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Depositional condition, provenance and tectonic framework of the Upper Tertiary sandstones of the Arunachal Himalaya, India

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ABSTRACT

The Upper Tertiary sandstones of the foothills of the Arunachal Himalaya, eastern India were studied to determine the depositional condition, provenance and tectonic framework of deposition of the sandstones. For this purpose, size analysis and mineralogical and basin configuration studies were carried out. The mineralogical composition of the sandstones indicates that the sandstones were mainly derived from the metamorphic and igneous rocks. The compositional study indicates that these immature sandstones were developed in the continental block provenance under humid climatic conditions affected by major tectonic disturbances. The sedimentological study shows that the sediments of the sandstones were waterlaid and deposited rapidly in the Arunachal basin, which was a shallow and fresh water basin and tectonically active at the time of sedimentation.

INTRODUCTION

The Upper Tertiary sandstones of the foothill regions of the Arunachal Himalaya, eastern India were studied to determine the depositional condition, provenance and tectonic conditions during deposition of the sandstones. The area is bounded by latitude 22°N to 24°N and longitude 92°E to 96°E (Fig. 1).

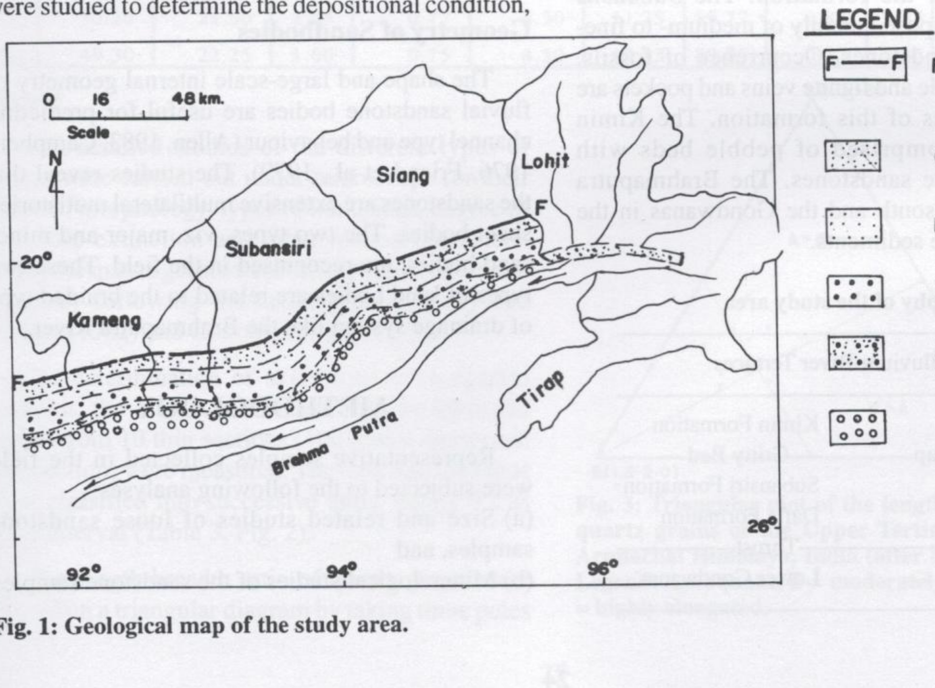

Fig. 1: Geological map of the study area.

GEOLOGY OF THE AREA

Following the continental collision between India and Eurasia, the Himalaya experienced intense uplift and erosion, and as a result, a large amount of siliciclastic sediment accumulated within foreland and remnant ocean basin developed from Eocene to the present in front of the collision zone and at both sides of the Indian block (Dewey et al., 1989; Harrison et. al., 1992). Terrestrial sedimentation is active within basins developed along the collision zone. Moreover, portions of the sediments were deposited by large rivers draining the uplifted Himalayan belt during the late Neogene (Mulder and Burbank, 1993).

