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Research Article

Petrological evaluation of Rangit Pebble Slate Formation from Sikkim Lesser Himalaya, NE India: with special reference to tectonic setting and provenance

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Abstract: The petrographic study of Permo-Carboniferous sediments of Rangit Gondwana Basin of Sikkim Lesser Himalaya was performed with an aim to determine mineralogical characteristics and to interpret the provenance and tectonic setting. The sedimentary sequence of the Rangit Pebble Slate Formation of Rangit Gondwana Basin consists of the conglomerate and diamictite facies at the base while the alternate band of sandstone and shale appear at the top of sequences. The modal analysis of 35 samples with poorly to well-sorted properties reveals the dominance of monocrystalline quartz (53.46 %), feldspar grain (10.34 %) and rock fragment (4.56 %). Investigations regarding the petrographic and compositional character of the sandstone revealed insights about provenance and tectonic setting. The different binary and ternary plots reveal that the detrital components of all studied samples of the Rangit Pebble Slate Formation were derived from plutonic igneous rocks and metamorphic rocks along with sedimentary fragments. A binary plot of climate discrimination diagram and sedimentary lithofacies clearly suggest that the sediments of the Rangit Pebble Slate Formation were deposited under cold climatic conditions.

Keywords: Gondwana, Rangit Pebble Slate Formation, Provenance, Tectonic setting.

Introduction

The Late Paleozoic era (Permo- Carboniferous Period) of the geological history is considered the wide span of climate change (Shi and Waterhouse, 2010). A larger part of Peninsular India witnessed this climate fluctuation and recorded it in the form of sedimentary facies. The Rangit Pebble Slate Formation (RPS Fm.) of the Rangit Gondwana Basin (RGB), Sikkim Lesser Himalaya has been examined petrographically and quantitatively plotted to discriminate the provenance, tectonic setting and paleoclimatic environment.

The detrital grains like Quartz, Feldspar, and rock fragments which are dominant in the studied sediments provide useful information about the geochemical nature of provenance and tectonic setting. The signature of the prevalent climatic condition, weathering, and transportation of sediments are significantly deciphered by the concentration of the mineral grains in the sediments (Savoy *et al*., 2000; Shao *et al*., 2001; Zimmermann and Bahlburg, 2003; Preston *et al*., 2004). The Lower Gondwana sediments were deposited during the early Permian marine transgression in different parts of the NW and NE Lesser Himalaya (Hayden, 1904; Srivastava and Mitra. 1994; Bhargava and Bassi, 1998; Ganai *et al*., 2016; Mahanta *et al*., 2019; Priya *et al*., 2019; 2021a; 2021b). The RPS Fm. of the Lower Gondwana sedimentary sequences in the Rangit basin from Sikkim Lesser Himalaya is one of the best lithological sequences, which records the Permo-Carboniferous paleoclimate change. The signatures of the Permo-Carboniferous global cryospheric event are well preserved in the Tatapani area and along the road section of Namchi-Sikkip road of the Rangit window in south Sikkim, Lesser Himalaya (Fig.1). The alternate beds of diamictite and coarse sandstone at the bottom of the sequence of this formation infer the glacial environment of deposition, while the upper part of the sequence consisting of the interbedded fine sandstone and shale with marine *Eurydesma* Fauna, is typical of the marine environment (Raichaudhri, 2002). The detailed petrographic and microfacies studies of diamictite reveal matrix-supported pebble and gravel with cemented shaly-silty facies together with rhythmites, strongly indicate the glaciomarine environment. The clasts of diamictite comprise the dark color, poorly sorted, sub-angular grains of quartz, feldspar, mica, and lithic fragments in a fine silty matrix. In some sections, the large size stromatolitic boulders and dropstones embedded in the consolidated massive diamictite bed and coarser sandstone are present. The principal objective of this study is to decipher the geochemical nature of the provenance, tectonic setting and paleoclimate of the RPS Fm. with the help of detrital grains from sandstone through various graphical and statistical analysis.

Methodology

Petrographic study of clastic sedimentary rock is useful to interpret provenance and tectonic setting (Dott, 1964; Basu *et al*., 1975; Suttner and Dutta, 1986; Dickinson *et al*., 1983; Hota *et al*., 2011). A total of 35 samples were collected from the study area and thin sections were prepared for petrographic analysis. The quantitative and modal analysis of RPS Fm. sandstone composition was computed on the basis of point counting methods with about 200-300 points counted for each thin section (Dickinson, 1970). The different types of mineral grains were observed under the Leica polarizing microscope (DM -2700P) as a major, secondary and accessory minerals. Quartz grains were identified and subdivided into monocrystalline (Q_M) and polycrystalline (Q_P). The monocrystalline quartz grains include both undulatory and non-undulatory extinction while polycrystalline consists of 1-3 crystal units per grain (Table 2). The feldspar (F) grains were categorized into plagioclase (P) and potash (K) feldspar. The dominance of sedimentary (R_S) and high-grade metamorphic rock fragments (R_M) were grouped under lithic fragments as total rock fragments (R). The modal analysis of thin section (petrography) of siliciclastic sedimentary rock has been used to determining the provenance and tectonic setting of sandstones (Basu *et al*., 1975; Dickinson and Suczek, 1979; Dickinson *et al*., 1983; Hota *et al*., 2011). The recalculated values (Table 4) of all mineral grains and lithic fragments were used to plot the diamond diagram, bivariate

