DEPOSITIONAL ENVIRONMENTS AND PROVENANCE STUDY OF THE WARCHHA SANDSTONE

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DEDICATED

TO
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MY
FRIEND AND TEACHER

ABSTRACT

The Warchha Sandsonte, of Lower Permian age is present in the Salt and Trans Indus Ranges. Three stratigraphic sections selected for detail study included Warchha Gorge and Zaluch Nala in the Salt Range and Saiduwali Nala in the Khisor Range. The six lithofacies recognized in the Warchha Sandstone are: 1. Trough cross bedded pebbly sandstone, 2. Pebbly Sandstone/ conglomerate, 3. Cross bedded sandstone, 4. Clay/siltstone, 5. Massive sandstone, and 6. Faintly laminated sandstone lithofacies. It is suggested that the Warchha Sandstone is an alluvial fan deposit. The similarity of Warchha Sandstone with the underlying Tobra Formation (in clasts collected and lithology) points either to a common source rock for both formations or indicates reworking and incorporation of Tobra Formation into the Warchha Sandstone.

In thin section study, according to QFL triangular diagrams after Folk (1954-1980), the rocks are classified as arkose, with relative abundance of quartz, feldspars (K>P) and lithic fragments. In the QFL provenance discrimination diagrams of Dickinson et al., (1982, 1983) the point count data occupy the field of continental block provenance. It is suggested by paleoclimatic and paleotectonic characteristics, that the Warchha Sandstone provenance was the area of low relief, humid and semiarid climate with lack of vegetation.

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CHAPTER-1

INTRODUCTION

1.1 STRATIGRAPHY:

The Warchha Sandstone belongs to the Permian rocks of Pakistan, exposed in the Salt and Trans-Indus Ranges. The Salt Range and its Trans-Indus extension communicates between the outermost ranges of the north western Himalaya and the Sulaiman Arc to the west. It forms impressive scarps, usually 750 to 1000m in altitude (Gee 1989), complete sections of older formations, and excellent exposures of rocks from Precambrian age to Recent. The exposed formations of the range are all unmetamorphosed sediments with the exception of thin local occurrences of Khewra Trap at the top of the Salt Range Formation of the eastern part of the range. The presence of four major unconformities between Cambrian and Permian, Early Cretaceous and Paleocene, Miocene and Late Pliocene are the significant regional features in the range. Rocks of Permian age are found in the Kohat-Potwar Province in the Upper Indus Basin and in the Axial Belt. The presence of these rocks is confirmed by various subsurface investigations in the Lower Indus basin too. All the Permian rocks are of sedimentary origin and their main lithologies are sandstones, limestones and shales. In the stratigraphic sequence below the Permian strata are the Cambrian (Middle and Early) rocks of Jhelum Group including Khewra Sandstone, Kussak, Jutana and Baghanwala Formations in the Salt Range and Khisor Formation in the Khisor Range in Upper Indus Basin. The main lithology of these Cambrian rocks is sandstone, shale, gypsum dolomite and glauconitic and dolomitic limestones. As in Indus Basin, Cambrian was followed by regional uplift and break in sedimentation and erosion, which prevailed until the end of Carboniferous. Therefore there is a major unconformity between the Cambrian and Permian rocks. In both Salt and Trans-Indus Ranges, above the Permian system is the paraconformity which separates these rocks from Musa Khel Group. In Musa Khel Group there are Triassic (Early to Late) rocks including Mianwali, Tredian and Kingriali Formations. General lithology of these formations is limestones, sandstones and shales with dolomite and dolomitic limestones.

1.2 STRATIGRAPHIC RELATIONSHIPS:

The Permian rocks of the Salt Range and Khisor Range are divided into two groups (Shah 1977);

b. Zaluch Group.

a. Nilawahan Group

The Warchha Sandstone belongs to the Nilawahan Group. The group is Lower Permian in age and includes, Tobra and Dandot Formations, Warchha Sandstone and Sardhai Formation in ascending order. The overall lithology of this group is sandstone, shale and clay. Above the Nilawahan Group is the Upper Permian Zaluch

Group which includes Amb, Wargal and Chhidru Formations in ascending order. The general lithology of this group is carbonaceous shale, limestone, calcareous sandstone and marl. The Warchha Sandstone is distributed in Salt Range and in the Khisor Ranges. In eastern Salt Range, the main exposure is in the Warchha Gorge while in Khisor Range it is exposed in the Saiduwali section (Plate 1.1 and 1.2). The type section is in the Warchha Gorge in the Salt Range (Figure 1.1). The formation conformably overlies the Dandot Formation in the Warchha Gorge section. In Zaluch Nala and Saiduwali sections the Dandot Formation is missing and Warchha Sandstone directly overlies the Tobra Formation (Plate 1.3 and 1.4). Its upper contact with overlying Sardhai Formation is transitional in all sections (Figure 1.2).

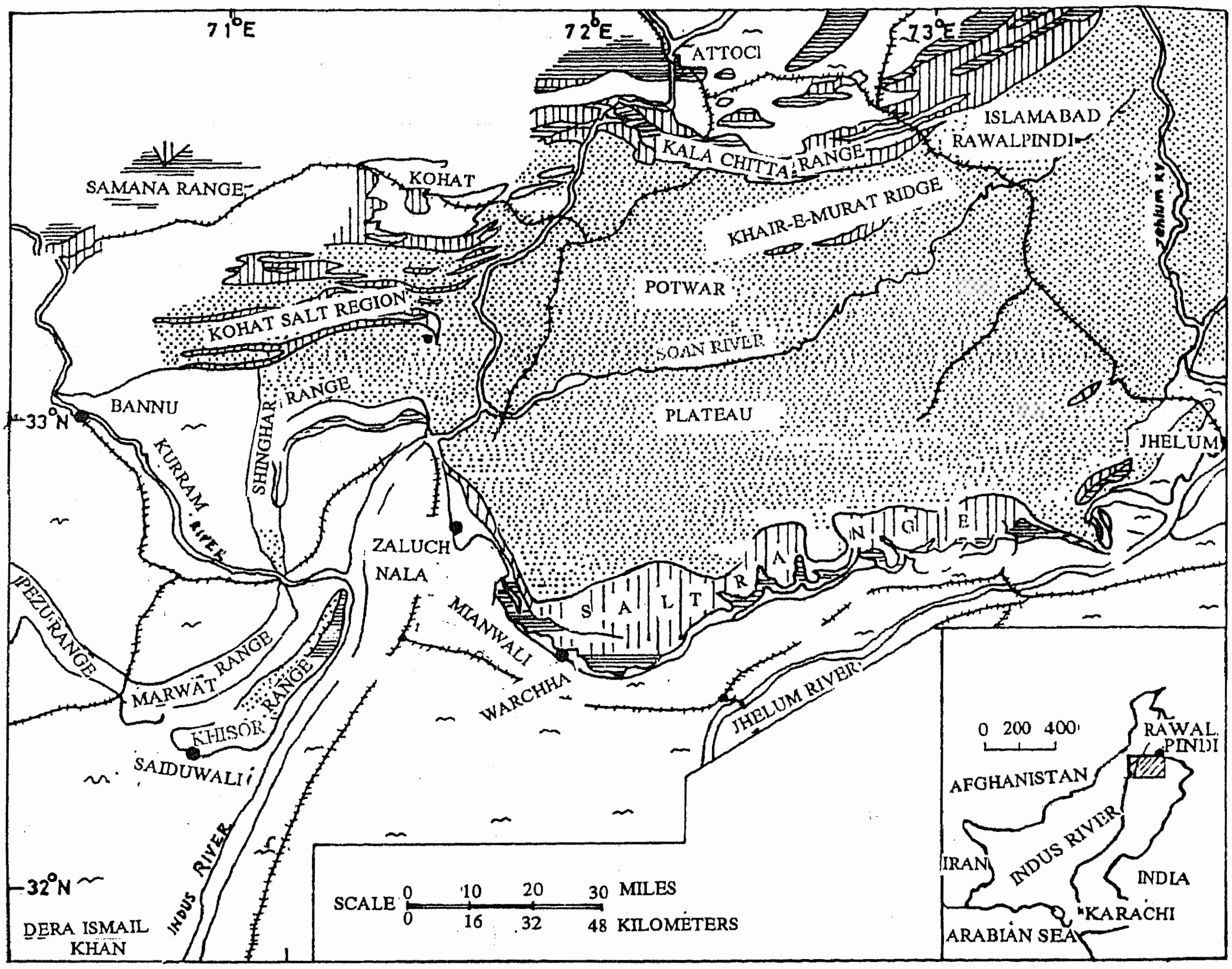

Figure 1.1 Map of Salt Range and Trans Indus Range showing location of measured stratigraphic sections of Warchha Sandstone (Adopted from Gee, 1983).