The Upper Tertiary sediments of Arunachal Pradesh occur at the foothills regions of the Himalaya. They are formerly classified as the Tipam and Dihing formations, depending on their lithological characters. Afterward, these were described as Siwaliks for their close resemblance to the Siwaliks of the western Himalaya. Karunakaran and Ranga Rao (1976) have finally divided the Upper Tertiary sediments of Arunachal Pradesh into the Dafla, Subansiri, and Kimin formations (Table 1). The Dafla Formation is composed of medium to coarse grained loose sandstones. Pebbles and pebbly layers, wood materials and current bedding are the main features of the formation. The Subansiri Formation is composed mainly of medium- to fine-grained, hard sandstones. Occurrence of fossils, carbonaceous shale and lignite veins and pockets are the main features of this formation. The Kimin Formation is comprised of pebble beds with intercalated loose sandstones. The Brahmaputra Alluvium in the south and the Gondwanas in the north bound these sediments.

Table 1: Stratigraphy of the study area

Brahmaputra Alluvium-River Terraces	
Upper Tertiary Group	Kimin Formation — Gritty Bed — Subansiri Formation Dafla Formation
	—Thrust—
Gondwanas	Lower Gondwanas

Field Sequences and Sedimentary Facies of the Sandstones

The Subansiri Formation consists of sandstone and siltstone litho-facies. The sandstones are fine to coarse grained, thick-bedded and cross-bedded. The formation at its stratotype is characterised by a dominance of multistoried sand bodies. The general lithic aspect of the base of the section is one of thick sandstone units interbedded with siltstones. The middle part of the section consists of sandstone, siltstone and carbonaceous lignite pocket. Concretionary layers are abundant in the section. The uppermost part of the sequence is composed of sandstone, pebbly sandstone with pebble layers. Sandstones are typically grey, micaceous with salt and pepper appearance.

The section can be subdivided into three parts based on the litho-facies:
(1) Sandstone-pebbly sandstone
(2) Multistoried sandstone
(3) Sandstone (fine) - siltstone

Fining up sequences with scour surfaces at the bottom through cross-bedded, planar cross-bedded, and ripple-drift laminated sandstone and siltstone at the top are present. The entire succession represents the sedimentary fill of the foreland basin.

Geometry of Sandbodies

The shape and large-scale internal geometry of fluvial sandstone bodies are useful for predicting channel type and behaviour (Allen, 1983, Campbell, 1976, Friend et al., 1979). The studies reveal that the sandstones are extensive multilateral mutistoried sheet bodies. The two types, viz. major and minor sand bodies, are recognised in the field. These two types of sand bodies are related to the braided type of drainage system like the Brahmaputra River.

METHODOLOGY

Representative samples collected in the field were subjected to the following analyses:
(a) Size and related studies of loose sandstone samples, and
(b) Mineralogical studies of the sandstone samples

Size analysis of loose sandstone samples was done following conventional procedures (Krumbein and Pettijohn, 1938). The results obtained from mechanical analysis were utilised for the determination of various statistical parameters, interrelationship of the size parameters, environmental analysis, and processes and hydrodynamic condition of deposition of the sediments.

The petrographic study covers description of mineral constituents and other petrographic properties including measurement of length and breadth of various mineral grains. Heavy minerals were separated following the bromoform method (Carver, 1971). Quartz and feldspar are the main light detritals and heavy minerals are the other detrital minerals (Table 2).

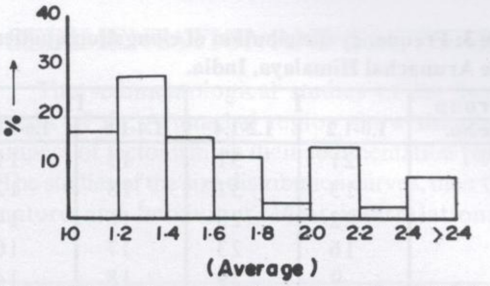

Fig. 2: Elongation ratio of quartz grains of the Upper Tertiary sandstones of Arunachal Himalaya, India.

A (L/B = 1.0-1.2), B (L/B = 1.2-2.0) and C (L/B = >2.0) (Table 4, Fig. 3). For this purpose, three sub-populations (equant - A, moderately elongated - B, highly elongated- C) were plotted using the triangular diagram of Mukherjee (1965), an improvement technique over Bokman (1952).