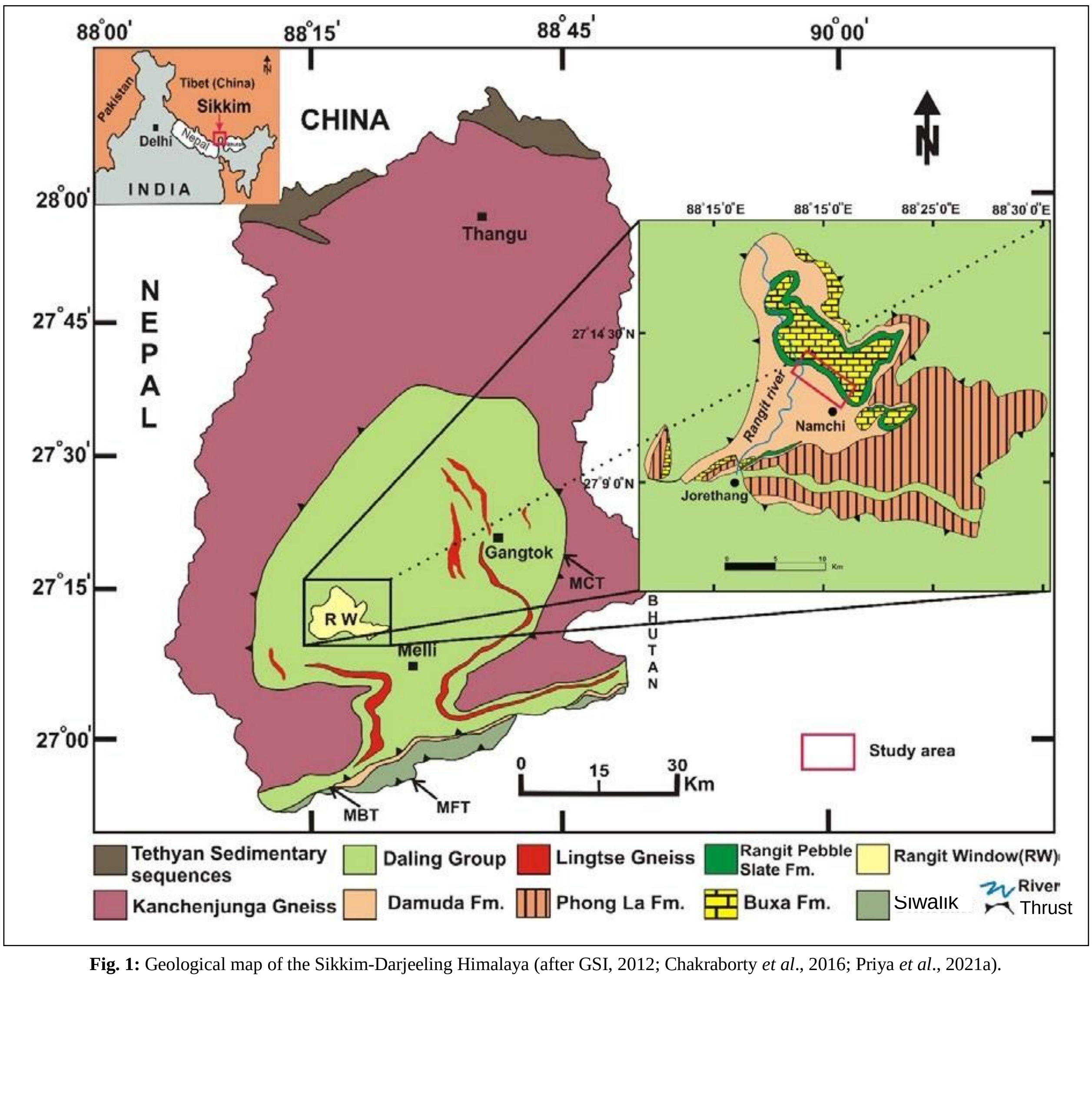


Fig. 1: Geological map of the Sikkim-Darjeeling Himalaya (after GSI, 2012; Chakraborty *et al*., 2016; Priya *et al*., 2021a).

plot, ternary diagram and classification of sandstone given by Basu *et al*., 1975; Suttner and Dutta, 1986; Dickinson *et al*., 1983, and Dott *et al*., 1964. These plots and diagrams help to interpret the composition, provenance, tectonic setting and paleo-environment of the RPS Fm. sandstone of the Lower Gondwana of Sikkim Lesser Himalaya.

Geological setting of the study area

The present study area falls in the Rangit window zone of Sikkim Lesser Himalaya. It comprises mainly of two litho structural units i.e. Daling Group and Gondwana Group (Ray and Neogi, 2011; GSI, 2012), which is given in Table 1. The RPS Fm. stratigraphically belongs to the Lower Gondwana Group and considered equivalent to the Talchir Formation of Peninsular India. The Gondwana Group of rocks is only exposed within the Rangit window of Sikkim Lesser Himalaya while the Daling Group of rock exposed in and out of the Rangit window (Fig.1).

Daling Group

The Daling Group constitutes the upper part of the oldest Palaeoproterozoic Group of rocks and is exposed in the Teesta valley in the form of a mushroom shaped window (Tewari, 2011; Priya *et al*., 2019; 2021a; 2021b). The Daling Group of rocks can be classified into three major formations viz. Gorubathan, Reyong and Buxa formations. The Gorubathan Formation consists of green slate, phyllite, fine-grained cherty quartzite, feldspathic greywacke and metabasic while, the Reyong Formation consists of quartzites, variegated slates and phyllites (Ray and Neogi, 2011; GSI, 2012). The Buxa Formation occurs below the horizon of the RPS Fm. as discontinuous patches and is well exposed near Tatopani and Mamley area of South Sikkim. It essentially comprises dolomite, cherty quartzite, limestone and variegated slate. Dolomite is characterized by the presence of laminated to massive grey to pink beds and stromatolite algal mat which is assigned Lower to middle Riphean ages by Ray (1976), Acharyya (1971) and Tewari (2011).

Lower Gondwana Group

The Lower Gondwana Group of rocks in the Sikkim Lesser Himalaya represents the youngest stratigraphic unit in the Teesta dome. Further, the Lower Gondwana Group is distinctly subdivided into the Upper and Lower sequences. The Upper sequences of the Lower Gondwana is designated as the Damuda Formation, while the Lower sequence is represented by the RPS Fm. as given in Fig. 1. The Damuda Formation is mainly composed of sandstone, shale and coal with Gondwana plant fossils (Gupta *et al*., 1981; Roy, 1973; Raichaudhri, 2002; Priya *et al*., 2019; 2021a). Alternate band of sandstone, carbonaceous shale and coal are well exposed along the Rangit River in Jorethang- Reshi road. Coal seams are exposed discontinuously as narrow strips of variable thickness around Namchi, Reshi and Jorethang areas. Carbonaceous shale and sandstone are commonly dominated with plant fossils like *Glossopteris* and *Vertebraria* (Raichaudhri, 2002). A Lower Gondwana sequence is distinctly recognized by the RPS Fm. which comprised diamictite unit, sandstone, shale, dark grey micaceous slate and para conglomerate (GSI, 2012; Priya *et al*., 2019). The outcrop of the RPS Fm. is scanty in nature and poorly exposed near Tatopani and along with Namchi-Wak-Sikkip road. The RPS Fm. sequence of the Sikkim Lesser Himalaya is tectonically disturbed. Highly complex folding and over thrusting can be seen along the Namchi – Jorethang, Namchi – Sikkip and Namchi – Damthang road sections. Ray and Neogi (2011) mapped a new formation i.e. Phong La Formation around the Rangit window which is siliciclastic (carbonate free) in composition and has been assigned under the Buxa Formation (Fig. 1). The presence of Cryogenic diamictites and marine *Eurydesma* Fauna in the lower unit of the Gondwana.Sikkim-Lesser Himalaya clearly indicates the influence of the glaciomarine environment during the Permo-Carboniferous Period (Acharyya and Ray, 1977; Ray and Neogi, 2011; Priya *et al*., 2019; 2021a; 2021b).