1.3 GENERAL GEOLOGY:

The Warchha Sandstone is predominantly composed of red and maroon sandstone, shale and conglomerate. The sandstone of the formation is arkosic and the pebbles are mostly granitic alongwith pieces of quartzite and chert. The rocks are speckled in places and therefore it was previously called "Speckled Sandstone". In Burikhel section (Western Salt Range) some coal seams are also found and is believed to be the only Permian coal in Pakistan. The formation shows cross-bedding and variable thickness (Plate 1.5). In Salt Range, the thickness of Zaluch Nala and Warchha section is 61 m and 69 m respectively. In Khisor Range, the thickness of Saiduwali section is 94 m. No fossils have been reported up to this time except plant remains.

1.4 PREVIOUS WORK:

Noetling (1901) proposed the name Warchha Group to these rocks, including "Levender clays" (previous name of Sardhai Formation).

Gee (1945) introduced the name Speckled Sandstone.

Hussain (1967) proposed the name Warchha Sandstone for the rocks, which was then approved by the Stratigraphic Committee of Pakistan, (Shah, 1977).

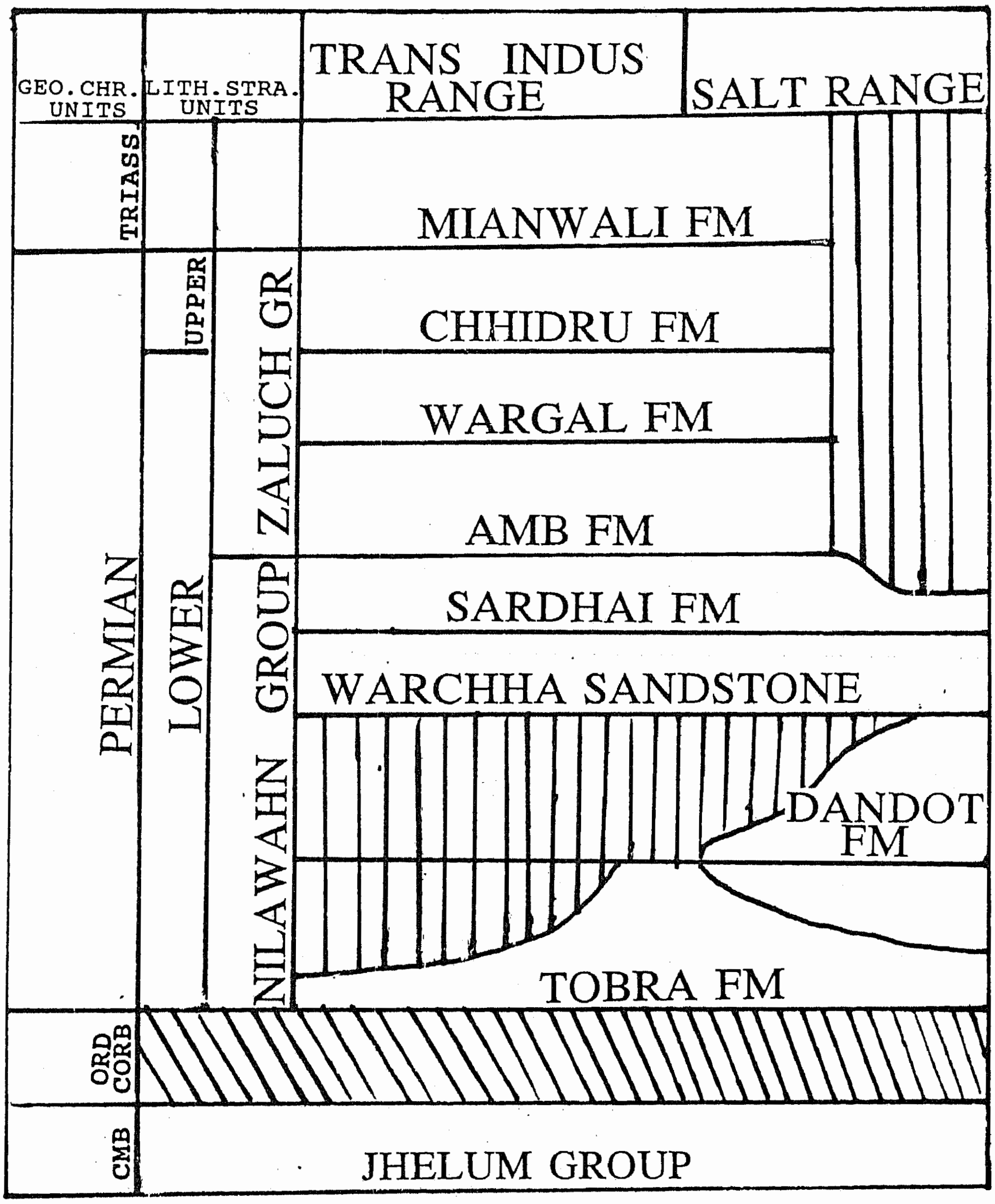

Figure 1.2

Permian stratigraphic succession in the Salt Range and Trans-Indus Ranges (After Kadri, 19 55).

No research work has been done on Warchha Sandstone except the unpublished report of Hussain (1967) which is described in Stratigraphy of Pakistan (Shah, 1977).

1.5 PRESENT WORK:

The purpose of the present study is:

i. To identify lithofacies and interpret depositional environments of the Warchha Sandstone.

ii. To determine source area and source rocks of the Warchha Sandstone.

1.6 METHOD OF STUDY:

This study is comprised of detailed field and laboratory work. In the field, three stratigraphic sections were selected on the basis of maximum thickness, and easy accessibility for detailed study. These stratigraphic sections are located widely apart and cover lateral variation in lithology and texture. The sections include, Warchha Gorge and Zaluch Nala in the Salt Range and Saiduwali Nala in the Khisor Range, Dera Ismail Khan.

The field study included, measurement of each stratigraphic section using Jacob's Staff. All field data in the form of bedforms, sedimentary structures and textural variations and samples were plotted on a graphic log. Samples were collected wherever textural and compositional variations were present. The formation at places is very coarse-grained, composed of large (cms) clasts of rock fragments. These conglomerates are poorly-cemented and weather out easily. At places clasts representing various lithologies were collected for detail petrographic studies. The field studies also included paleo-current data on cross-bedding. In total fifty five rock samples were collected for laboratory studies.

The laboratory studies comprised of preparation of thin sections for petrographic analysis. Thirty four thin sections were prepared using standard techniques. Loosely cemented samples were impregnated with epoxy before cutting thin section billets.

Detailed study of each thin section was carried out using polarizing microscope. In each thin section, textural and compositional data in the form of grain size, shape, sorting and mineralogy were collected. Visual estimates for each mineral in a thin section were determined. Point counting of 200 grains of selected thin sections were carried out to verify visual percentages. Folk (1980) and Dickinson (1985) classification were used for the classification and determination of petrofacies.

Plate 1.1 Panoramic view of Khisor Range. The cliff forming sequence along the skyline is Upper Permian carbonates. The Warchha Sandstone occur at the base of the range.

Plate 1.2 Weathered outcrop of Warchha Sandstone in the Saiduwali Section. This section is characterized by medium-grained sandstone with rare pebbly beds.

Plate 1.3 Photograph showing contact of Tobra Formation (right) with Warchha Sandstone in Zaluch Nala. Note lithological variations and colour contrast.

Plate 1.4 Gradational contact of Tobra Formation with Warchha Sandstone (right) in the Saiduwali Section, Khisor Range.

Plate 1.5 Photograph of Warchha Sandstone displaying bedforms and internal configurations of beds. Note large scale cross-bedding and grain-size variations. Hammer is 27 cm long.

CHAPTER - 2

PETROGRAPHY

The rocks of various stratigraphic sections of the Warchha Sandstone are medium to coarse grained, loosely cemented, pinkish to reddish brown in colour. In total fifty five rocks samples were collected, out of which 34 are selected for petrographic investigation. All the rocks are classified on the basis of relative abundance of framework grains like quartz, feldspar and lithic fragments.