Table 2: Modal point count data of the Upper Tertiary Sandstones of the Arunachal Himalaya, India.

S. N.	Primary Detrital Constituents									Other detrital constituents	
	Monocrystalline quartz			Polycrystalline quartz			Total quartz	Feldspar	Mica	Accessory minerals	Rock frag-ments
	Unit non undulatory quartz	Unit undulatory quartz	Vein quartz	Composite quartz	Schistose quartz	Pressure quartz					
1.	50.60	23.40	1.90	0.75	4.47	10.44	91.56	1.85	1.30	0.79	4.50
4.	51.41	22.45	2.20	0.80	4.02	11.45	92.33	1.50	1.40	0.77	4.00
6.	45.60	24.50	1.20	0.90	4.30	11.72	88.22	1.60	1.60	4.58	4.00
8.	48.30	23.40	1.35	0.75	4.45	11.80	90.05	0.75	2.55	2.15	4.50
9.	45.60	21.56	1.20	0.85	5.56	10.77	85.54	0.90	2.20	6.86	4.50
12.	50.20	21.50	1.25	0.77	4.30	11.75	89.77	0.82	2.35	2.61	4.45
16.	49.30	22.25	1.60	0.75	4.50	10.85	89.25	0.72	2.45	2.83	4.75

Quartz

The detailed studies of the different types of quartz were carried out under microscope for their external morphology, types of inclusions, degree of undulose extinction and other related characters. Then, the quartz grains were classified into different types by following the techniques of Dotty and Hubert (1962) and Conolly (1965).

For determination of axial ratio or elongation quotient, the length and breadth of one thousand grains from 10 thin sections (100 grains from each thin section) were measured. The data obtained thus were classified into successive units, taking 0.2 as class interval (Table 3, Fig. 2).

The length-breadth ratio of quartz grains were plotted on a triangular diagram by taking three poles

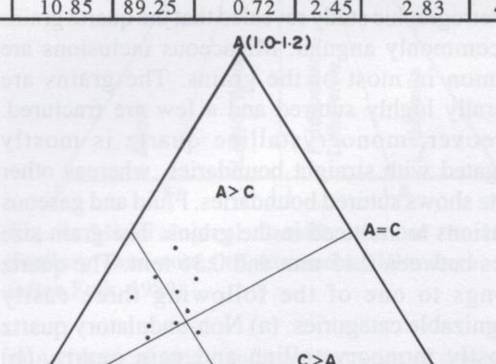

Fig. 3: Triangular plot of the length/breadth ratio of quartz grains of the Upper Tertiary sandstones of Arunachal Himalaya, India (after Mukherjee, 1975). Legend: A = equant, B = moderately elongated and C = highly elongated.

Table 3: Frequency distribution of elongation quotient of quartz grains of Upper Tertiary Sandstones of the Arunachal Himalaya, India.

Group	I		II		III			IV	
Slide No.	1.0-1.2	1.2-1.4	1.4-1.6	1.6-1.8	1.8-2.0	2.0-2.2	2.2-2.4	> 2.4	Total
1	21	31	11	11	2	13	1	10	100
5	13	31	18	12	4	13	1	8	100
12	22	28	16	14	2	10	2	6	100
20	16	23	17	10	3	16	5	10	100
24	9	29	18	14	4	17	2	7	100
28	22	30	16	12	2	10	1	7	100
32	16	29	16	10	5	13	3	8	100
36	18	27	15	13	3	12	2	10	100
43	17	26	18	12	2	15	2	8	100
45	15	30	16	10	5	12	2	10	100
Average	17	18	16	12	3	14	2	8	100

Table 4: The length-breadth ratio of quartz grains of Upper Tertiary Sandstones of the Arunachal Himalaya, India.