Table 1: Stratigraphy of Sikkim Lesser Himalaya (modified after Acharyya and Ray, 1977; GSI, 2012; Priya *et al*., 2019; 2021a).

Era	Peroid	Formation		Lithology
PALAEOZOIC	Carboniferous-Permian	Damuda Formation	Gondwana Supergroup	Fossiliferous sandstone, siltstone, shale,carbonaceous slate, coal
		Rangit pebble slate Formation		Diamictite, Pebble-slate,shale quartzite, siltstone, sandstone, dark claystones
PRECAMBRIAN	Proterozoic (Undifferentiated)	Buxa Formation	Daling Group	Dolomite, Stromatolite bearing limestone, cherty quartzite, variegated slate
		Reyong Formation		Green slate, phyllite, cherty quartzite
		Gorubathan Formation		Quartzite, variegated slate, phyllite
		Central crystalline gneiss complex (Kanchenjunga gneiss)		Banded migmatite, augen bearing biotite gneiss, mica schist, sillimanite granite gneiss

Lithofacies of Rangit Pebble Slate Formation

The detailed lithofacies of the RPS Fm. reveals three major facies associations, viz., diamictite-conglomerate facies, sandstone - olive green shale facies and interbedded carbonaceous shale-sandstone facies as shown in Fig. 2 and Figs. 3. The contacts between all three major facies are conformable. They are easily detectable and can be marked in outcrop sections. The massive conglomerate-sandstone facies are exposed near Tatopani and along with Namchi-Wak-Sikkip road. The diamictite-conglomerate facies is considered one of the important marker strata for the Permo-Carboniferous Lower Gondwana sequence and is equivalent to the Talchir

Formation in the Indian Peninsular Gondwana (Priya *et al*., 2019; 2021a). The massive diamictite-bearing facies are poorly sorted and composed of various sub-angular clasts of quartz, chert, dolomite and other lithic fragments with the matrix (Fig. 2, Figs. 3b & 3c). Many large sized stromatolitic boulders, dropstones, pebble grains of slate, carbonate and quartzite embedded in the consolidated diamictite beds are also observed, which infers cryogenic sedimentation (Fig. 2, Figs. 3b & 3c). Dropstones are one of the most significant sedimentary structures which indicate glacial environment of deposition. The pebbly sandstone-siltstone-shale facies occurs just above the diamictite facies with erosional and gradational contact (Figs. 2 & 3c). The sandstone - olive shale facies is mainly composed of massive and horizontally-stratified sandstone with interbedded shales (Fig. 2, Figs. 3e & 3f). Whereas, the upper most carbonaceous shale-sandstone facies were deposited under marine environment. This can be inferred through turbidites and lenticular sedimentary features displayed in Figs.3a & 3d. The sedimentary facies of upper and lower sequences of RPS Fm. strongly suggest the confluence of glacio-marine environment of deposition.

Petrographic Investigation of Rangit Pebble Slate Formation

The petrographic study of the RPS Fm. sandstone reveals the composition on the basis of the study of mineral grains and other lithic fragments. The sandstones of RPS Fm. are fine to coarser-grained, poor to moderately sorted. A few samples of massive diamictite have also been analyzed under petrographic studies that reveal the mineralogical composition. The texture of coarser sandstones is sub-angular to sub-rounded and poor to moderately sorted in the bottom sequence whereas sub-rounded to rounded and well sorted in the upper sequence of the RPS Fm.. The petrographic results of the RPS Fm. sandstone are given in Table-3. The percentage of quartz increases gradually from bottom to top in the lithostratigraphic sequence of RPS Fm. (Fig. 2). Quartz (Q), Feldspar (F) and rock fragments (R) are the most detrital constituents of RPS Fm. Sandstone, which are averagely calculated with the dominance of Quartz minerals. The RPS Fm. sandstone is averagely composed of 43.79 % monocrystalline non-undulatory quartz (Q_{MNU}), 9.67 % monocrystalline undulatory quartz (Q_{MU}), 6.87 % polycrystalline quartz of 2-3 crystal units per grain (Q_{P2-3}), 1.96 % polycrystalline quartz of more than 3 crystal units per grain ($Q_{P>3}$), 6.96% plagioclase feldspar (P), 3.38 % potash feldspar (K), 1.87 % sedimentary rock fragments (Rs), 2.69 % metamorphic rock fragments (Rm), 2.17% heavy accessory minerals and 21.64 % matrix and cement (Table 3). The non-strained quartz and alkali feldspar like microcline (Figs. 4 a-f) are more common than plagioclase feldspar in fine sandstone of upper part of the sequences of RPS Fm., whereas coarser sandstone of lower sequence of this Fm. contains various proportions of strained quartz, plagioclase feldspar and lithic