2.1 GENERAL CHARACTERISTICS:

Detailed petrographic study of selected thin sections of rocks from the Warchha Sandstone indicates that the main framework grains present are, quartz, feldspars lithic fragments and accessory minerals in descending order. Matrix is mostly composed of both quartz and feldspars grains and in few thin sections, it is invisible due to intense cementation. Cementation has taken place mostly by carbonates or by dark reddish coloured ferogeneous materials. As sediments are derived from the weathering of minralogically complex source rocks. During the process of weathering and transportation, relatively unstable minerals are destroyed and chemically stable mineral thus increase proportionally. Quartz is a common stable mineral and feldspar is the example of unstable mineral. The processes include weathering the source area and the effects of transportation and deposition, tend to destroy the less durable and less stable component feldspars and rock fragments. With abundance of quartz, if feldspar is less than 25%, it shows the chemical or mineralogical maturity of a rock. In the rocks of Warchha Sandstone feldspars are more than 25%, (Tables 2.1 and 2.2), which indicates that the rock is compositionally immature. Textural details of the minerals are such that all the grains are subrounded to subangular in shape, the clay content in matrix is rather low and grains are moderately sorted in these thin sections. Therefore this indicates the physical or textural sub maturity of the rocks. The chemical immaturity of the rocks, specially the abundance of feldspars is related with the provenance of the rocks and indicates that the source rock was rich both in quartz and feldspars. The physical or textural sub maturity indicates the moderate effectiveness of the environment in winnowing, sorting and abrading the detritus furnished to it. This concept proposes that sediments have suffered a rather low input of mechanical energy through the abrasive and strong action of waves or currents.

2.2 FRAMEWORK GRAINS

Framework grains are:

1. Quartz.
2. Feldspar.
3. Rock fragments.
4. Accessory minerals.

QUARTZ

The most abundant mineral in these rocks is quartz. In average it is more than 55% in all the thin sections studied (Tables 2.1, 2.2 and 2.3, calculated from 2.2). The detrital modes listed in tables 2.1, 2.2,2.3 and 2.4 are based on counts of 150-200 framework grains per thin section. The maximum grains coming under definite power of microscopic field were counted and then percentage of individual quartz grains (i.e. poly and monocrystalline) were calculated. The average of Qt (Total quartz) for Zaluch Nala section is 62.4% for Saiduwali is 61.3% and for Warchha Gorge it is 36.3%. The average value of monocrystalline quartz to polycrystalline quartz ratio (Qm/Qp) in the rocks of Zaluch Nala section is 8.8, in Saiduwali it is 10.0 and in Warchha Gorge section it is 4.7, (Table 2.2), which means that Qm:Qp is upto 9:1 in Zaluch, 10:1 in Saiduwali and 5:1 in Warchha Gorge section. The quartz vary in shape from angular to subrounded and subhedral to anhedral in form. Both poly and moncrystalline quartz are present. Monocrystalline quartz exceeds the polycrystalline and show both strained and unstrained extinction (Plate 2.1 and 2.2). The average percentage of monocrystalline quartz for the rocks of Zaluch Nala section is 54.9, for Saiduwali is 56.4 and for Warchha Gorge it is 31.3. Polycrystalline quartz grains are larger in size and show strained or undulatory extinction (Plate 2.2). Its average is 7.6 percent in the rock of Zaluch Nala, section 7.2% in Saiduwali and 8.5% in the rocks of Warchha Gorge section. Some of the quartz grains require rotation of the stage for more than 5° to obtain extinction, while some others requiring less than 5°. In these rocks both the types of quartz grains are present.

Nearly all quartz grains show fracturing and inclusions. Inclusions are mostly in the form of vacuoles or minute bubbles filled with fluid are in the form of threads or needles. Sometimes in these needles like fractures, carbonate material is incorporated. Some of the quartz grains have sutured boundaries and show secondary overgrowth (Plate 2.4 and 2.5). Few grains have overgrowth but they do not interlock with other overgrowth, and show no optical continuity with parent grains, therefore they are probably recycled.

FELDSPAR:

Feldspar is the second most abundantly occurring mineral present in these rocks. The average of total feldspar (k+p) is more than 40% in all thin sections .The average of feldspar in the rocks of Zaluch nala is 33.5%, in Saiduwali section is 35.7% and in Warchha section it is 66.4% (Tables 2.1, 2.2 and 2.3). As the percentage in average is more than 25, in each thin section(except few), therefore majority of the data has been plotted in the field of arkosic sandstone (Figures 4.1 and 4.2). Both potassium feldspars and plagioclase are present but plagioclase are in lesser amount. The average of potassium feldspars is 28.0% in Saiduwali section 24.5% in Zaluch Nala and in Warchha George section it is 58.3%. Plagioclase average in Zaluch nala section is 6.1%, in Saiduwali 11.2% and in Warchha George section it is 9.1%. Ratio of potassium feldspar to plagioclase (K/P) in average is 6.5 in the rocks of Zaluch Nala section, 2.6 in Saiduwali section and 9.2 in Warchha section, (Table 2.2). It means that average ratios of k:p in the rocks of Zaluch Nala is 6:1 ,in Saiduwali Nala is 3:1 ,and in Warchha Gorge section it is 9:1. The grains are subhedral to anhedral in from and subrounded to subangular in shape. Some grains are fresh and some other are altered. Majority of fresh grains are of potassium feldspars specially orthoclase showing Carlsbad twinning and microclines show typical polysynthetic, two direction microcline twinning (Plate 2.6). In Plagiocalase, albite can be identified by typical albite twinning (Plate 2.7) and some grains show combined albite-carlsbad twinning. Some feldspars show perthitic texture (Plate 2.8) and some other grains are in intergrowth with quartz showing myrmekitic texture (Plate 2.9). Most of the grains in all thin sections are colourless but some are cloudy on account of incipient alteration. Intense alteration of feldspars has taken place in some rocks. Secricitization is very common, however alteration to kaolin and carbonate materials can also be seen in places (Plate 2.10). It is hard to tell whether Sericitization or kaolonization had occurred by hydrothermal alteration of the source rocks, during weathering, or through diagenesis. The presence of potassium feldspar grains in these thin sections indicates that the source rocks were probably acidic volcanic or plutonic, though the possibility of volcanic as a parent rock is rare because feldspar derived from volcanic rocks are fresh and show bright twinning, moreover no zoned crystal of feldspar are present in these thin sections.

ROCK FRAGMENTS:

A variety of rock fragments are present in these rocks. These rock fragments range from zero to 11.8% in these thin sections. The average percentage of these fragments in Saiduawali section is 2.5 in Warchha Gorge is 4.3 and in Zaluch Nala is 4.4. Representative coarse clasts, varying in size from 1-20 cm in diameter, of rock fragments collected from various beds in all the measured stratigraphic sections were studied separately to determine their lithological composition. These clasts represent several lithological suites indicating a complex source area.

The lithic types identified include the following groups:

i. Sedimentary; Which includes mainly yellowish to brown coloured banded quartzites, blood red jasper and siliceous siltstone. These sedimentary rock fragments are about 45% of the total clasts collected from various stratigraphic sections.

ii. Volcanic; These clasts contain mainly brownish pink welded tuff (Ignimbrite), porphyritic rhyolites and greet black dolerites. These are 40% of the total clasts.

iii. Plutonic; Plutonic group comprises the pinkish coloured granitic clasts i.e. rapakivi types granite with pinkish feldspars and banded amphibolites. These plutonic clasts are 15% of the total clasts collected.

ACCESSORY MINERALS:

Among the accessory minerals, muscovite, chert, heavy mineral, chlorite and apatite are present in these rocks (Plate 2.11). Muscovite is present in the form irregular flakes and threads in some thin sections (plate 2.12). Heavy minerals are present in the form of small dark opaque grains. Chert is the next abundant mineral which is the aggregate of small rounded well twinned and colourless grains present in the form of group of grains in few thin sections (Plate 2.13).

2.3 MATRIX AND CEMENT:

In the rocks of the Warchha Sandstone, matrix is composed of very fine grained quartz and feldspars grains. The relative abundance of matrix to cement is 85%. Due to intense alteration of feldspars, the matrix grains are cloudy or sometime invisible in few thin sections. Cement represent about 15%. In some cases the cement seems to have dissolved away leaving behind pore spaces and making grains easily disaggregateable. The dominant mineral however, is carbonate (Plate 2.14). Iron oxide (Hematite, limonite?) coating on the grains as well as cement is common throughout the sections.