Slide No.	1.0-1.2	1.2-2.0	>2.0
1	21	55	24
5	13	65	22
12	22	60	18
20	16	53	31
24	9	65	26
28	22	60	18
32	16	60	24
36	18	58	24
43	17	58	25
45	15	61	24

Petrographic study revealed that the quartz grains are commonly angular. Micaceous inclusions are common in most of the grains. The grains are generally highly sutured and a few are fractured. Moreover, monocrystalline quartz is mostly elongated with straight boundaries, whereas other quartz shows sutured boundaries. Fluid and gaseous inclusions are noticed in the grains. The grain size varies between 0.15 mm and 0.36 mm. The quartz belongs to one of the following three easily recognizable categories: (a) Non-undulatory quartz - mostly monocrystalline and vein quartz, (b) Undulatory quartz - mostly undulose quartz, (c) Polycrystalline quartz - mostly composite, schistose and pressure metaquartzites.

Feldspars

Feldspars are the second abundant mineral in the sandstones. Microcline and orthoclase as well as Na-feldspars (mostly albite variety) are found. Microcline grains show characteristic cross-hatch twinning. Perthitic and myrmekitic inter-growths are also observed in many sections. Most of the grains are fresh and angular. Some grains are fractured owing to internal grain pressure.

Micas

Shreds of muscovite, biotite and chlorite are observed. Development of kink bands and chloritisation of biotite is also observed. Inclusions are common.

Other Detritals

These include opaque and non-opaque varieties. Amongst the opaques, iron-minerals are most dominant. Zircon, tourmaline, rutile and garnet are the common non-opaque accessory minerals.

Lithic Grains

Particles having recognisable characteristics of their parent rocks are designated as lithic grains or rock-fragments. The lithic grains in the sandstones belong to schists, quartzite, and gneisses.

Matrix and Cement

Relatively fine grains with less than thirty microns in their sizes around the larger grains are recognized as matrix. They are mostly quartz and clay. The cementing materials are mostly calcareous. Ferruginous and siliceous cements are also found in lower percentage.

Heavy Minerals

The heavy mineral suite of the Upper Tertiary sandstones consists of tourmaline, zircon, rutile, epidote, garnet, kyanite, staurolite and opaque minerals. Zircon and tourmaline occur abundantly in comparison to the other heavy minerals (Table 5).

Table 5: Heavy mineral percentages.

Sample No.	Epidote & Zoisite	Garnet	Kyanite	Stau-rolite	Horn-blende	Zircon	Tour-maline	Rutile	Silli-manite	Amphi-boles	Mica	Opaque
3	20.2	6.4	3.5	2.17	6.6	4.6	10.4	1.2	1.4	0.72	6.61	36.2
4	16.4	9.6	6.3	2.4	10.5	5.5	8.2	1.5	1.5	0.73	8.3	29.1
8	18.5	15.2	4.5	1.8	10.4	4.6	8.3	0.23	1.3	0.52	3.41	31.2
11	15.5	14.5	2.4	1.3	3.6	2.5	17.3	1.1	2.8	0.20	2.35	36.3
13	21.0	17.1	3.4	1.2	6.4	3.7	6.4	0.80	2.5	0.39	2.25	34.7
14	18.5	21.8	4.3	1.3	6.1	4.5	16.6	0.73	1.6	0.32	2.55	21.7
15	20.7	18.5	1.5	1.5	7.6	3.7	12.7	0.53	1.7	0.45	2.76	28.2
18	18.1	18.8	1.5	2.5	3.6	2.4	13.6	0.45	1.8	0.5	2.8	33.9
21	19.2	16.2	1.4	1.3	8.5	3.4	8.7	1.09	2.5	0.34	2.55	35.7
23	22.4	16.7	1.6	2.5	6.7	3.5	10.4	1.08	2.6	1.24	2.97	27.0
24	16.2	11.5	4.5	3.2	5.4	4.5	10.3	1.7	2.4	0.96	4.2	35.1
25	18.3	9.5	5.5	2.5	6.6	3.2	8.3	1.61	1.8	0.64	3.55	39.2
26	16.0	19.3	5.5	2.7	6.3	5.7	9.3	1.82	2.6	0.33	2.45	29.0
27	18.3	16.2	4.6	2.4	5.3	4.7	6.5	1.7	0.98	0.66	1.97	36.6

TECTONIC FRAMEWORK

Dickinson and Suczek (1979) and Dickinson (1985) have emphasized the role of Plate Tectonics in determining the composition of sandstones on a regional scale. Plate tectonics controls the distribution of different sandstones governing the key relationships between provenance and basin configuration (Dickinson and Suczek, op. cit.). Composition of sandstones, however, is also affected by factors other than tectonic setting viz. transportation history (Suttner, 1974, Franzinelli and Potter, 1983), sedimentary processes within the depositional basin (Davis and Ethridge, 1975) and palaeoclimate (Basu, 1985, Suttner et al., 1981).