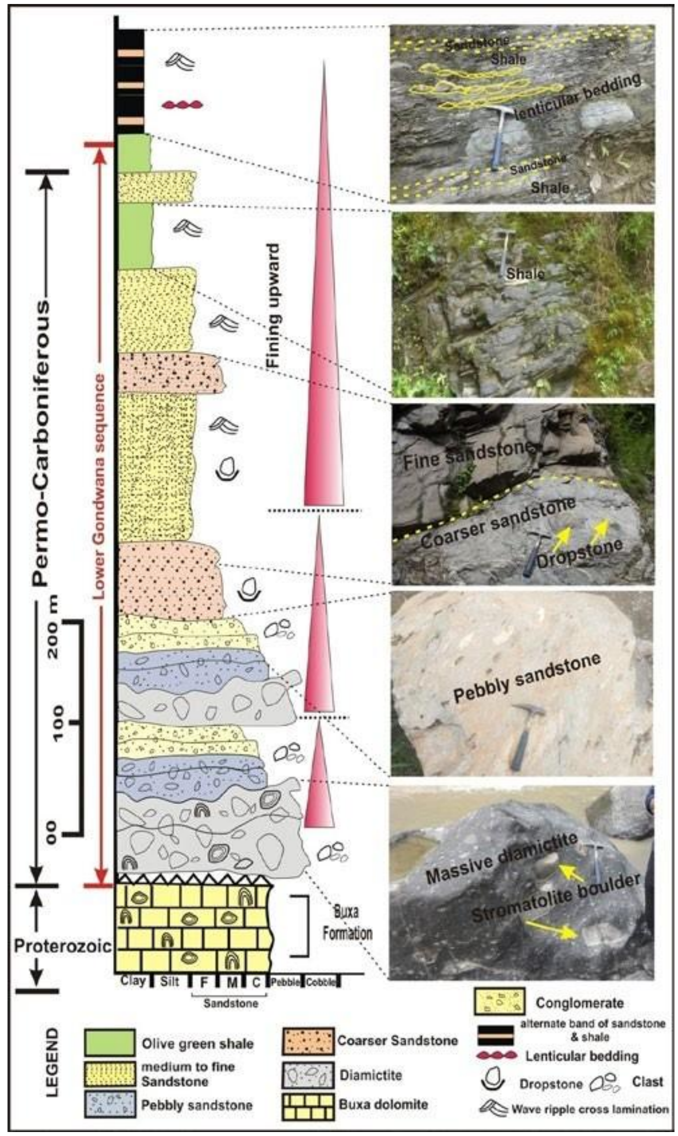
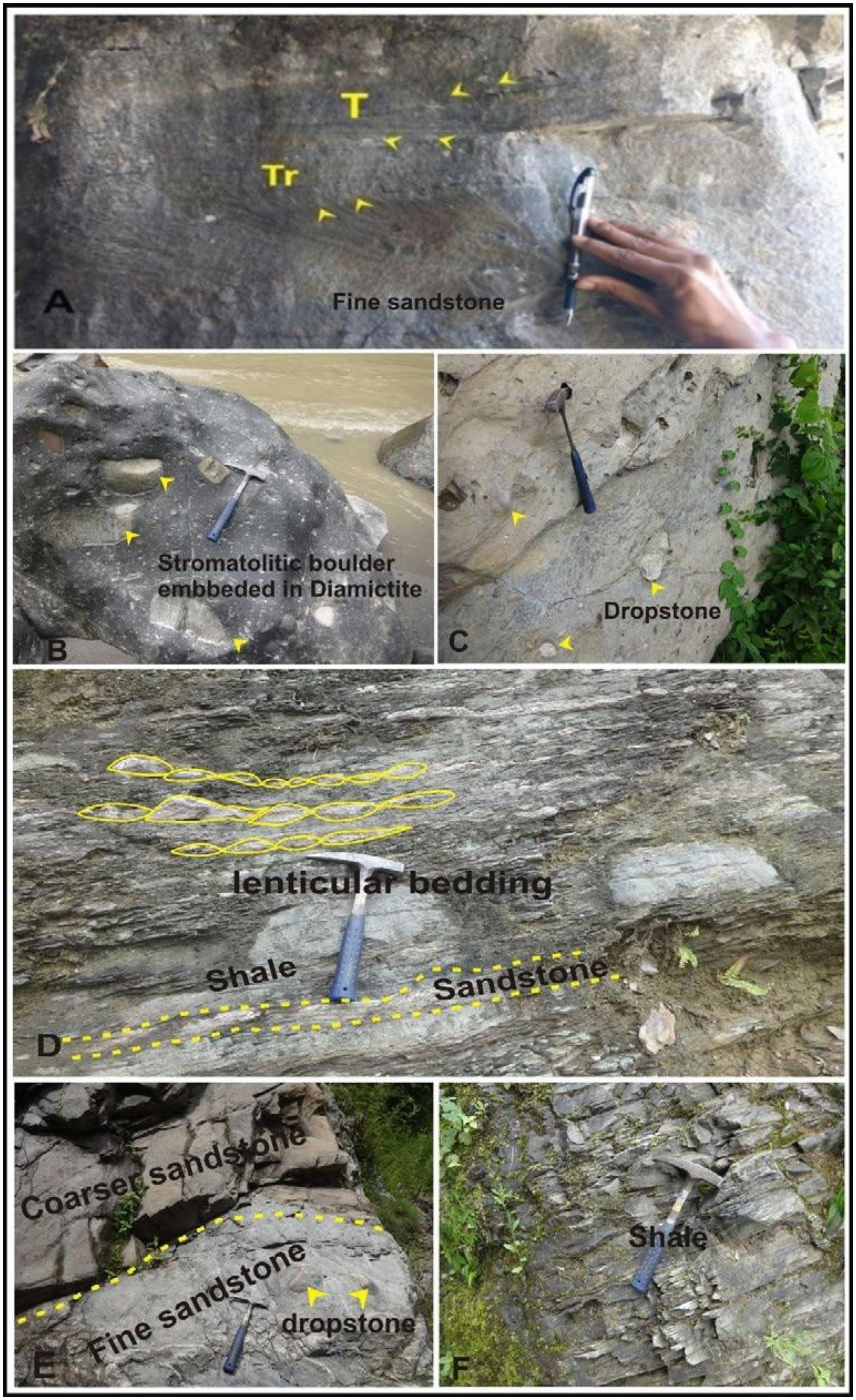


Fig. 2: General lithostratigraphy of the RPS Fm. of Sikkim Lesser Himalaya along with field outcrop.

fragments (Figs. 4, a-f). Heavy minerals like zircon, rutile, magnetite and other sedimentary (pebbly shale, slate) and metamorphic (quartz, muscovite, rutile) rock fragments are abundantly present in the sandstone (Figs. 4) with siliceous cement.

Provenance and Tectonic settings

The quantitative modal analysis of mineral grains from any sandstone suite provide information about the composition and tectonic setting of the provenance area (Basu *et al*., 1975; Dickinson *et al*., 1983; Hota *et al*., 2011). The discrimination diagram of Provenance given by Basu *et al*., (1975) is a very useful indicator to depict the geochemical nature of provenance. The diamond diagram (Fig. 5b) of Quartz (Monocrystalline & Polycrystalline Quartz; Undulatory & Non-undulatory Quartz)



Figs. 3: Field photograph of the study area showing (A) Tidal rhythmites (Tr) with cross bedded feature and Tide dominating (T) cross strata in thick sandstone (B) Massive diamictite with stromatolite boulder (C) Pebbly sandstone with dropstone (D) Lenticular bedding with continuous thick lenses, (E) Alternate coarser and fine sandstone along with dropstone (F) Shale.