Table 2.1 Percentage of each mineral.

T-Sec. No.	Qt Qp+Qm	Qm Qt-Qp	Qp Qt-Qm	F (K+P)	F(k)	F(p)	R.F	Lt=L +Qp	Chert	Mus	Ore	L = R.F+ACC.
Z1	55.5	47.2	8.3	41.6	33.3	8.3	-	11.2	-	1.45	1.45	2.9
Z2	36.3	22.7	13.6	63.7	54.7	9.0	-	13.6	-	-	-	-
Z3	63.6	59.0	4.4	35.4	35.4	-	-	5.6	-	-	1.0	1.0
Z4	58.0	50.0	8.0	41.0	37.0	4.0	-	9.0	-	-	1.0	1.0
Z5	66.6	58.3	8.3	35.4	29.1	4.3	-	8.3	-	-	-	-
Z6	38.5	27.2	11.5	57.6	46.1	11.5	3.9	15.4	-	-	-	3.9
Z7	56.0	47.0	9.0	42.0	38.0	4.0	1	11.0	-	-	1.0	2.0
Z8	50.0	43.0	7.0	39.2	25.0	14.2	10.8	17.8	-	-	-	10.8
Z9	61.4	53.8	7.6	26.8	15.3	11.5	11.8	19.4	-	-	-	11.8
Z10	67.8	64.5	3.3	28.7	27.0	1.7	3.5	6.8	-	-	-	3.5
Z11	78.4	70.6	7.8	11.7	9.8	1.9	-	17.7	-	9.9	-	17.7
Z12	66.6	60.0	6.6	22.2	20.0	2.2	2.2	13.3	4.5	4.5	-	6.7
Z13	64.0	56.0	8.0	29.0	27.0	2.0	1.0	11.0	4.0	1.0	1.0	3.0
Z14	72.5	66.6	5.9	23.5	23.5	-	1.0	8.9	1.0	2.0	-	3.0
Z15	77.7	73.3	4.4	15.5	13.3	2.2	6.8	11.2	-	-	-	6.8
Z16	64.5	61.2	3.3	32.2	25.8	6.4	2.3	6.6	-	1.0	-	3.3
Z17	60.7	52.1	8.6	26.0	17.0	9.0	-	8.6	13.3	-	-	-
S1	67.5	57.5	10.0	25.0	20.0	5.0	3.0	17.5	-	2.5	2	7.5
S2	51.2	51.2	-	41.0	28.2	12.8	-	3.8	4.0	2.0	1.8	3.8
S3	59.0	59.0	-	41.0	26.3	14.7	-	-	-	-	-	-

Table - 2.1 continue

S4	51.7	51.7	-	44.8	37.9	6.9	-	3.5	-	1.5	2.0	3.5
S5	58.0	51.6	6.4	38.7	22.6	16.1	2.0	9.7	-	-	1.3	3.3
S6	52.1	43.4	8.7	34.7	21.7	13.0	-	9.9	12.0	-	1.2	1.2
S7	68.5	62.8	5.7	25.7	11.4	14.3	-	5.7	5.8	-	-	-
S8	65.3	57.7	7.6	30.7	19.2	11.5	-	9.6	2.0	-	2.0	2.0
S9	54.8	52.5	2.3	40.4	33.3	7.1	2.5	7.1	-	1.0	1.3	4.8
W1	45.0	40.0	5.0	50.0	40.0	10.0	5.0	10.0	-	-	-	5.0
W2	37.1	31.4	5.7	62.9	57.2	5.7	-	5.7	-	-	-	-
W3	23.5	5.9	17.6	70.6	70.6	-	5.9	23.5	-	-	-	5.9
W4	-	-	-	98.0	80.0	18.0	-	2.0	-	-	-	2.0
W5	5.0	5.0	-	93.0	90.0	3.0	2.0	2.0	-	-	-	2.0
W6	35.4	29.4	6.0	64.6	58.0	5.8	-	6.0	-	-	-	-
W7	80.0	80.0	-	20.0	15.0	5.0	-	-	-	-	-	-
W8	28.0	28.0	-	72.0	55.5	16.5	-	-	-	-	-	-

Table 2.2 Data consolidated with Qm/Qp and k/p ratios.

T.Sec. No.	Qt = Qp+Qm	F = (K+P)	L = R.F+Acc	%	Qm = Qt-Qp	Qp = Qt-Qm	Lt = L+Qp	F(k+p)	%	F(k)	F(p)	Qm/Qp	K/P
Z1	55.5	41.6	2.9	100	47.2	8.3	11.2	41.6	100	33.3	8.3	5.68	4.01
Z2	36.3	63.7	-	100	22.7	13.6	13.6	63.7	100	54.7	9.0	1.66	6.07
Z3	63.6	35.4	1.0	100	59.0	4.6	5.6	35.4	100	35.4	-	12.8	-
Z4	58.0	41.0	1.0	100	50.0	8.0	9.0	41.0	100	37.0	4.0	6.2	9.25
Z5	66.6	33.4	-	100	58.3	8.3	8.3	33.4	100	29.1	4.3	7.02	6.76
Z6	38.5	57.6	3.9	100	27.0	11.5	15.4	57.6	100	46.1	11.5	2.3	4.0
Z7	56.0	42.0	2.0	100	47.0	9.0	11.0	42.0	100	38.0	4.0	5.2	9.5
Z8	50.0	39.2	10.8	100	43.0	7.0	17.8	39.2	100	25.0	14.2	6.1	1.7
Z9	61.4	26.8	11.8	100	53.8	7.6	19.4	26.8	100	15.3	11.5	7.07	1.3
Z10	67.8	28.7	3.5	100	64.5	3.3	6.8	28.7	100	27.0	1.7	19.5	15.7
Z11	78.4	11.7	9.9	100	70.6	7.8	17.7	11.7	100	9.8	1.9	9.05	5.1
Z12	71.1	22.2	6.7	100	64.0	7.1	13.8	22.2	100	20.0	2.2	9.01	9.09
Z13	68.0	29.0	3.0	100	59.5	8.5	11.5	29.0	100	27.0	2.0	7.0	13.5
Z14	73.5	23.5	3.0	100	67.5	6.0	9.0	23.5	100	23.5	-	11.2	-
Z15	77.5	15.5	6.8	100	73.3	4.4	11.2	15.5	100	13.3	2.2	16.6	6.04
Z16	64.5	32.2	3.3	100	61.3	3.3	6.6	32.2	100	25.8	6.4	18.5	4.03

Table - 2.2 continued

Z17	74.0	26.0	-	100	63.1	10.9	10.9	26.0	100	17.0	9.0	5.78	1.88
S1	67.5	25.0	7.5	100	57.5	10.0	17.5	25.0	100	20.0	5.0	5.75	4.0
S2	55.2	41.0	3.8	100	55.2	-	3.8	41.0	100	28.2	12.8	-	2.2
S3	59.0	41.0	-	100	59.0	-	-	41.0	100	26.3	14.7	-	1.78
S4	51.7	44.8	3.5	100	51.7	-	3.5	44.8	100	37.9	6.9	-	5.4
S5	58.0	38.7	3.3	100	51.6	6.4	9.7	38.7	100	22.6	16.1	8.06	1.4
S6	64.1	34.7	1.2	100	53.4	10.7	11.9	34.7	100	21.7	13.0	4.99	1.66
S7	74.3	25.7	-	100	68.1	6.2	6.2	25.7	100	11.4	14.3	10.99	0.79
S8	67.3	30.7	-	100	59.4	7.9	9.9	30.7	100	19.2	11.5	7.51	1.66
S9	54.8	40.4	4.8	100	52.5	2.3	7.1	40.4	100	33.3	7.1	22.82	4.6
W1	45.0	50.0	5.0	100	40.0	5.0	10.0	50.0	100	40.0	10.0	8.0	4.0
W2	37.1	62.9	-	100	31.4	5.7	5.7	62.9	100	57.2	5.7	5.5	10.0
W3	23.5	70.6	5.9	100	5.9	17.6	23.5	70.6	100	70.6	-	0.33	-
W4	-	98.0	2.0	100	-	-	2.0	98.0	100	80.0	18.0	-	4.4
W5	5.0	93.0	2.0	100	5.0	-	2.0	93.0	100	90.0	3.0	-	30.0
W6	35.4	64.6	-	100	29.4	6.0	6.0	64.6	100	58.8	5.8	4.9	10.1
W7	80.0	20.0	-	100	80.0	-	-	20.0	100	15.0	5.0	-	3.0
W8	28.0	72.0	-	100	28.0	-	-	72.0	100	55.5	16.5	-	3.36

Table 2.3 Final data for plating. Assessories are added to lithic fragments (L) and total lithic fragments, (Lt). Chert is added to Qt,Qm,Qp.