From modal analysis it is seen that the rock is mostly sub-litharenite to litharenite (Fig. 4). The source rock identification from the petrography of the sandstones fits in the Continental Block Provenance of Dickinson 1985 (Fig. 5). An attempt has been made to compare the framework composition of the sandstones to climatic control following Suttner and Dutta (1986). The bivariant log-log plot indicates a humid climate during the deposition of the sediments (Fig. 6).

SEDIMENTATION AND TECTONISM

The sedimentological studies of the Tertiary rocks of the Arunachal region show the distinct impact of tectonism on their sedimentation pattern. The studies of the size distribution curves, their types, nature and behaviour, their interrelationship,

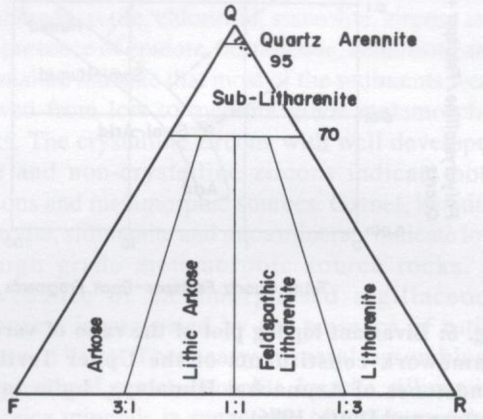

Fig. 4: Mineralogical classification of the Upper Tertiary sandstones of Arunachal Himalaya, India (after Folk, 1980).

mineralogical study and environment of deposition of the sandstones indicate rapid river deposition and tectonic influence on the sediments. Moreover, the lithostratigraphic relationship in the field also support these views.

The leptokurtic nature of the size curves with their modes and variations in the peaks and slopes,

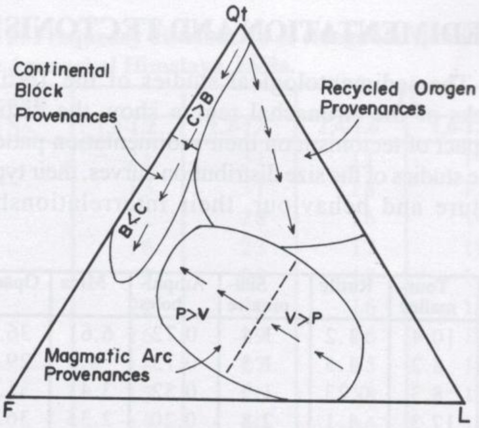

Fig. 5: Qt FL plot of the Upper Tertiary sandstones of Arunachal Himalaya, India (after Dickinson, 1985).

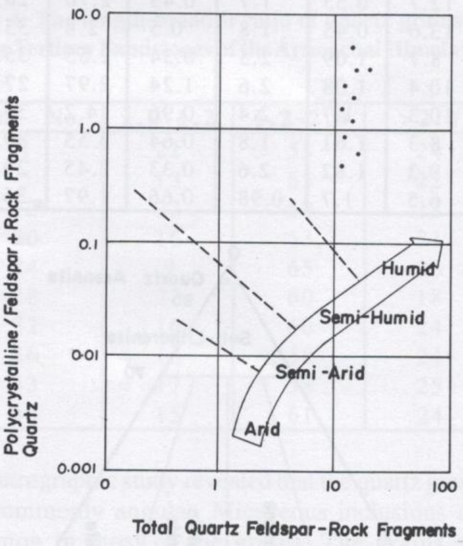

Fig. 6: Bivariant log/log plot of the ratio of various framework constituents of the Upper Tertiary sandstones of Arunachal Himalaya, India (after Suttner and Dutta, 1986).

