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Provenance and tectonic settings of the Lower Siwalik Subgroup, Jammu, Northwest Himalaya

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ABSTRACT

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The sandstones of the two representative stratigraphic sections of the Lower Siwalik Subgroup of Ramnagar area in Jammu region of Northwest Himalaya are studied to infer the provenance and tectonic settings of the source area. The sandstones are fine– to medium–grained and moderately to well sorted. These sandstones consist of three varieties of quartz with small amounts of feldspar, lithic fragments and micas and are classified as sublitharenites, subarkoses and litharenites. These rocks belong to the collision orogenic belt of tectonic regime and have been derived from a mixed provenance that includes plutonic basement, sedimentary and meta–sedimentary rocks.

Key–words—Lower Siwalik Subgroup, Provenance, Tectonic settings, Jammu.

उत्तर–पश्चिम हिमालय में जम्मू के निम्न शिवालिक उपसमूह के मूल स्रोत और विवर्तनिक विन्यास

संदीप के. पंडिता, सुनील के. भट्ट, शाम एस. कोतवाल, युधबीर सिंह एवं कुलदीप के. ठाकुर

सारांश

उत्तर–पश्चिम हिमालय के जम्मू प्रांत में रामनगर क्षेत्र के निम्न शिवालिक उपसमूह के दो निरूपक स्तरिक खंडों के बलुआपत्थरों का स्रोत क्षेत्र के मूल स्रोत एवं विवर्तनिक विन्यासों के अनुमान लगाने हेतु अध्ययन किया गया है। बलुआपत्थर पतले से मध्य दानेदार एवं मध्यम रूप से अच्छे प्रकार के हैं। इन बलुआपत्थरों में फेल्डस्पारों, शिली खंडजों एवं अभ्रकों की कम मात्रा सहित क्वार्टज़ के तीन प्रकार सन्निहित हैं तथा सबलिथेरेनाइटीज, सबआर्कोजिज व लिथेरेनाइटीज के रूप में वर्गीकृत हैं। ये शैल (चट्टानें) विवर्तनिक प्रवृत्ति की संघट्ट पर्वतनी पट्टी की हैं तथा मिश्रित मूल स्रोत से व्युत्पन्न हुई हैं जो वितलीक आधार, अवसादी एवं आप्लव–अवसादी चट्टान अंतर्विष्ट हैं।

सूचक शब्द—निम्न शिवालिक उपसमूह, मूल स्रोत, विवर्तनिक विन्यास, जम्मू।

INTRODUCTION

THE origin of Himalaya was due to continental collision between Indian and Eurasian plates that took place during the Late Cretaceous to Early Eocene times (Searle *et al.*, 1987; LeFort, 1989; Searle, 1991; Thakur, 1992). The northward movement of Indian Plate closed the Neo–Tethys Ocean to its north, and subsequently it collided with Eurasian Plate along Indus Suture Zone around 55 Ma (Besse & Courtillot, 1988; Dewey *et al.*, 1989). Northward movement of Indian Plate resulted in continuous uplift of the Himalayan arc and increase in erosion rate. Huge quantities of sediments got accumulated in the Himalayan Foreland Basin (HFB) due to intense uplift and erosion of Himalaya after the collision. This foreland basin is a product of tectonic activities that have been taking place in the orogenic belt in the Cenozoic era and continue till date. The rock sequence in the HFB includes Murree (Dharamsala) Group of Late Eocene (or Oligocene) to Early Miocene age and the overlying Siwalik Group of Middle Miocene to Early Pleistocene age. The Siwalik