T.Sec. No.	Qt = Qp+Qm	F = (K+P)	L = R.F+Acc	%	Qm = Qt-Qp	Qp = Qt-Qm	Lt = L+Qp	F(k+p)	%
Z1	55.5	41.6	2.9	100	47.2	8.3	11.2	41.6	100
Z2	36.3	63.7	-	100	22.7	13.6	13.6	63.7	100
Z3	63.6	35.4	1.0	100	59.0	4.6	5.6	35.4	100
Z4	58.0	41.0	1.0	100	50.0	8.0	9.0	41.0	100
Z5	66.6	33.4	-	100	58.3	8.3	8.3	33.4	100
Z6	38.5	57.6	3.9	100	27.0	11.5	15.4	57.6	100
Z7	56.0	42.0	2.0	100	47.0	9.0	11.0	42.0	100
Z8	50.0	39.2	10.8	100	43.0	7.0	17.8	39.2	100
Z9	61.4	26.8	11.8	100	53.8	7.6	19.4	26.8	100
Z10	67.8	28.7	3.5	100	64.5	3.3	6.8	28.7	100
Z11	78.4	11.7	9.9	100	70.6	7.8	17.7	11.7	100
Z12	71.1	22.2	6.7	100	64.0	7.1	13.8	22.2	100
Z13	68.0	29.0	3.0	100	59.5	8.5	11.5	29.0	100
Z14	73.5	23.5	3.0	100	67.5	6.0	9.0	23.5	100
Z15	77.5	15.5	6.8	100	73.3	4.4	11.2	15.5	100
Z16	64.5	32.2	3.3	100	61.3	3.3	6.6	32.2	100

Table - 2.3 continued

Z17	74.0	26.0	-	100	63.1	10.9	10.9	26.0	100
S1	67.5	25.0	7.5	100	57.5	10.0	17.5	25.0	100
S2	55.2	41.0	3.8	100	55.2	-	3.8	41.0	100
S3	59.0	41.0	-	100	59.0	-	-	41.0	100
S4	51.7	44.8	3.5	100	51.7	-	3.5	44.8	100
S5	58.0	38.7	3.3	100	51.6	6.4	9.7	38.7	100
S6	64.1	34.7	1.2	100	53.4	10.7	11.9	34.7	100
S7	74.3	25.7	-	100	68.1	6.2	6.2	25.7	100
S8	67.3	30.7	-	100	59.4	7.9	9.9	30.7	100
S9	54.8	40.4	4.8	100	52.5	2.3	7.1	40.4	100
W1	45.0	50.0	5.0	100	40.0	5.0	10.0	50.0	100
W2	37.1	62.9	-	100	31.4	5.7	5.7	62.9	100
W3	23.5	70.6	5.9	100	5.9	17.6	23.5	70.6	100
W4	-	98.0	2.0	100	-	-	2.0	98.0	100
W5	5.0	93.0	2.0	100	5.0	-	2.0	93.0	100
W6	35.4	64.6	-	100	29.4	6.0	6.0	64.6	100
W7	80.0	20.0	-	100	80.0	-	-	20.0	100
W8	28.0	72.0	-	100	28.0	-	-	72.0	100

Table - 2.4 In Qm. F, Lt, Value of Lt is omitted and in the remaining total, percentage of Qm, K and P (PLAG) is calculated for QmPK triangular diagram.

T.Sc. No.	Qm	F(K)	K(p)	Lt	%	Qm+K+P	Qm	F(K)	K(p)	%
Z1	47.2	33.3	8.3	11.2	100	88.8	53.1	37.5	9.4	100
Z2	22.7	54.7	9.0	13.6	100	86.4	26.7	63.3	10.0	100
Z3	59.0	35.4	-	5.6	100	94.4	62.5	37.5	-	100
Z4	50.0	37.0	4.0	9.0	100	91.0	54.9	40.6	4.5	100
Z5	58.3	29.1	4.3	8.3	100	91.7	63.5	31.7	4.8	100
Z6	27.0	46.1	11.5	15.4	100	84.6	31.9	54.4	13.7	100
Z7	47.0	38.0	4.0	11.0	100	89.0	52.8	42.7	4.5	100
Z8	43.0	25.0	14.2	17.8	100	82.2	52.3	30.4	17.3	100
Z9	53.8	15.3	11.5	19.4	100	80.6	66.7	18.9	14.4	100
Z10	64.5	27.0	1.7	6.8	100	93.2	69.2	28.9	1.9	100
Z11	70.6	9.8	1.9	17.7	100	82.3	85.0	12.0	3.0	100
Z12	64.0	20.0	2.2	13.8	100	86.2	74.2	23.2	2.6	100
Z13	59.5	27.0	2.0	11.5	100	88.5	67.2	30.5	2.3	100
Z14	67.5	23.5	-	9.0	100	91.0	74.1	25.9	-	100
Z15	73.3	13.3	2.2	11.2	100	88.8	82.4	14.9	2.7	100
Z16	61.3	25.8	6.4	6.6	100	93.4	65.5	27.6	6.9	100

Table - 2.4 continued

Z17	63.1	17.0	9.0	10.9	100	89.1	70.8	19.0	10.2	100
S1	57.5	20.0	5.0	17.5	100	82.5	69.6	24.2	6.2	100
S2	55.2	28.2	12.8	3.8	100	96.2	57.3	29.3	13.4	100
S3	59.0	26.3	14.7	-	100	100	59.0	26.3	14.7	100
S4	51.7	37.9	6.9	3.5	100	96.5	53.5	39.2	7.3	100
S5	51.6	22.6	16.1	9.7	100	90.3	57.1	25.0	17.9	100
S6	53.4	21.7	13.0	11.9	100	88.1	60.6	24.6	14.8	100
S7	68.1	11.4	14.3	6.2	100	93.8	72.6	12.2	15.2	100
S8	59.4	19.2	11.5	9.9	100	90.1	65.9	21.3	12.8	100
S9	52.5	33.3	7.1	7.1	100	92.9	56.4	35.8	7.7	100
W1	40.0	40.0	10.0	10.0	100	90.0	44.4	44.4	11.2	100
W2	31.4	57.2	5.7	5.7	100	94.3	33.2	60.6	6.2	100
W3	5.9	70.6	-	23.5	100	76.5	7.7	92.2	-	100
W4	-	80.0	18.0	2.0	100	98.0	-	81.6	18.4	100
W5	5.0	90.0	3.0	2.0	100	98.0	5.1	91.8	3.1	100
W6	29.4	58.8	5.8	6.0	100	94.0	31.3	62.5	6.2	100
W7	80.0	15.0	5.0	-	100	100	80.0	15.5	5.0	100
W8	28.0	55.5	16.5	-	100	100	28.0	55.5	16.5	100

Plate 2.1 Photomicrograph of a monocrystalline quartz grain with carbonate cement. (S6) Mag. x 10 (Crossed nicols).

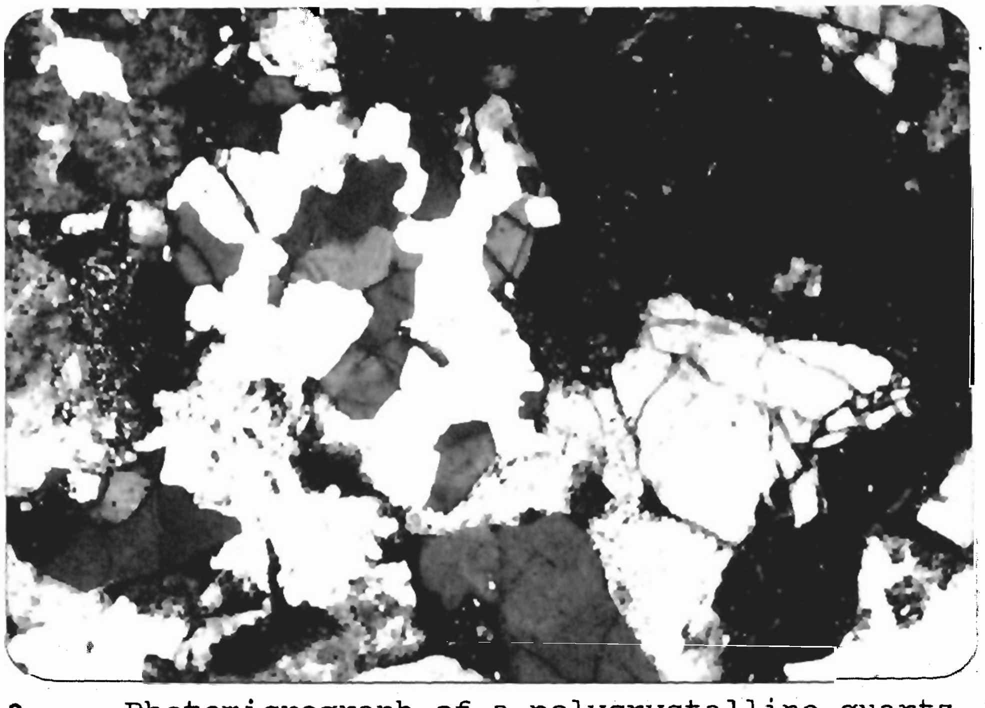

Plate 2.2 Photomicrograph of a polycrystalline quartz grain exhibiting undulatory extinction (W3) Mag. x 4 (Crossed nicols).