indicates fluctuation of the kinetic energy of the depositing media either in the source, or in the site of deposition, which may be due to tectonic instability in the site or in the source area. The extension of the tails in the finer sides of the size curves up to 99.99% indicates the presence of more finer silt mode in the sandstones, thus supporting the river deposition of the sediments. The increase in mean grain size values indicates tectonic disturbances in the site of deposition with rapid and quick deposition, without having any reworking of the sediments in the site of deposition, which may also be the result of seasonal uplift encompassing both the site as well as the area of deposition (Cadigan, 1961). The standard deviation values show poor sorting of the sediments indicating immaturity of the sandstones and their river deposition with rapid and short transportation in a tectonically unstable region. Positive skewness and leptokurtic nature of the size curves also support river deposition along with the impact of tectonism.

The textural and grain size indices classifications of the sandstones also show the presence of more silt in the sandstones resulting their 'lithic' character and indicate the development of intense tectonism in the site of deposition and the deposition took place in a molassic conditions.

The shape analysis shows spherical as well as low to moderate roundness of the grains which indicate immaturity of the sandstones, short transportation and rapid deposition under river conditions with some amount of tectonic disturbances at the site of deposition.

The shape of the log-probability curves resembles the shape of the curves of fresh water river deposition described by Visher (1969). The pattern studies of the Upper Tertiary sandstones indicate deposition of the sediments mostly under river tractive current environment. Moreover the bivariant plots of some of the parameters followed by Moiola and Weiser, (1968) show river environment of deposition of the sediments (Fig. 7).

DISCUSSION AND INTERPRETATION

Milner (1962), Krumbein and Sloss (1963), Carver (1971), and Pettijohn (1975), have brought out the petrographic study of different mineral constituents which are useful indicators of source area.

The volumetric percentage of different quartz types shows that most of the grains are of polycrystalline and undulatory types. The presence of polycrystalline quartz is the indication of metamorphic source (Blatt, 1967; Bokman, 1952).

The dominance of polycrystalline quartz with multicrystal grains indicates a metamorphic source

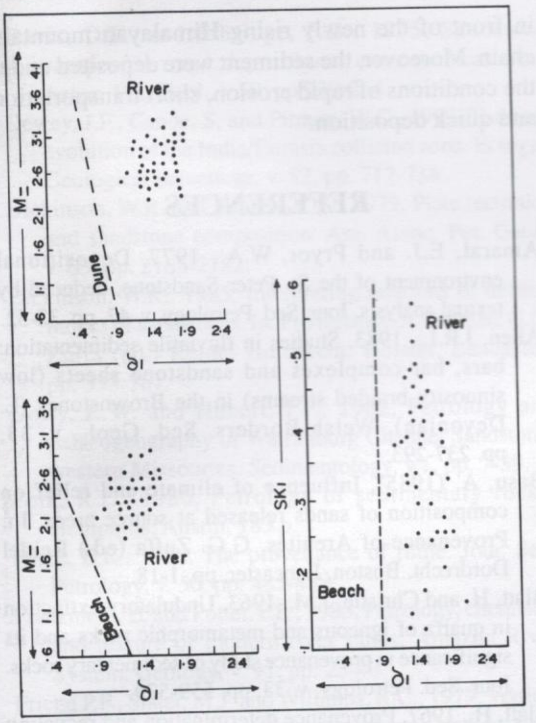

Fig. 7: Bivariant plot of statistical parameters (after Moiola and Weiser).

with some contributions from the plutonic rocks. Metamorphic source is also suggested by a significant proportion of the monocrystalline quartz grains showing undulose extinction (Blatt and Christie, 1963). The statistical parameters of quartz grains indicate that the sandstones were derived from schistose rocks. Elongated quartz with straight boundaries and gaseous inclusions in them indicate igneous derivation, whereas sutured contacts indicate metamorphic derivation of the sediments. Thereby quartz shows dual source for the sediments. Tandon (1972), in his study of quartz axial ratio for the Siwalik sediments around Ramnagar of Kumaon Himalaya, obtained the primary modes between 1.4-1.8 in the axial ratio histograms and he concluded that the provenance was mainly metamorphic rocks with some contributions from igneous rocks. From the triangular plot of Mukherjee (1975), it is observed that sandstones were mainly derived from middle to upper rank of metamorphic rocks (nearer to the pole-B).