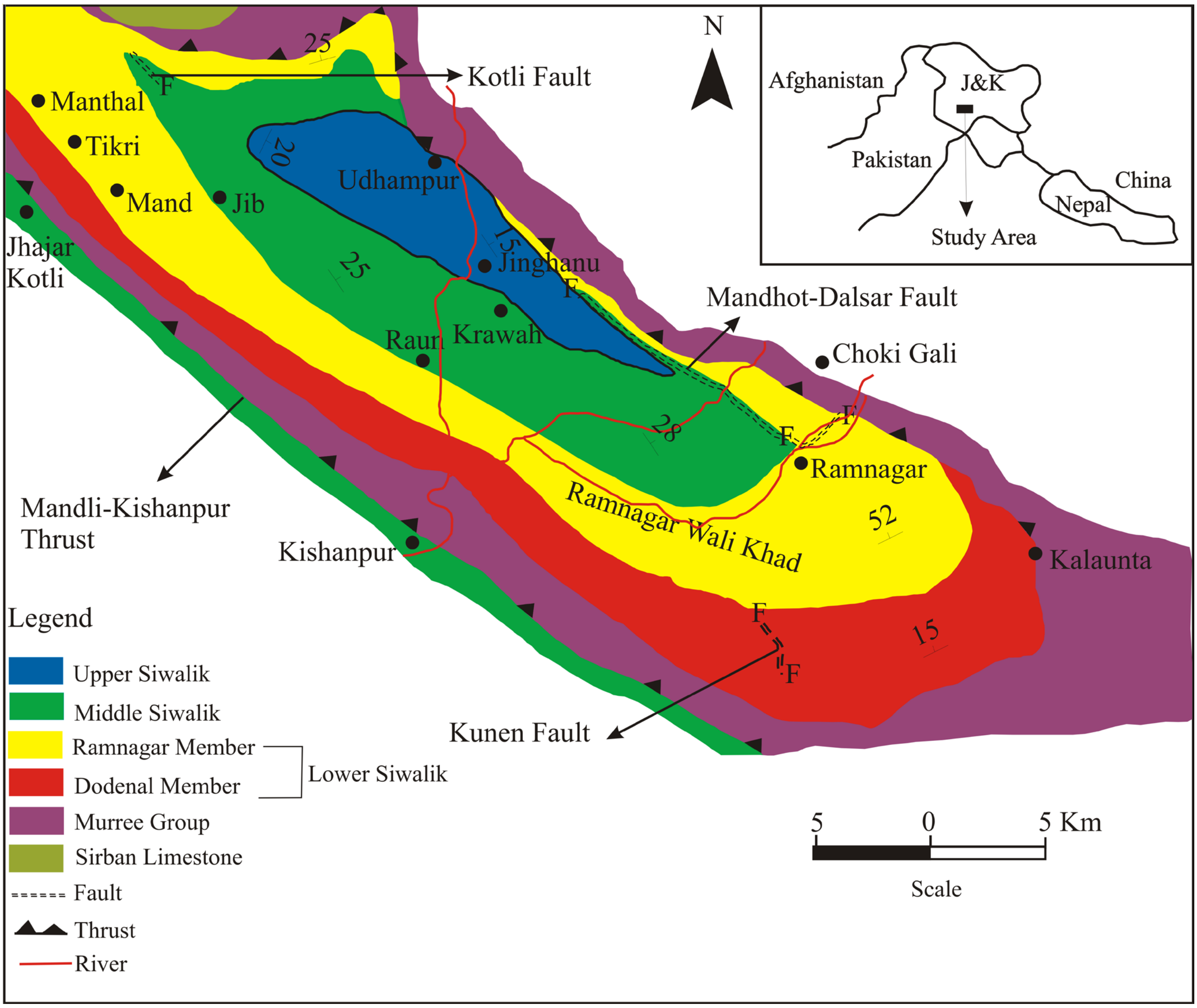

Fig. 1—Location and geological map of the study area (modified after Gupta, 2000).

Group represents a thick succession composed of sandstones, mudstones and conglomerates extending from Potwar Plateau in the west through the well developed stratigraphic sections in Jammu and Kashmir to Arunachal Pradesh in the east.

The Siwalik Group has received significant attention in terms of stratigraphy, structural geology, sedimentology and petrography. However, the data on the petrography of these rocks in Jammu and Kashmir is meagre. The available data on these rocks is only from the Middle and Upper Siwalik subgroups (Wakhloo & Bhatia, 1967; Bhatia, 1970; Pandita, 1991, 1996; Bhat & Pandita, 1991).

The present work is the first account of petrographic characters and mineral composition of Lower Siwalik sandstones of Ramnagar area (Fig. 1). The main objective of this study is to identify the source rock characters and tectonic setting.

GEOLOGICAL SETTING

In Jammu region the Siwalik Group of rocks is exposed on the northern and southern limbs of the thrust cored Suruin–Mastgarh anticline extending from west to east as a connecting link between the Siwalik rocks exposed in Pakistan and beyond Ravi River (India). The Siwalik Group represents Lower–, Middle–, and Upper Siwalik subgroups and is disposed in parallel folded zones. These rocks generally dip in southwest–northeast direction at varying angles between 80° (Lower Siwalik) to 10° (Upper Siwalik).