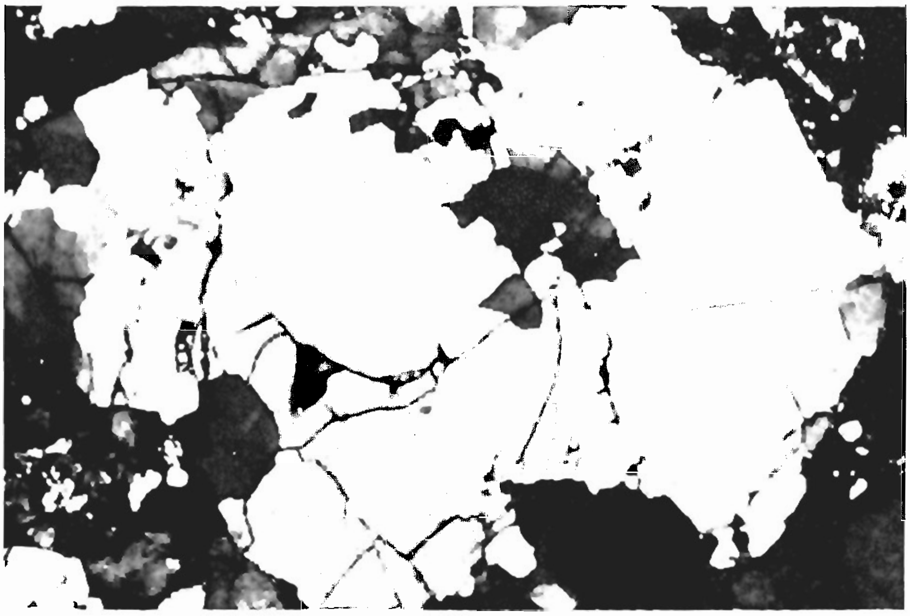

Plate 2.3 Photomicrograph of a large polycrystalline quartz grain with fractures and strained extinction. (S9) Mag. x 4 (Crossed nicols).

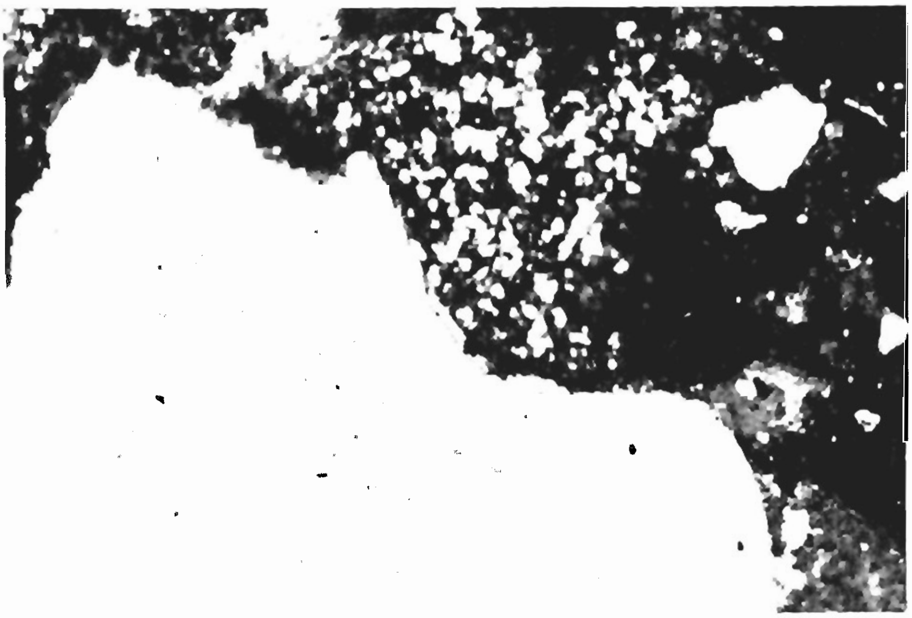

Plate 2.4 Photomicrograph of a sutured boundried quartz with small chert grains. (S8) Mag. x 10 (Crossed nicols).

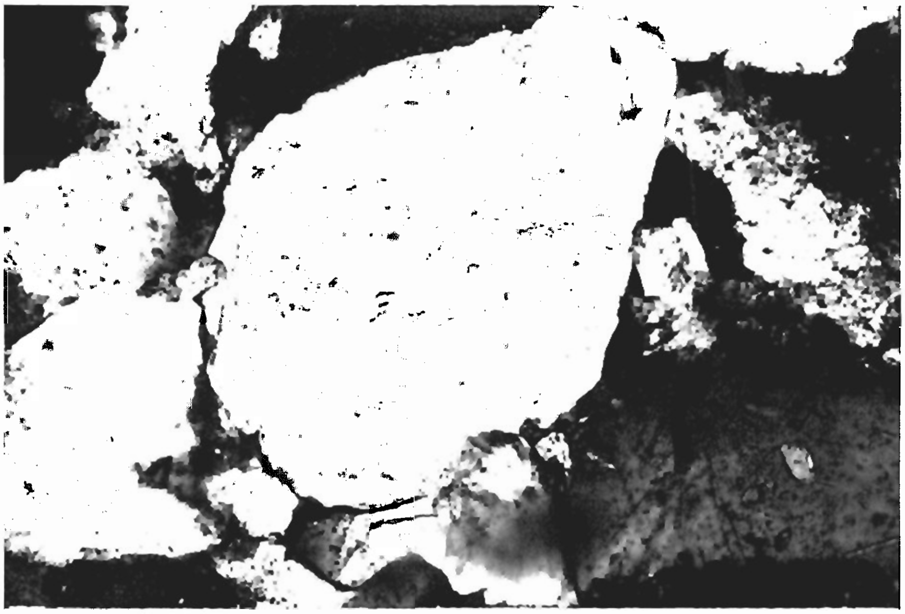

Plate 2.5 Photomicrograph of a sutured boundried quartz showing secondary overgrowth (S6) Mag. x 4 (Cross nicols).

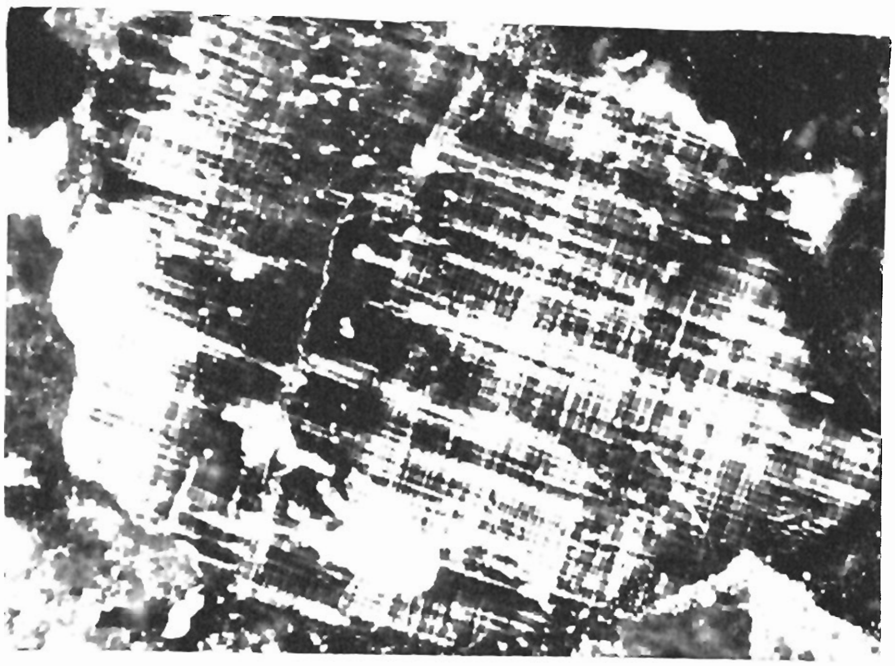

Plate 2.6 Photomicrograph of a large feldspar grain exhibiting typical microcline twinning.(S8) Mag. x 10 (Crossed nicols).