The detrital feldspars are mainly potash and plagioclase feldspars. Alkali feldspars are mainly derived from granite and granitic gneisses, whereas plagioclase feldspars are mainly derived from low-grade mica schists. Thus, the detrital feldspar grains clearly point out to the provenance of igneous and metamorphic rocks. Similarly, the lithic fragments present imply metasedimentary and crystalline sources.

The elongation quotient of detrital quartz shows that majority of them were derived from dual source i.e., metamorphic and igneous. Angular and subangular grains indicate short transportation of the sediments from the source to the place of deposition.

The compositional tectonic framework studies indicates that the sandstones can be fitted in the Continental Block Provenance under humid climatic conditions affected by major tectonic disturbances leading to the development of these immature sandstones.

The heavy mineral assemblage of the Tertiary sandstones contains complex and unstable minerals like epidote, tourmaline (green, yellow and brown varieties), garnet, kyanite, chlorite, biotite, hornblende, rutile, chloritoid, staurolite, zircon, etc. The presence of epidote, hornblende, andalusite and tourmaline indicate that most of the sediments were derived from low to medium grade metamorphic rocks. The crystalline zircons with well developed core and non-crystalline zircons indicate both igneous and metamorphic sources. Garnet, kyanite, staurolite, sillimanite and mica minerals indicate low to high grade metamorphic source rocks. A provenance of metamorphosed argillaceous sediments is suggested by the presence of rutile (Force, 1980). The heavy mineral assemblage comprising of garnet, staurolite, kyanite, sillimanite and mica minerals is suggestive of a metamorphic source rock (Chaudhri and Gill, 1981). Blatt et al. (1980) have suggested a metamorphic source for brown and yellow varieties of tourmaline. Pettijohn (1975) also observed that the presence of garnet, epidote and biotite is suggestive of derivation of the minerals from the metamorphic source rocks which are lying in north of the study area (Das, 1979). The low to high grade metamorphic rocks are the main source of the sedimentary rocks of the study area. The Smithson's diagram indicates less wear and tear, and short transportation of the sediments.

DEPOSITIONAL CONDITION

The vast thickness and lateral extent of the Tertiary rocks show a complex sedimentation patterns in the basin. The marked variability of the geometry of sandbodies is reflective of variability in channel behaviour and type. These multi-storied sand complexes contain large-scale trough cross-bedded medium to coarse grained facies, small-scale through cross-bedded, fine- to medium-grained sandstone, and fine- to medium-grained horizontal laminated sandstone. From the pattern of the litho-facies, the individual storeys represent channel bars in big shifting braided river like the Brahmaputra. This river was shallow relative to their width, floored by bars and channels of low sinuosity and with a bedload of sand and pebbly sand. It is also significant that the depositional site predominantly remained a channel belt accumulating over a kilometer thick multistoried sandstones. Comparison with the modern Brahmaputra plain reveals a similarity of these characters with this river. During rainy season, floods may flow over the river bed and the river bank and as a result multistory sands with secondary channels stacked laterally for few kilometres.

These fluvial sandstones characterise the sedimentary style of the Siwalik Group of the Western Himalaya. The pebbly sandstone and cross-bedded sandstone occurring on top of a scour surface constitute channel lag and channel bar deposits. The thinly bedded fine grained sandstones and siltstones of the upper part represent overbank deposits of the levee, flood basin and backswamp areas (Behrensmeyer and Tauxe, 1982, Visher and Johnson, 1978).

CONCLUSION

The Upper Tertiary sandstones of the Arunachal Himalayas were derived from metamorphic and igneous sources. The compositional characters indicate that the sandstones can be fitted in the Continental Block Provenance under humid climatic condition affected by major tectonic disturbance leading to the development of these immature sandstones. The sandstones were deposited in a tectonically active, fresh water, shallow basin named as Arunachal basin developed due to plate collision in front of the newly rising Himalayan mountain chain. Moreover, the sediment were deposited under the conditions of rapid erosion, short transportation and quick deposition.

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