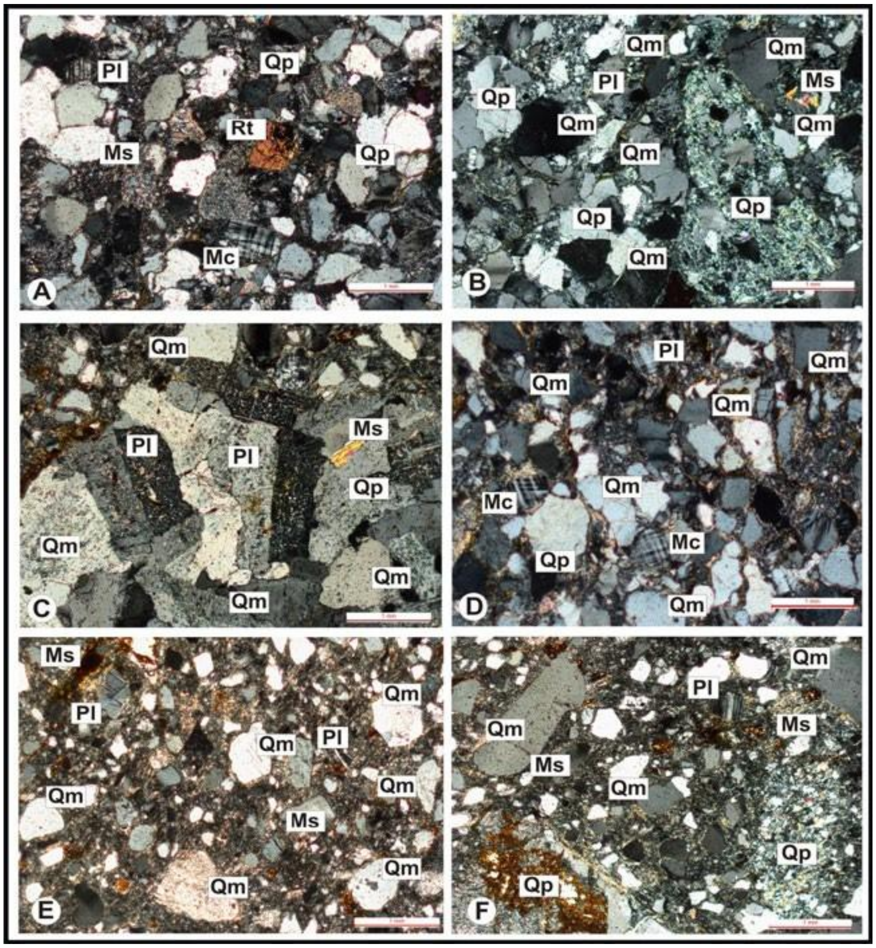


Fig 4: (a-f) Microphotograph of coarse sandstone from RPS Fm. showing monocrystalline quartz (Qm), polycrystalline quartz (Qp), Plagioclase (Pl), Microcline (Mc), Rutile (Rt), Muscovite (Ms) and a siliceous cement surrounding quartz grains.

suggest that the sediments of RPS Fm. were mostly derived from middle to upper rank of metamorphic rocks. Indeed, the sedimentary siliciclastic sediments (i.e., pebble, slate, quartz) also equally contributed during the sedimentation of the RPS Fm. in the Rangit Gondwana basin (RGB) of Sikkim. The large size of stromatolite fragments embedded in the diamictite were derived from the Meso-Proterozoic Buxa Fm. which is just adjacent to the Damuda Group of rocks. The sandstone classification is after by Folk (1970) based upon the major detrital component i.e., Quartz (Q), Feldspar (F) and lithic fragments (R) of sandstone have been recalculated into percentages among themselves for QFR triangular plot (Table 4). The ternary diagram of QFR shows that the RPS Fm. sandstone occupies all the three (Sub-arkose/Sub-lithic arenite/Quartz arenites) areas in a plot (Fig. 5a). The studied sample of coarser sandstone of the lower part of sequence falls in the area between sub-lithic arenites to sub-arkose, whereas fine sandstone of upper part of the sequence occupies between sub-arkose to quartz arenites. The Q_T-F-L and Q_M-F-L_T ternary plot given by Dickinson *et al*., (1983) play a vital role in discrimination of different tectonic environments from which sediments were derived. In this diagram, most of the studied sediments of RPS Fm. fall in the cratonic area, whereas a few samples plot in the area of recycled orogen provenance (Fig. 6a). The Q_M-P-K diagram (Fig. 6b) based on monocrystalline quartz (Qm) and feldspar grain (P & K) also confirm that the RPS Fm. sediments were derived from continental block provenance.

The abundance of K-feldspar in the studied sediments with perthite intergrowth exhibits the characteristics of plutonic igneous source rock, which might have been derived from the Indian craton. The Q_P-L_V-L_S plot (Fig. 7a) helps to determine the other polygenetic source with the help of rock fragments like quartz, shale, siltstone, slate, altered feldspar grains and detrital muscovite which suggests the contribution of sedimentary and meta-sedimentary provenance.

Paleoclimatic condition of the Rangit Pebble Slate Formation

The Permo-Carboniferous Gondwana sequences of Sikkim

Table 2: Recalculated sandstone grain parameters used in the present study (after Dott, 1964; Basu *et al*., 1975; Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979; Dickinson *et al*., (1983) and Suttner and Dutta, 1986).

QFR
Q = Total quartz grains (Q_M + Q_P) where
$\mathbf{Q_M}$ = Total monocrystalline quartz grains (Q_{MNU} + Q_{MU}) where
$\mathbf{Q_{MNU}}$ = Monocrystalline non-undulatory quartz grains
$\mathbf{Q_{MU}}$ = Monocrystalline undulatory quartz grains
$\mathbf{Q_P}$ = Total polycrystalline quartz grains (Q_{P2-3}+ $Q_{P>3}$) where
$\mathbf{Q_{P2-3}}$ = Polycrystalline quartz 2-3 crystal units per grain
$\mathbf{Q_{P>3}}$ = Polycrystalline quartz more than 3 crystal units per grain
F = Total feldspar grains (K + P) where
K = Potash feldspar
P = Plagioclase feldspar
R = Total rock fragments (R_M + R_S)
$\mathbf{R_M}$ = Metamorphic rock fragment
$\mathbf{R_S}$ = Sedimentary rock fragment
QtFL
$\mathbf{Q_T}$ = Total quartz grains (Q_{MNU} + Q_{MU}+ Q_{P2-3} + $Q_{P>3}$)
F = Total feldspar grains (K + P)
L = Total rock fragments (Rm + Rs)
QmFLt
$\mathbf{Q_M}$= Total monocrystalline quartz grains (Q_{MNU} + Q_{MU})
F = Total feldspar grains (K + P)
$\mathbf{L_T}$= L + Q_P (R_M + R_S + Q_{P2-3} + $Q_{P>3}$)
QpLvLs
$\mathbf{Q_P}$ = Total polycrystalline quartz grains (Q_{P2-3} + $Q_{P>3}$)
$\mathbf{L_V}$ = Total volcanic rock fragments
$\mathbf{L_S}$ = Rs
LvLmLs
Lv = Total volcanic rock fragments
Lm = Total metamorphic rock fragments
Ls = Total sedimentary rock fragments
Qp/(F + R) and Qt/(F + R)
$\mathbf{Q_P}$ = Total polycrystalline quartz grains (Q_{P2-3} + $Q_{P>3}$)
F = Total feldspar grains (K + P)
R = Total rock fragments (R_M + R_S)
$\mathbf{Q_T}$ = Total quartz grains (Q_{MNU} + Q_{MU} + Q_{P2-3} + $Q_{P>}$