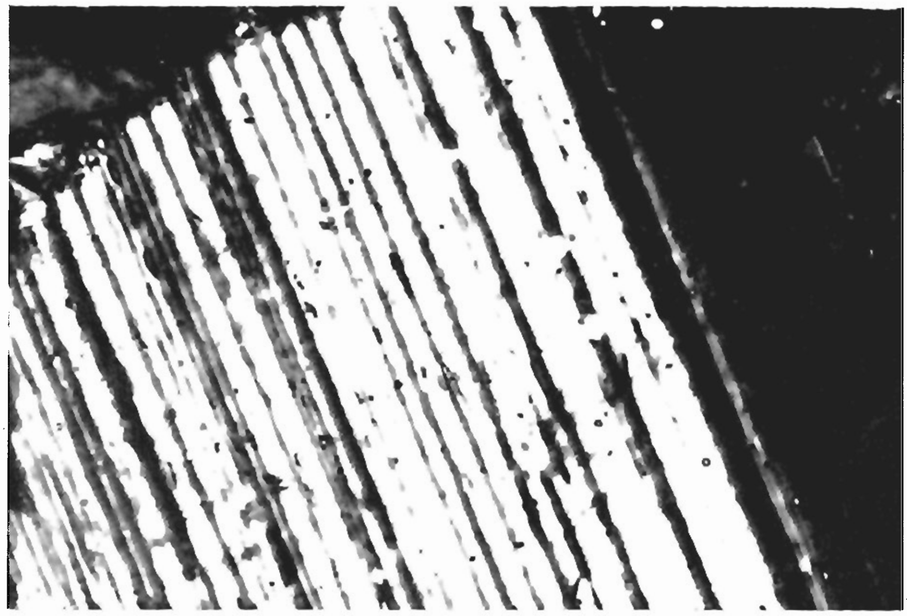

Plate 2.7 Photomicrograph of a feldspar grain, showing typical albite twinning. (W1) Mag. x 10 (Crossed nicols).

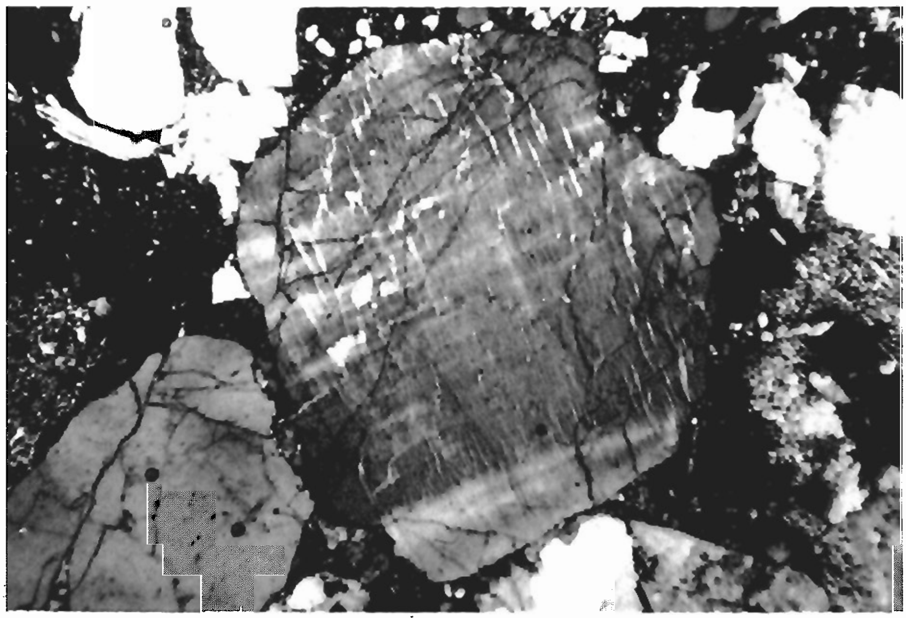

Plate 2.8 Photomicrograph of perthitic feldspar. (S6) Mag. x 4 (Crossed nicols).

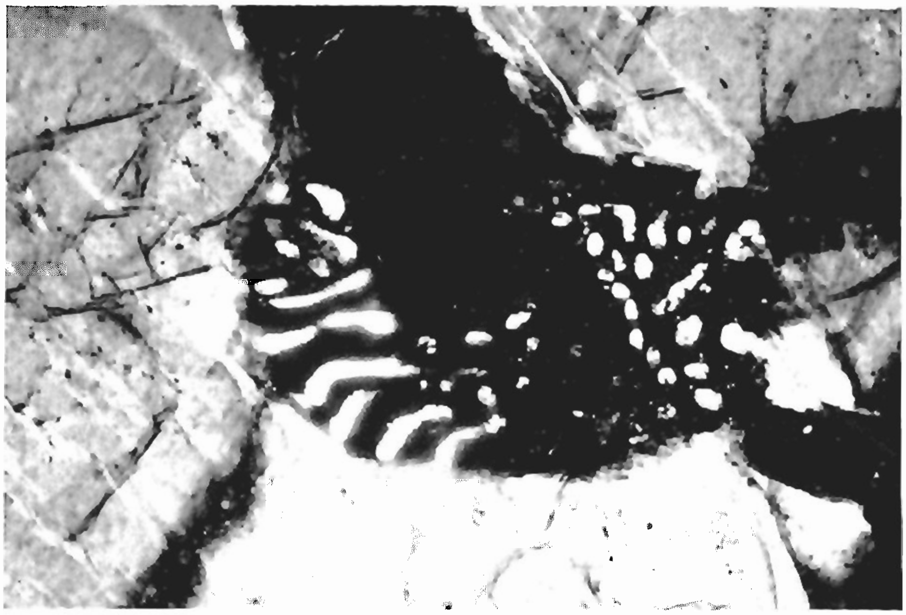

Plate 2.9 Photomicrograph of a typical myrmekitic texture of feldspar grain showing vermicular intergrowth with quartz (S7) Mag. x 10 (Crossed nicols).

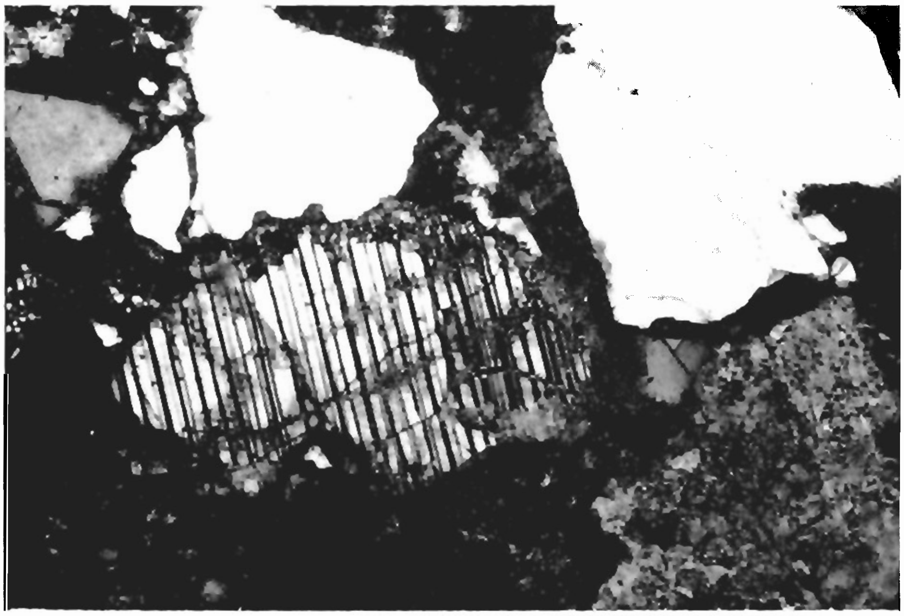

Plate 2.10 Photomicrograph of a plagioclase grain in which alteration to carbonates is going on. (S5) Mag. x 4 (Crossed nicols).

