhwal Lesser Himalaya. Oxides are in wt%.

	Lansdowne Granite Gneiss																	
Sample No.	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1	BV1
Mineral	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag
SiO_2	67.17	66.92	68.48	66.85	68.3	66.97	66.97	67.97	68.88	67.49	67.21	66.01	66.57	67.49	65.61	65.57	65.44	65.93
TiO_2	0	0	0.01	0.04	0.01	0	0.01	0	0	0.01	0.01	0	0.01	0.01	0	0	0	0
Al_2O_3	19.9	19.66	19.83	20.06	19.64	20.26	19.02	19.8	19.39	19.82	20.47	20.94	20.78	20.12	21.24	20.23	20.63	18.71
FeO	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0.01	0
CaO	0.34	0.45	0.12	1.06	0.13	0.89	0.1	0.16	0.01	0.44	0.96	1.2	1.19	0.67	1.94	1.22	1.47	1.2
Na_2O	11.82	11.02	11.74	10.69	11.41	11.4	7.29	11.68	11.69	11.64	11.08	10.95	11.05	11.33	10.78	11.24	11.14	11.9
K_2O	0.11	1.4	0.11	0.09	0.13	0.05	6.34	0.08	0.13	0.13	0.12	0.19	0.13	0.09	0.1	0.14	0.08	0.01
P_2O_5	0.14	0.16	0	0.5	0	0.39	0	0	0	0.02	0.29	0.53	0.6	0.18	0.2	0.5	0.54	1.24
TOTAL	99.49	99.62	100.28	99.29	99.61	99.96	99.74	99.68	100.1	99.56	100.14	99.83	100.44	99.9	99.87	98.9	99.32	98.99
Tot.oxy	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Cation																		
Si	12.281	12.235	12.52	12.221	12.486	12.244	12.244	12.426	12.593	12.339	12.287	12.069	12.171	12.339	11.996	11.987	11.964	12.053
Ti	0	0	0.001	0.005	0.001	0	0.001	0	0	0.001	0.001	0.001	0.001	0.002	0	0	0	0
Al	4.288	4.236	4.272	4.323	4.231	4.365	4.098	4.265	4.178	4.271	4.41	4.512	4.478	4.335	4.575	4.358	4.444	4.031
Fe	0	0	0	0	0	0	0	0	0	0	0	0	0.016	0	0	0	0.002	0
Ca	0.067	0.089	0.024	0.208	0.026	0.174	0.02	0.031	0.001	0.086	0.189	0.236	0.233	0.132	0.379	0.24	0.289	0.235
Na	4.191	3.907	4.16	3.788	4.043	4.04	2.583	4.139	4.144	4.126	3.926	3.881	3.918	4.015	3.822	3.984	3.949	4.217
K	0.025	0.325	0.025	0.02	0.03	0.012	1.48	0.018	0.03	0.031	0.028	0.043	0.031	0.022	0.023	0.033	0.019	0.002
Ba	0.011	0.012	0	0.039	0	0.03	0	0	0	0.002	0.023	0.041	0.046	0.014	0.016	0.039	0.042	0.096
TOTAL	20.85	20.79	21	20.57	20.82	20.84	20.43	20.88	20.95	20.85	20.84	20.74	20.85	20.84	20.8	20.6	20.67	20.54
An	1.57	2.06	0.57	5.19	0.64	4.13	0.5	0.75	0.02	2.03	4.55	5.67	5.57	3.16	8.98	5.63	6.78	5.28
Ab	97.84	90.41	98.84	94.31	98.62	95.59	63.26	98.81	99.26	97.24	94.77	93.29	93.68	96.32	90.48	93.58	92.78	94.67
Or	0.59	7.53	0.59	0.5	0.73	0.28	36.24	0.44	0.72	0.73	0.68	1.04	0.74	0.52	0.54	0.79	0.44	0.06

Table 9. Microprobe analysis of plagioclase (Plag) from the Lansdowne granite gneiss sample JH2, Garhwal Lesser Himalaya. Oxides are in wt%.