The Ramnagar area of the Udhampur District in Jammu and Kashmir State exposes a thick pile of the Lower Siwalik rocks classified as Ramnagar Formation by Gupta and Shali (1989) and is famous for its rich vertebrate fossil record. Various workers have described the fauna in this area (e.g.,

Symbol	Definition
Qm	Monocrystalline quartz
Qp	Polycrystalline quartz
C	Chert
P	Palgioclase feldspar
K	Potassium feldspar
Ls	Meta–sedimentary rock fragments
Lv	Volcanic rock fragments
NUM	Non–undulatory monocrystalline quartz grains
UM	Undulatory monocrystalline quartz grains
Recalculated components	
Qt	Total quartzose grains (=Qm+Qp+C)
F	Total feldspar grains (=P+K)
L	Total unstable lithic fragments (=Ls+Lv)
Lt	Total lithic grains (=L+Ls+Lv)
Qp	Total polycrystalline quartzose grains (=Qp+C)

Table 1—Key for petrographic and other parameters used in this study.

Satsangi, 1964; Dutta *et al.*, 1976; Vasishta *et al.*, 1978; Gaur & Chopra, 1983; Gupta & Shali, 1989, 1990; Nanda & Sehgal, 1993, 2005; Sehgal, 1994, 1998; Gupta, 2000; Parmar & Prasad, 2006; Parmar, 2007). These rocks have been divided into Dodenal (= Kamlial Formation) and Ramnagar (= Chinji Formation) members by Gupta (2000). The Dodenal Member, lower part of the subgroup, has very good exposures along the Kalaunta locality and consists of brown, reddish brown, grey and buff sandstones, reddish brown to dark brown siltstones and light brown to reddish brown mudstones. The upper part of the subgroup, Ramnagar Member, is exposed along the Ramnagar *Khad* (seasonal stream) and comprises of multistoried sandstone bodies with fine– to medium–grained grey, greenish grey, buff, purple to dull grey sandstones, reddish brown to dark brown siltstones and bright red to reddish brown mudstones. These rocks are sandwiched between the Murree Formation and the Middle Siwalik on both the limbs of the doubly plunging Udhampur Syncline (Fig. 1).

METHODOLOGY

Twenty three sandstone samples from the Lower Siwalik Subgroup in Kalaunta and Ramnagar areas were studied for petrographic analysis. The thin sections were examined under a polarizing petrological microscope. The modal compositional fields are shown as triangular QtFL (total quartz–feldspar–lithic fragments) and QmFLt (monocrystalline quartz–feldspar–total lithic fragments) diagrams to differentiate maturity and source rocks. The constituent minerals of the sandstones were classified into mono–crystalline quartz, polycrystalline quartz, feldspar and lithic fragments (volcanics, sedimentary, meta–sediments and cherts). Classification and tabulation of grain types was done following the method of Dickinson (1985). Definitions of raw and recalculated parameters used in the analysis are given in Table 1.

PETROFACIES

Kalaunta Section

The studied sandstones are fine– to medium–grained; moderately to well sorted and the shape of the grains varies from subangular to subrounded. The average framework composition of the sandstone is Qt = 86 %, F = 5 % and L = 9 % (Table 2) which is classified as sublitharenite, subarkose and litharenite. The quartz grains are of monocrystalline type and generally show undulatory extinction. Feldspar occur in small amount and are present commonly as plagioclase feldspar and microcline. The rock fragments observed include

Sample No.	Qt(%)	F	L(%)	Qm(%)	NUM	UM	Lt(%)	P_{2-3}	$P_{>3}$	Qp(%)	Lv(%)	Ls(%)	P(%)
K–1	88	4	8	80	5	62	16	8	25	8	6	2	4
K–2	80	5	15	70	8	58	25	4	30	10	9	6	5
K–3	81	6	13	68	4	65	26	5	26	13	11	2	6
K–4	88	4	8	70	6	60	26	7	27	18	3	5	4
K–5	87	6	7	75	8	62	19	8	22	12	2	5	6
K–6	88	3	9	75	5	67	22	3	25	13	3	6	3
K–7	88	5	7	77	7	64	18	2	27	11	4	2	5
K–9	89	3	8	75	5	65	22	4	26	14	6	2	3
K–10	84	6	10	65	6	56	29	3	35	19	6	4	6
Avg.	**86**	**5**	**9**	**73**			**22**			**13**	**6**	**4**	**5**

Qt=Total quartz, Qm=Monocrystalline quartz, Qp=Polycrystalline quartz, F=Total feldspar, L=Lithic fragments, NUM=Non–undulatory monocrystalline quartz, UM=Undulatory monocrystalline quartz, Lt=Total lithic fragments, Ls=Meta–sedimentary rock fragments, Lv=Volcanic lithics, P=Palgioclase feldspar, P_{2-3}=≥75% of total polycrystalline quartz, $P_{>3}$=>25% of total polycrystalline quartz.