Lesser Himalaya have witnessed the events of Late Paleozoic glaciations in the form of sedimentary facies. The occurrence of glacial diamictite and dropstones in the coarser sandstone of RPS Fm. is a remarkable feature of the glacial environment of sedimentary deposit. A bivariate plot was given by Suttner and Dutta (1986) for climate discrimination is a useful tool to distinguish the different types of climatic environment (i.e., Arid, semi-arid, semi-humid and humid) in which sediments were transported and deposited. This plot consists of Q_T/(F + R) and Q_P/(F + R) ratios of feldspar (R), quartz (Q_T & Q_P) and rock fragments (R). The RPS Fm. sandstones in this binary diagram occupy cold semi-arid to warm humid areas (Fig. 7b), which strongly suggests the prevalence of cold to warm-humid climatic conditions during the deposition. The Talchir Fm. of the Peninsular India, which is equivalent to RPS Fm. was also deposited in the same type of climatic condition (Maejima *et al*., 2004; Priya *et al*., 2019; 2021a; 2021b). With the passage of time, the climate gradually changed from cold semi-arid to warm humid during deposition of RPS Fm. The massive diamictite and coarser sandstone at the base of RPS Fm. sequence have unaltered feldspar grains with angular to the sub-angular texture which indicates the cold environment of deposition.

Results and Conclusion

The Rangit Gondwana Basin of Sikkim Lesser Himalaya has been taken into consideration to elucidate the petrographic analysis of the RPS Fm. The petrography has been done with an aim to provide an idea about the possible provenance and tectonic setting for the sediment of the RPS Fm. The RPS Fm. provides clear sedimentological signature of glacial-interglacial event of the Permo-Carboniferous period which is also analogical to Gondwana deposits of the Peninsular India. The stratigraphic sequence of RPS Fm. consists diamictite and coarser sandstone at the base whereas the upper part of the sequence includes the alternate bands of fine sandstone and shale which indicate a transgressive tract system. The large floating boulders (dropstone) that occur in graded and massive sandstone facies of the RPS Fm. have shown glacial environment of deposition. The large boulders and clasts of stromatolites and carbonates have been derived and deposited by mass flow from their local source i.e., Buxa Fm. (Fig. 2 & Figs. 3b, c). The upper most Sandstone-Shale facies could be the result of marine transgression during the inter-glacial phase which might have been deposited in the predominantly shallow marine environment in the early period of Permian (Fig. 3d-f). Further, lenticular bedding with continuous thick lenses in the uppermost sequence of RPS Fm. shows the evidence of tidal current (Fig.3a, & Fig. 3d). The whole lithofacies sequence shows a series of fining-upwards cycles which might be due to transgression of Tethys sea after Permian glaciations Period. The presence of marine fossils like *Eurydesma* also confirm the marine environment of deposition. *Eurydesma* is considered to be one of the most distinctive components of the Permian southern cool-temperate marine biota and characterizes the Late Pennsylvanian-Permian glacial-postglacial sediments that have been recorded in several Gondwanan basins during the Late Paleozoic Ice Age (LPIA) (Venkatachala and Tewari, 1988; López-Gamundí et al., 1997; Fielding *et al*., 2008; Isbell *et al*,. 2008; Shi and Waterhouse, 2010; Cisterna *et al*., 2019).

The ternary and diamond diagrams (Fig. 5a & Fig. 5b) for the composition of sandstone indicate that sediments of RPS Fm. are dominant with monocrystalline quartz, feldspar,

Table 3: Petrographic results (modal analysis) of the Rangit Pebble Slate Formation sandstone in percentage (%).

Sample	Qmnu	Qmu	Qp2-3	Qp>3	K	P	Rm	Rs	A	Clastic	M+C
R-1	39.23	16.23	9.31	1.23	2.21	0.21	1.29	2.34	1.23	63.34	23.45
R-2	41.34	14.67	12.5	3.12	3.56	0	1.31	1.45	0.65	51.68	19.45
R-3	38.67	17.34	7.26	2.56	4.76	0.12	1.38	0.56	0.38	45.87	16.73
R-4	42.12	13.56	5.32	0.31	2.32	0	2.45	1.72	0	43.56	17.78
R-5	36.27	15.56	4.51	0	1.35	0	2.37	1.31	0.42	39.87	23.67
R-6	49.02	19.53	4.31	0.24	2.67	1.14	2.56	0.41	0	52.67	26.31
R-7	47.83	22.71	7.85	1.21	3.78	0.14	0.76	1.22	0.53	61.45	17.48
R-8	51.01	16.83	2.34	0.73	2.43	0.22	1.45	1.87	0	67.83	17.21
R-9	43.23	18.91	3.41	2.13	1.67	0	1.55	1.21	0.72	71.45	16.38
R-10	42.54	20.54	1.78	0	4.03	0	1.67	1.84	0.59	65.23	25.84
R-11	41.68	14.86	0.76	1.76	2.54	0	1.77	1.54	1.05	72.41	24.67
R-12	48.38	11.73	2.54	1.43	3.98	0.23	1.53	0.79	0	76.26	19.45
R-13	44.26	16.81	4.92	0.35	2.56	0.11	1.38	1.43	0	55.23	22.57
R-14	42.76	13.56	3.43	1.34	1.98	0.16	1.71	1.64	0.91	61.37	14.56
R-15	47.12	15.21	5.06	2.03	2.51	0	1.43	1.59	0.61	48.42	19.37
R-16	45.61	18.34	2.53	3.01	3.14	0.17	1.41	1.22	0.53	77.24	17.86
R-17	46.36	21.14	3.76	0.78	1.34	1.21	2.08	2.44	0.64	69.36	16.54
R-18	37.83	18.32	2.45	1.12	2.45	1.34	2	1.35	0.27	55.78	11.47
R-19	43.56	14.76	1.87	1.89	3.42	0.48	2.63	2.14	0	67.21	18.31
R-20	47.43	26.51	0.65	2.62	1.23	1.83	1.54	0.59	1.23	61.38	21.79
R-21	42.78	17.53	1.87	0.76	2.56	0	1.29	1.54	0.58	71.56	24.31
R-22	46.32	10.21	3.16	0.45	1.89	0.43	1.87	2.32	0	53.56	17.72
R-23	41.89	16.43	1.56	0	2.33	1.21	0.78	1.33	0.86	55.25	14.56
R-24	48.12	21.58	3.21	1	5.16	0.67	2.54	1.83	0.83	65.37	13.79
R-25	52.31	24.31	1.72	3.02	1.34	0.56	1.34	2.74	0.65	58.92	11.89
R-26	49.38	19.56	2.21	1.45	2.53	0.72	1.06	1.34	0.72	54.67	13.44
R-27	51.21	18.78	1.87	0.57	3.21	0.87	0	1.23	0.69	58.34	16.76
R-28	39.74	22.67	1.24	0.87	1.76	1.21	1.23	1.17	0.71	59.53	18.74
R-29	47.68	15.74	2.23	0	1.79	0.32	1.49	1.24	0.54	61.67	12.84
R-30	38.71	17.74	0.63	1.21	2.21	0.54	2.08	1.41	0.61	63.45	11.67
R-31	37.89	16.45	3.12	1.56	2.83	0.62	1.78	1.15	0.58	58.67	22.87
R-32	44.32	15.54	2.53	0.29	1.69	0.76	0	1.26	0	52.52	23.74
R-33	39.89	13.35	2.91	0.67	3.42	0.67	1.65	1.32	1.11	55.85	14.63
R-34	41.21	12.56	1.87	1.12	2.76	0.53	2.31	1.25	0.23	64.37	13.71
R-35	43.11	15.42	1.26	0.84	1.82	0.71	1.13	1.21	0.19	63.84	15.63