	Lansdowne Granite Gneiss																	
Sample No.	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2	JH2
Mineral	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag	Plag
SiO_2	66.43	66.78	66.55	66.09	65.83	68.67	66.5	66.56	66.32	63.73	65.31	67.18	63.48	64.77	63.93	66.64	65.44	65.71
TiO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0
Al_2O_3	19.21	19	19.09	19.38	19.5	19.37	19.4	19.36	19.47	21.56	20.21	19.39	21.55	20.86	21.79	19.91	19.8	19.96
FeO	0	0	0	0	0	0	0	0	0	0	0.09	0	0	0.12	0	0.09	0.24	0.18
CaO	1.26	0.72	0.88	1.23	1.48	0.42	0.94	0.57	0.82	2.87	1.73	0.78	2.93	1.92	3.03	1.11	0.5	0.52
Na_2O	11.26	11.59	11.65	11.79	11.42	11.2	11	11.7	11.38	9.78	10.93	11.09	10.23	10.74	10.33	11.17	11.41	10.79
K_2O	0.03	0.03	0.04	0.02	0.06	0.08	0.15	0.03	0.04	0.19	0.14	0.15	0.19	0.21	0.2	0.12	0.88	2.12
P_2O_5	0	0.4	0.14	0.14	0.36	0.1	0.04	0	0	0.23	0	0	0.25	0.35	0.24	0	0.07	0
TOTAL	98.19	98.53	98.36	98.65	98.64	99.83	98.04	98.22	98.02	98.37	98.4	98.59	98.63	98.96	99.51	99.04	98.34	99.29
Tot.oxy	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Cation																		
Si	12.145	12.209	12.167	12.082	12.035	12.554	12.158	12.169	12.124	11.651	11.94	12.281	11.605	11.841	11.687	12.182	11.965	12.013
Ti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0.001	0
Al	4.139	4.093	4.113	4.176	4.202	4.172	4.18	4.172	4.195	4.646	4.353	4.177	4.643	4.494	4.695	4.289	4.265	4.301
Fe	0	0	0	0	0	0	0	0	0	0	0.014	0	0	0.018	0	0.014	0.037	0.028
Ca	0.246	0.142	0.172	0.242	0.29	0.082	0.185	0.112	0.16	0.562	0.34	0.153	0.574	0.376	0.593	0.218	0.098	0.103
Na	3.992	4.109	4.131	4.177	4.047	3.97	3.899	4.147	4.035	3.466	3.873	3.932	3.627	3.806	3.662	3.958	4.043	3.823
K	0.007	0.006	0.009	0.005	0.013	0.019	0.036	0.006	0.008	0.045	0.032	0.035	0.044	0.05	0.047	0.029	0.206	0.495
Ba	0	0.031	0.011	0.011	0.028	0.007	0.003	0	0	0.018	0	0	0.019	0.027	0.018	0	0.005	0
TOTAL	20.53	20.56	20.59	20.68	20.59	20.8	20.46	20.61	20.52	20.37	20.55	20.58	20.49	20.58	20.68	20.69	20.61	20.76
An	5.8	3.33	4	5.46	6.66	2	4.48	2.62	3.81	13.79	8	3.72	13.52	8.89	13.78	5.19	2.25	2.32
Ab	94.03	96.53	95.8	94.43	93.04	97.54	94.65	97.24	96	85.09	91.24	95.42	85.44	89.94	85.13	94.12	93.02	86.49
Or	0.17	0.14	0.2	0.11	0.3	0.46	0.87	0.14	0.2	1.12	0.76	0.86	1.04	1.17	1.08	0.68	4.73	11.19