Table 2—Detrital framework grains (count percentage) of the Lower Siwalik Subgroup of the Kalaunta Section.

polycrystalline quartz grains, lithic fragments and chert. Muscovite flakes are also observed in these sandstones. Lithic fragments range from 16 to 29 % (av. 22 %) and are dominated by polycrystalline lithics including chert followed by volcanic (Lv, av. 6 %) and sedimentary (Ls, av. 4 %) fragments.

Ramnagar Section

The sandstones in the Ramnagar Section range from fine– to medium–grained, moderately to well sorted and subangular to subrounded. These sandstones belong to sublitharenite group with the framework consisting predominantly of quartz (av. 86 vol. %), lithic fragment (av. 10 vol. %) and feldspar (av. 4 vol. %) (Table 3). Few samples also belong to subarkoses and litharenites. The framework grains are dominated by monocrystalline quartz, followed by lithic fragments and micas. Both altered and fresh varieties of feldspar occur in the form of plagioclase and microcline. Alteration and leaching of the feldspar grains is observed along the cleavage planes and grain boundaries. Tiny and large muscovite flakes are also observed in these sandstones. The lithic fragments include polycrystalline quartz grains (Qp), chert fragments and meta sedimentary lithics (Ls). Chert grains are rare and are distinguished from polycrystalline quartz by their fine internal grain size**.** For the purpose of counting, chert fragments were included in the polycrystalline quartz counts. Polycrystalline quartz grains constitute an average of 12 vol. % and metasedimentary lithics constitute 5 vol. %. The quartz grains generally show undulatory extinction. Some of the quartz grains contain inclusions and overgrowths. Polycrystalline quartz grains posses both sharp and sutured intercrystal boundaries.

PROVENANCE

Detrital quartz grains in sedimentary rocks are often used as an indicator of provenance. Basu *et al.* (1975), Young (1976) and Zuffa (1980) have shown usefulness of quartz types like nonundulatory monocrystalline (NUM), undulatory monocrystalline (UM), polycrystalline with 2–3 crystal units per grain (P_{2-3}) and polycrystalline with more than 3 crystal units per grain ($P_{>3}$) in determining the provenance for detrital quartz populations.

In the present study the data obtained on quartz types is shown in Tables 2 and 3 and is plotted on diamond diagrams (*after* Basu *et al.*, 1975). In both the studied sections the data on quartz types fall in low rank metamorphic source (Fig. 2a, b). Polycrystalline quartz showing two distinctly different sizes of crystals within a single grain is diagnostics of metamorphic quartz (Pettijohn *et al.*, 1972). Metamorphic source lying to the north of the Siwalik belt has been suggested for Chinji Formation in Pakistan (Khan, 1994). The volcanic rock fragments, biotite and muscovite are also seen in some of the thin sections. This study reveals that quartz is the most dominant constituent (86 vol. % on an average) in these sandstones and most of the monocrystalline quartz shows undulose extinction and contains few inclusions and overgrowths. Presence of the non–undulatory quartz grains is indicative of metamorphic and igneous provenance (Blatt *et al.*, 1980). Predominance of unit quartz and undulose extinction counterpart is indicative of plutonic and low rank metamorphic source (Basu *et al.*, 1975). Undulose quartz points to tectonic disturbances in the depositional site (Blatt & Christie, 1963). Polycrystalline quartz with three to four intra–crystalline units and poorly sutured boundaries are