Index: Qmnu – Monocrystalline nonundulatory quartz, Qmu – Monocrystalline undulatory quartz, Qp2-3 – Polycrystalline quartz, 2-3 crystal units per grain,Qp>3 – Polycrystalline quartz, more than 3 crystal units per grain, K – Potash feldspar (orthoclase and microcline), P – Plagioclase feldspar, Rm – Metamorphicrock fragment, Rs – Sedimentary rock fragment, A – Accessory minerals (garnet, mica and opaque minerals), Clastic – Total framework grains, M + C – Matrix+ Cement.

Table 4: Recalculated values of Rangit Pebble Slate Formation sandstone from Rangit Gondwana Basin of Sikkim.

Sample	Q=Qt	F	R=L	Qm	F	Lt	Qm	P	K	Qp	Lv	Ls	Qp/F+R	Qt/F+R
R-1	91.60	3.36	5.04	76.97	3.36	19.67	95.82	0.36	3.82	81.83	0.00	18.17	1.74	10.91
R-2	91.89	4.57	3.54	71.85	4.57	23.58	94.02	0.00	5.98	91.51	0.00	8.49	2.47	11.33
R-3	90.61	6.72	2.67	77.10	6.72	16.19	91.99	0.20	7.82	94.61	0.00	5.39	1.44	9.65
R-4	90.43	3.42	6.15	82.12	3.42	14.45	96.00	0.00	4.00	76.60	0.00	23.40	0.87	9.45
R-5	91.80	2.20	6.00	84.45	2.20	13.35	97.46	0.00	2.54	77.49	0.00	22.51	0.90	11.20
R-6	91.51	4.77	3.72	85.82	4.77	9.41	94.73	1.58	3.69	91.73	0.00	8.27	0.67	10.78
R-7	93.10	4.58	2.32	82.50	4.58	12.91	94.74	0.19	5.08	88.13	0.00	11.87	1.54	13.49
R-8	92.23	3.45	4.32	88.24	3.45	8.31	96.24	0.31	3.45	62.15	0.00	37.85	0.51	11.88
R-9	93.86	2.32	3.83	86.17	2.32	11.51	97.38	0.00	2.62	82.07	0.00	17.93	1.25	15.28
R-10	89.59	5.57	4.85	87.13	5.57	7.31	93.99	0.00	6.01	49.17	0.00	50.83	0.24	8.60
R-11	90.99	3.91	5.10	87.11	3.91	8.98	95.70	0.00	4.30	62.07	0.00	37.93	0.43	10.10
R-12	90.75	5.96	3.29	85.13	5.96	8.91	93.45	0.36	6.19	83.40	0.00	16.60	0.61	9.81
R-13	92.37	3.72	3.91	85.03	3.72	11.25	95.81	0.17	4.02	78.66	0.00	21.34	0.96	12.11
R-14	91.75	3.21	5.03	84.59	3.21	12.20	96.34	0.27	3.39	74.41	0.00	25.59	0.87	11.13
R-15	92.62	3.35	4.03	83.16	3.35	13.49	96.13	0.00	3.87	81.68	0.00	18.32	1.28	12.55
R-16	92.13	4.39	3.49	84.78	4.39	10.83	95.08	0.25	4.67	81.95	0.00	18.05	0.93	11.70
R-17	91.06	3.22	5.71	85.32	3.22	11.45	96.36	1.73	1.91	65.04	0.00	34.96	0.64	10.19
R-18	89.32	5.67	5.01	83.98	5.67	10.35	93.68	2.24	4.09	72.56	0.00	27.44	0.50	8.36
R-19	87.75	5.51	6.74	82.43	5.51	12.06	93.73	0.77	5.50	63.73	0.00	36.27	0.43	7.16
R-20	93.70	3.71	2.58	89.73	3.71	6.55	96.03	2.38	1.60	84.72	0.00	15.28	0.63	14.88
R-21	92.11	3.75	4.14	88.26	3.75	7.99	95.93	0.00	4.07	63.07	0.00	36.93	0.49	11.68
R-22	90.23	3.48	6.29	84.82	3.48	11.70	96.06	0.73	3.21	60.88	0.00	39.12	0.55	9.24
R-23	91.38	5.40	3.22	89.00	5.40	5.60	94.28	1.96	3.77	53.98	0.00	46.02	0.28	10.60
R-24	87.87	6.93	5.20	82.87	6.93	10.20	92.28	0.89	6.83	69.70	0.00	30.30	0.41	7.25
R-25	93.15	2.18	4.67	87.73	2.18	10.10	97.58	0.71	1.71	63.37	0.00	36.63	0.79	13.61
R-26	92.78	4.15	3.07	88.10	4.15	7.74	95.50	1.00	3.50	73.20	0.00	26.80	0.65	12.85
R-27	93.17	5.25	1.58	90.03	5.25	4.72	94.49	1.17	4.33	66.49	0.00	33.51	0.46	13.64
R-28	92.32	4.25	3.43	89.30	4.25	6.45	95.46	1.85	2.69	64.33	0.00	35.67	0.39	12.01
R-29	93.13	2.99	3.87	89.97	2.99	7.04	96.78	0.49	2.73	64.27	0.00	35.73	0.46	13.56
R-30	90.33	4.26	5.41	87.48	4.26	8.26	95.35	0.91	3.73	56.62	0.00	43.38	0.29	9.34
R-31	90.24	5.28	4.48	83.09	5.28	11.64	94.03	1.07	4.90	80.27	0.00	19.73	0.73	9.25
R-32	94.41	3.69	1.90	90.16	3.69	6.15	96.07	1.22	2.71	69.12	0.00	30.88	0.76	16.89
R-33	88.95	6.40	4.65	83.34	6.40	10.25	92.87	1.17	5.97	73.06	0.00	26.94	0.51	8.05
R-34	89.23	5.17	5.60	84.53	5.17	10.30	94.23	0.93	4.84	70.52	0.00	29.48	0.44	8.29
R-35	92.56	3.86	3.57	89.36	3.86	6.78	95.86	1.16	2.98	63.44	0.00	36.56	0.43	12.45