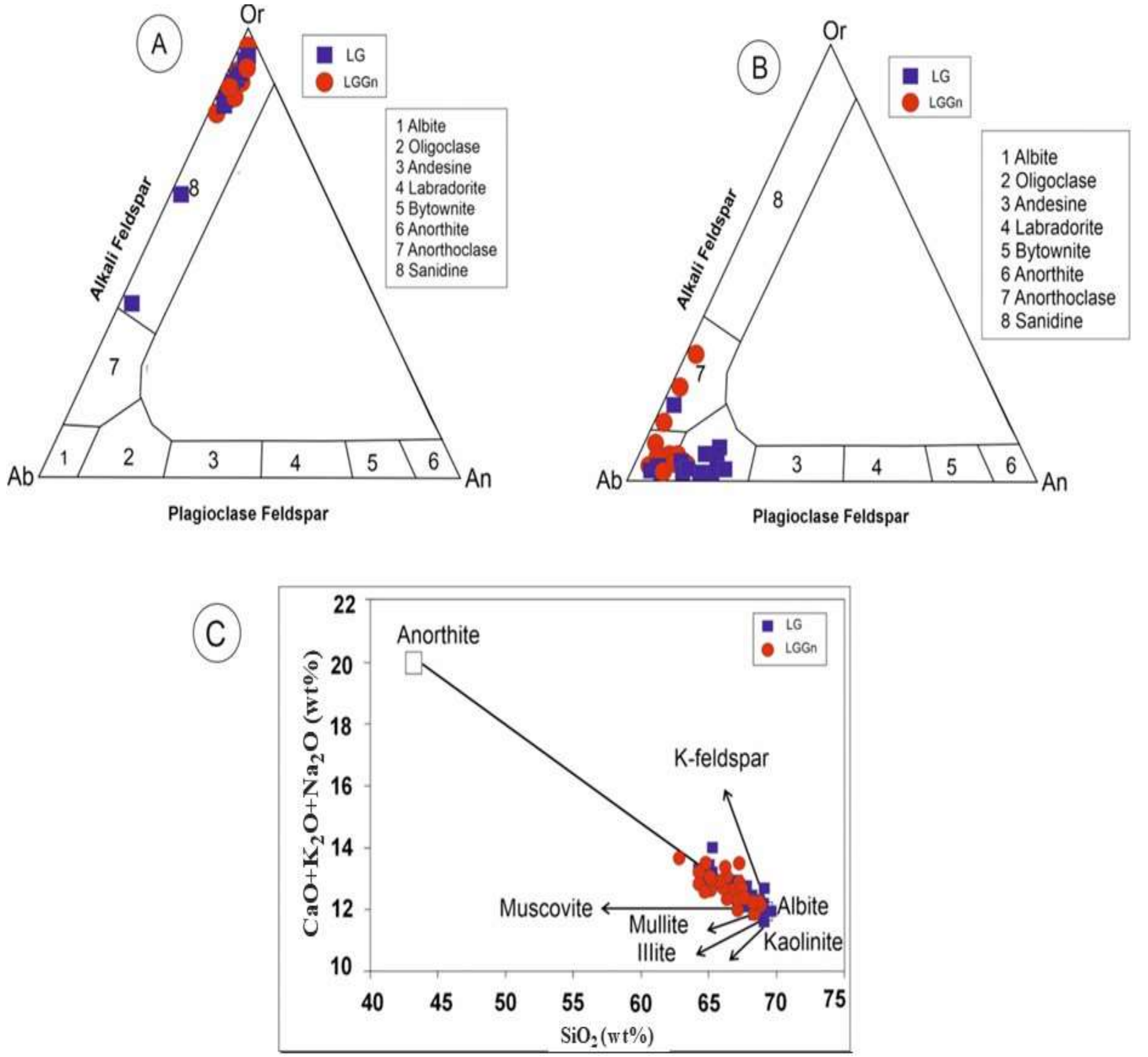
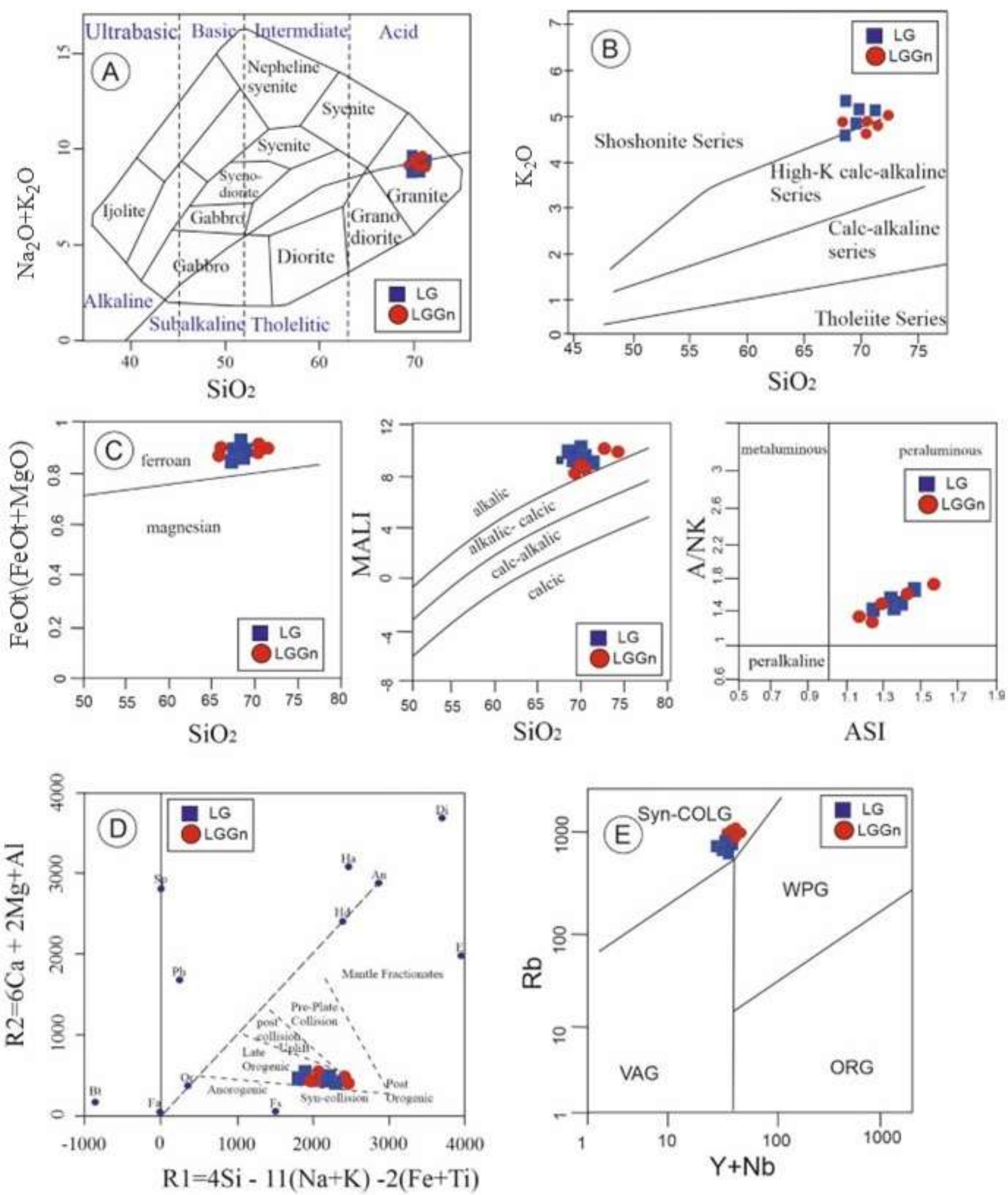