Sample No.	**Qt(%)**	**F**	**L (%)**	**Qm(%)**	**NUM**	**UM**	**Lt(%)**	**P_{2-3}**	**$P_{>3}$**	**Qp(%)**	**Lv(%)**	**Ls(%)**	**P(%)**
R–1	87	6	7	80	6	65	14	4	25	7	4	3	6
R–2	84	5	11	68	5	60	27	5	30	16	5	6	5
R–4	83	5	12	68	8	69	27	3	20	15	7	5	5
R–5	85	2	13	70	3	60	28	5	32	15	6	7	2
R–6	80	5	15	65	3	66	30	3	28	15	9	6	5
R–7	86	4	10	76	7	62	20	6	25	10	4	6	4
R–8	84	6	10	70	5	58	24	4	33	14	6	4	6
R–9	87	5	8	79	4	60	16	10	26	8	5	3	5
R–10	89	6	5	82	7	68	12	5	20	7	2	3	6
R–12	84	5	11	70	4	66	25	2	28	14	5	6	5
R–13	92	2	6	82	5	56	16	7	32	10	0	6	2
R–14	84	4	12	72	6	70	24	2	22	12	7	5	4
R–15	90	4	6	80	6	62	16	5	27	10	1	5	4
R–16	86	4	10	75	7	65	21	3	25	11	4	6	4
Avg.	**86**	**4**	**10**	**74**			**21**			**12**	**5**	**5**	**5**

Table 3—Detrital framework grains (count percentage) of the Lower Siwalik Subgroup of the Ramnagar Section.

suggestive of a low rank metamorphic source (Blatt & Christie, 1963; Blatt, 1967). This study reveals that sediments of the investigated area may have been derived from variety of source rocks. This interpretation is also supported by the presence of opaque mineral grains, which reflect derivation from metamorphic and igneous rocks (Bhat, 2008).

TECTONIC SETTINGS

To understand the tectonic setting, the petrofacies were plotted in standard triangular diagrams Qt–F–L and Qm–F–Lt after Dickinson (1985). The Qt–F–L diagram emphasizing factors controlled by provenance, relief, weathering and transport mechanism is based on total quartzose, feldspar and lithic modes. In this diagram, the samples of both the studied sections lie in the recycled orogen provenance (Fig. 3a, b) with a source primarily in the quartzose recycled orogen provenance field. Global sandstone petrographic classification show that petrofacies that plot within the recycled orogen provenance field are commonly derived from meta–sedimentary and sedimentary rocks that were originally deposited along former passive continental margins (Dickinson & Suczek, 1979; Dickinson, 1985).

The Qm–F–Lt diagram (Fig. 4a, b) shows that the data plot of both the studied lithosections fall in the quartzose recycled provenances field. The sandstone petrofacies indicate multiple rock sources for these sandstones, which are not reflected in the triangular plots. The apparent reason for this could be diagenetic alteration and weathering of unstable framework grains, and consequent increase in the proportion of quartz grains relative to the original detrital composition (Bhat, 2008).

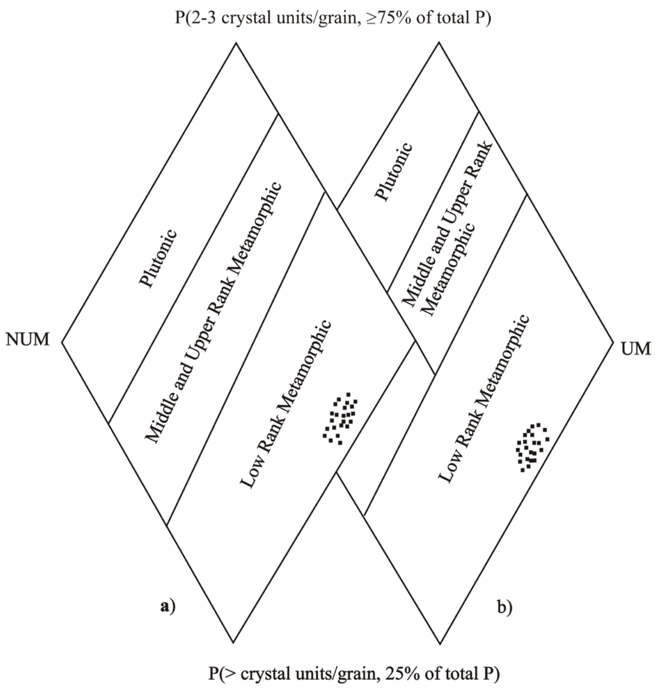

Fig. 2—Diamond diagram showing provenance of different quartz types of (a) Ramnagar and (b) Kalaunta sections (after Basu *et al.*, 1975).