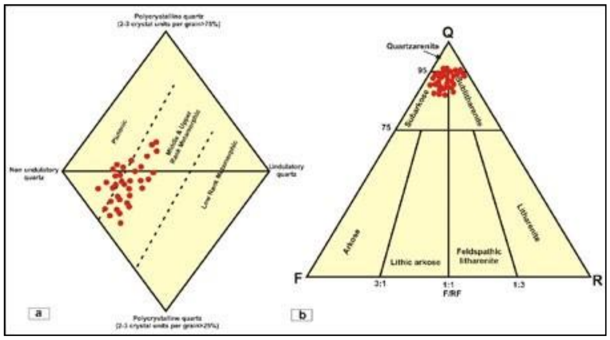


Fig. 5: (a) Triangular plot (Q-F-R) for sandstone from the RPS Fm., Rangit Gondwana Basin showing different provenance field (after Folk, 1970) (b) Diamond diagram for interpretation of provenance of RPS Formation (after Basu *et al*., 1975).

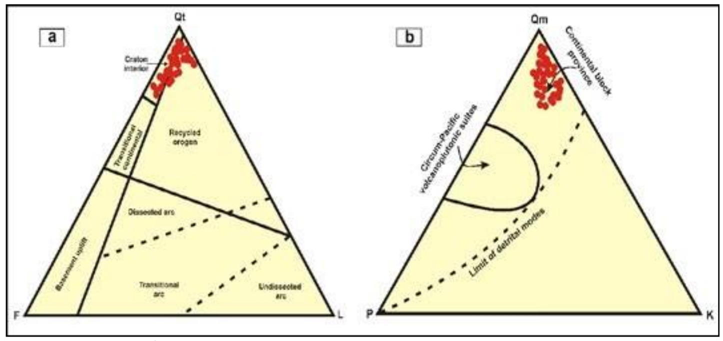


Fig. 6: (a) Plot of RPS Fm. sandstones in ternary provenance discrimination diagram of Dickinson *et al*., (1983). Symbols Qt, F and L are as per Table-4. **(b)** Plot of RPS Formation sandstones in ternary provenance discrimination diagram of Dickinson, (1985). Symbols Qm, P and K are as per Table-4.

rock fragments, and are classified as sub-arkose and arkosic arenites. Both coarser and fine-grained sandstones from the study area were evaluated and it was observed that these sediments were derived from the plutonic and high-grade metamorphic terrain. The ternary plot of provenance and tectonic setting (Fig. 6a, Fig. 6b & Fig. 7a) clearly suggests that the sediments of the RPS Fm. were derived from stable cratonic and interior continental areas, which were originally deposited in passive continental margins. Most of the studied samples were plotted in the plutonic fields which indicate a granitic source of rock which might have been derived from the stable plutonic craton of Peninsular India i.e., Chotanagpur Granite Gneissic Complex (CGGC), Shillong Plateau Gneissic Complex, quartzose sedimentary rocks, etc. The Chotanagpur Granite Gneissic Complex (CGGC) and Shillong Plateau Gneissic Complex of the Indian shield lying to the southwest of Sikkim-Darjeeling Gondwana basin, which are composed of high-grade migmatitic gneiss, khondalite, quartzite and basic igneous rock (Mukherjee *et al*., 2019). The RPS Fm. is the youngest lithostratigraphic unit of the Sikkim Lesser Himalaya and its sedimentation was probably initiated during the Late Carboniferous in a cold climatic condition and with the advancement of time (early Permian), the climate gradually changed over to humid. The Peri-Gondwana sequences of Kashmir, Himachal Pradesh, Arunachal Pradesh and Sikkim also have the Gondwana sedimentary deposits with identical depositional features (Raichaudhri, 2002; Rashid and Ganai, 2015; Priya *et al*., 2019; 2021a; 2021b; Mahanta *et al*., 2020). The climate discrimination diagram (Fig. 7b) also positively confirms that the sediments of RPS Fm. were deposited in cold semi-arid to warm humid paleoclimatic conditions. The analogy between the source and paleoclimate of deposition of the Rangit Gondwana Basin of Sikkim and the other Himalayan Gondwana basin of Arunachal Pradesh and Spiti region of Himachal Pradesh shows the close similarity in terms of provenance tectonic setting and climatic condition (Ganai *et al*., 2016; Mahanta *et al*., 2019; Priya *et al*., 2019; 2021a).

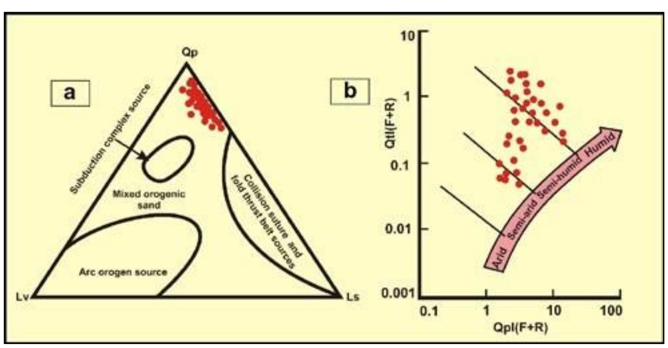


Fig. 7: (a) Plot of RPS Fm. sandstones in ternary provenance discrimination diagram (after Dickinson, 1985). Symbols Qp, Lv and Ls are as per Table-4. **(b)** A bivariate log – log plot of Qt/(F + R) and Qp/(F + R) ratios of RPS Formation sandstones in climate discrimination diagram (after Suttner and Dutta, 1986).

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