Figure 7. **(A)** Feldspars (Ab-Or-An) triangular diagram showing compositions of analysed granite and granite gneiss samples of Lansdowne Klippe. LG- Lansdowne Granite, LGGn- Lansdowne Granite gneiss. (**B)** Feldspars (Ab-Or-An) triangular diagram showing compositions of analyzed plagioclase from granite and granite gneiss samples of Lansdowne Klippe. LG- Lansdowne Granite, LGGn-Lansdowne Granite gneiss. (**C)** SiO_2 vs. $CaO+Na_2O+K_2O$ (wt. %) binary diagram (after Williamson et al., 2016) for plagioclases from granite and granite gneiss. All samples follow the Ab-An tie line corresponding to unaltered composition. LG- Lansdowne Granite, LGGn-Lansdowne Granite gneiss.

Plagioclase

In granite, plagioclase show a high albitic composition with a limited variation (Ab=84.75-99.67, An=0.00-14.55) and very low K (K_{apfu}= 0.00-0.37), probably suggesting the source of host magma was continent crust. Most of the analyzed spots of plagioclase from LG, fall in albite to oligoclase field (Figure 7B). The LGGn plagioclase (Ab = 84.86-99.26, An = 0.02-13.79) is almost similar to LG plagioclase and clustering in albitic to oligoclase plagioclase field (Figure 7) with relatively low K (K_{apfu}=0.021-0.73). In SiO_2 vs. $CaO+Na_2O+K_2O$ wt. % plot, all the analysed plagioclases from LG and LGGn fall on the An, and Ab tie line indicating specifically the connection between An and Ab forming a compositional spectrum known as the plagioclase feldspar series (Figure 7C), their position on this tie-line help to classify feldspars according to their chemical compositions and crystallization conditions suggesting their magmatic origin which is petrographically explained by textures such as zoning, twining and inclusion patterns. However, the observed more albitic nature and high SiO_2 contents for LG and LGGn plagioclase, may have been caused by post-magmatic albitization (Williamson et al., 2016), or evolved nature of host melt.

In the Na_2O+ K_2O versus SiO_2 binary diagram the granite and granite gneiss are categorized in the granite field (Figure 8A). The K_2O versus SiO_2 binary plot, defines that granite and granite gneisses belong to shoshonite magma series. It follows distinct ferroan trend, displaying an alkalic-alkali-calcic composition, illustrating its peraluminous nature (Figure 8B, C). R_1-R_2 [$R_1 = 4Si_4^{+}$-$11(Na^{++}K^{+})$ $2(Fe^{3++}Ti^{4+})$, molar; $R_2 = 6Ca^{2++}2Mg^{2++}Al^{3+}$, molar] tectonic discrimination diagram displays, syn-collisional tectonic setting of granite and granite gneiss reflecting their crustal source, peraluminous nature and enrichment in Al, Ca, and Mg due to partial melting of meta sedimentary rocks during continental collition (Figure 8D). Rb vs. (Y + Nb) diagram suggests their syn-collisional tectonic setting (Figure 8E). Based on geochemical analysis, they are enriched in LREE and relatively depleted in HREE, with prominent negative Eu anomalies and high Rb, K, Th and Y content, showing positive anomaly as well as negative Ba, Zr, Ti, and Nb anomalies (Figure 8F).