DISCUSSION AND CONCLUSIONS

The dominant framework constituents of the sandstones of the study area are composed of abundant quartz with small amount of feldspar, lithic fragments, micas and accessory minerals. Mineralogically, the sandstones of the studied lithosections are sublitharenites. However, a few are subarkose and litharenite. The abundance of subangular to subrounded, fine monocrystalline quartz grains reflects a moderate abrasion history and relatively longer transport. The low concentration of feldspar and comparatively significant proportion of rock fragments characterise a heterogenous source terrain and longer transport history. The occurrence of different sizes of crystals with sutured intercrystal boundaries within polycrystalline quartz grains points to their metamorphic origin. The diamond diagram shows that these sandstones are derived from low–grade metamorphic source rocks. The relatively greater abundance of monocrystalline quartz indicates that the presence of granitic and volcanic rocks in the source areas, or else the quartz grains have travelled a longer distance of transportation. Pandita and Bhat (1995) and Pandita (1996) have come to the conclusion that the Middle and Upper Siwalik rocks of the southern limb of the Suruin–Mastgarh anticline have been derived from the low to middle and upper rank metamorphic sources in the Himalayan terrain. The progressive increase of the grade from low to high rank in Lower through Middle and Upper Siwalik rocks can be related to the unroofing of the metamorphic terrain in the orogenic Himalaya.

The ternary diagrams (Qt–F–L and Qm–F–Lt) study reveals that sediments of the lithosections were derived from

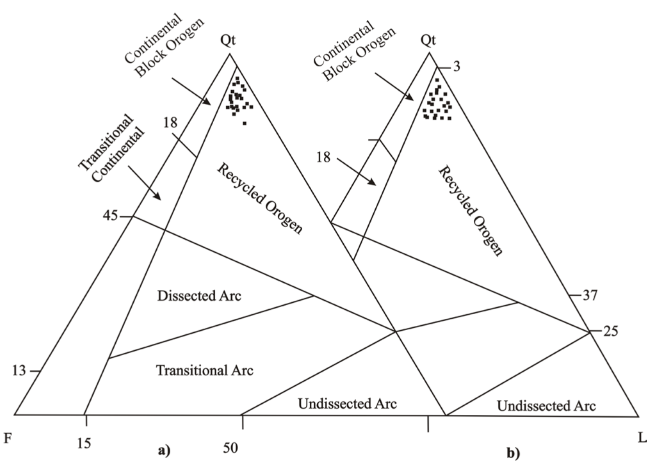

Fig. 3—Qt-F-L diagram of (a) Ramnagar and (b) Kalaunta sections.

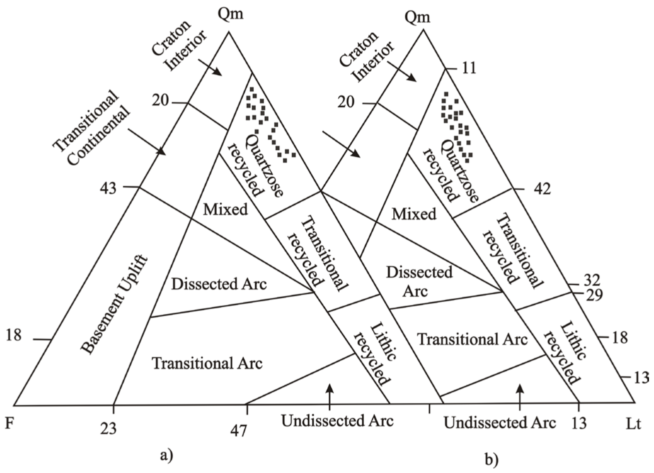

Fig. 4—Qm-F-Lt diagram of (a) Ramnagar and (b) Kalaunta sections.

collision orogenic belt (recycled orogen) provenance. Mostly the sedimentary, partly metamorphic and subordinately volcanic rocks of the orogenic belt constitute the recycled orogen (Dickinson *et al.*, 1983). The sources of the recycled orogenic provenance are deformed and uplifted stratal sequences in subduction zones along collision orogen or within foreland fold–thrust belts. These types of recycled orogenic sandstones (rich in quartz and other lithic fragments) are often deposited in closing ocean basins, diverse successor basins and foreland basins (Dickinson & Suczek, 1979). Sands derived from fold–thrust systems of indurated sedimentary and low–grade metamorphic rocks have consistently low contents of feldspar and volcanic rock fragments (Dickinson & Suczek, 1979). Pandita (1996) has come to the conclusion that the Middle and Upper Siwalik subgroups in Jammu have been derived from collision orogenic belts. These results are consistent with observations (collision orogen) made in Kohat–Potwar area by Abassi and Friend (1989), in Surai Khola and Bakiya Khola sections in Nepal (recycled orogen provenance) by Critelli and Ingersol (1994), and in modern Indus River (Kohistan island arc terrain) by Johnson *et al.* (1985).

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