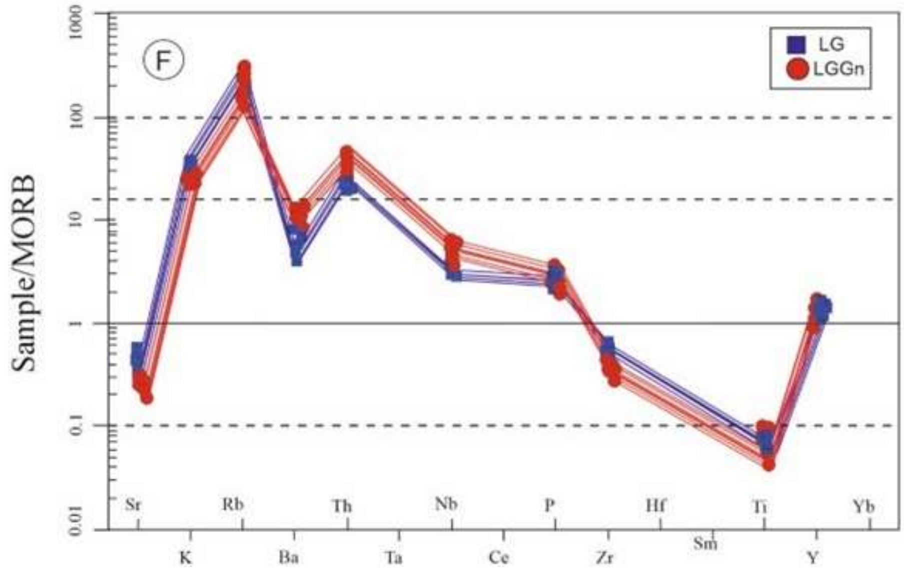


Fig 8. (A) Binary Plot (Na_2O+ K_2O) versus SiO_2 **(B)** Binary plot (K_2O versus SiO_2) granite and granite gneiss belonging to the high K calc-alkaline to shoshonite magma series after (Le Maitre et al., 1989). **(C)** FeOt/FeOt+MgO vs SiO_2, modified alkali lime index (MALI) vs SiO_2 and Alumina saturation index (ASI) vs SiO_2 plots are after Frost et al. (2001). **(D)** The R1 - R2 [R1 = 4Si4+-11(Na++K+) 2(Fe3++Ti4+), molar; R2 = 6Ca2++2Mg2++Al3+, molar] (after Batchelor and Bowden, 1985) tectonic discrimination diagram showing syn-collision type of tectonic setting. **(E)** (Yb + Nb) vs Rb discrimination diagram of granite and granite gneiss (after Pearce et al., 1984). **(F)** Spider diagram of the granite and granite gneiss. LG- Lansdowne Granite, LGGn- Lansdowne Granite gneiss.

Mineral chemistry data reveals feldspar formation by fractional differentiation of the granitic magma. Its component suggest the crystallization at high temperature, with magmatic origin.

CONCLUSIONS

Following conclusions can be drawn from the present study

(i) Field observations reveal that the studied granite is a small pluton consisting quartz and feldspar phenocrysts, exhibiting porphyritic texture. Granites are transformed into granitic gneiss due to metamorphism and deformation.

(ii) Petrography of granite and granite gneiss reveals porphyritic, porphyroblastic, perthitic, and equigranular textures, exhibiting Carlsbad and albite twinning. These features indicate slow magma cooling, dual crystallization, and differential mineral growth suggesting the rock was emplaced at a specific depth.

(iii) The geochemical data indicate their affinity to S-type granite, showing syn-collisional tectonic settings, and its evolution is related to partial melting of continental crust derived from metasedimentary source.

(iv) Mineral chemistry of K-feldspar suggests that the crystallization occurred above the solidus at high temperature, illustrating its evolved nature of host magmatic melt.

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Author Credit Statement

Deepa Arya and Gunjan Arya are responsible for inception and preparation of the manuscript and R.B. Ananth have contributions in data generation.

Data Availability

The data supporting this study's findings are available from the corresponding author upon reasonable request.

Compliance with Ethical Standards

The authors declare no conflict of interest and adhere to copyright norms.

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