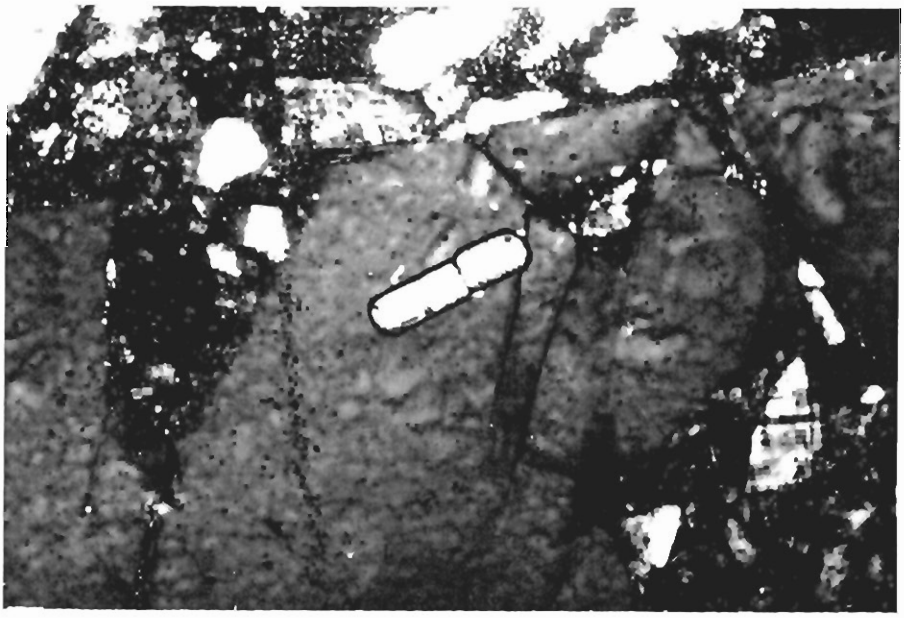

Plate 2.11 Photomicrograph of an apatite grain. In the background a large fractured quartz grain can be seen. (S6) Mag. x 10 (Crossed nicols).

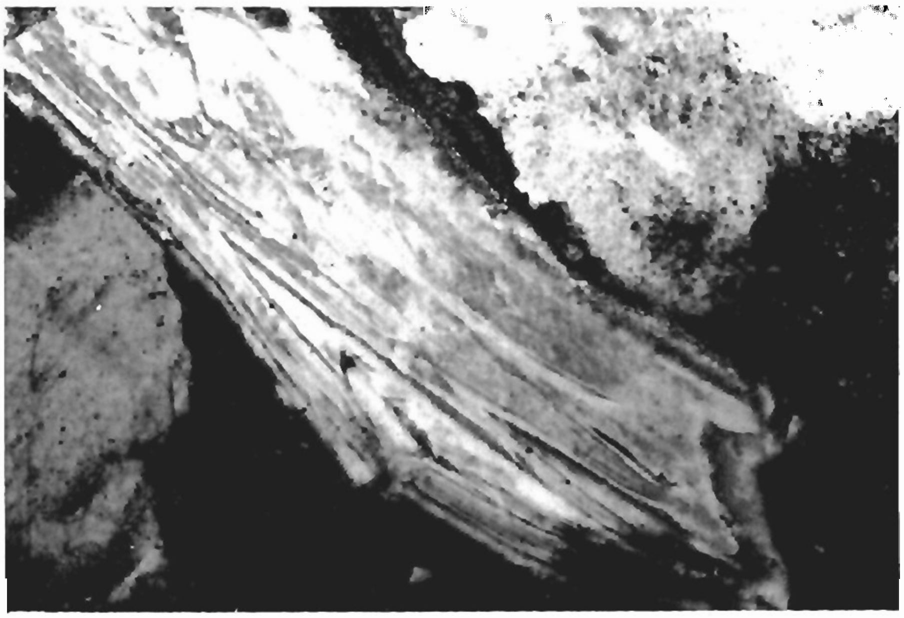

Plate 2.12 Photomicrograph of a muscovite flake. (Z1) Mag. x 10 (Crossed nicols).

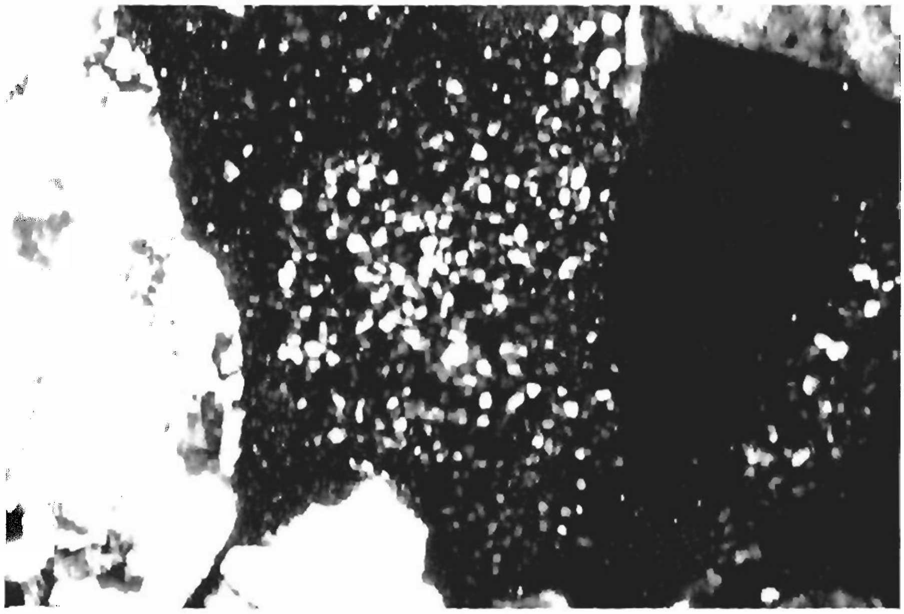

Plate 2.13 Photomicrograph of chert, present in the form of a group of small rounded grains. (S7) Mag. x 10 (Crossed nicols).

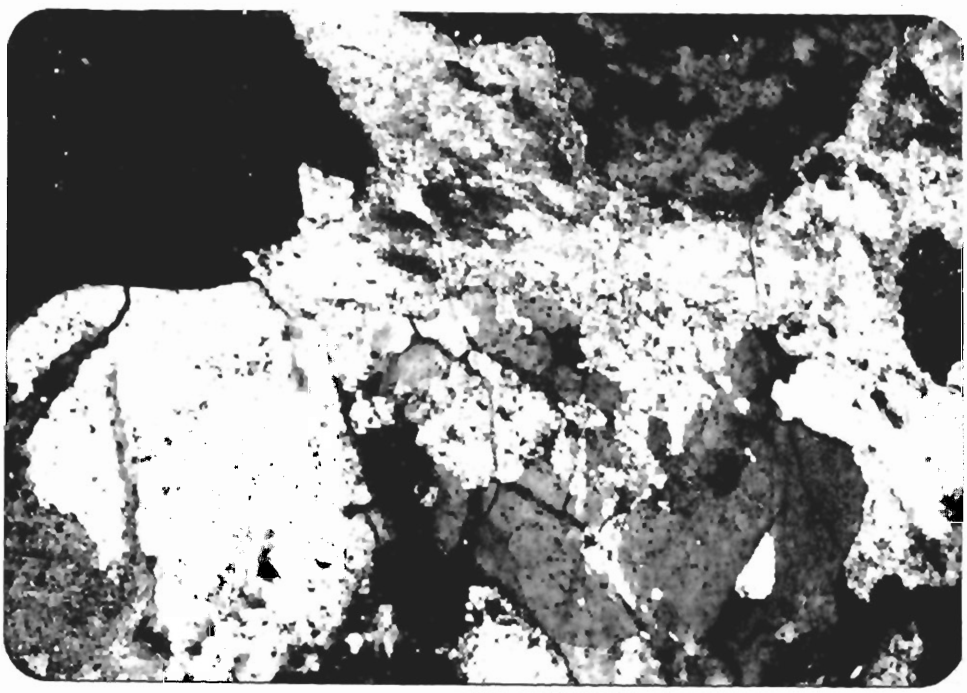

Plate 2.14 Photomicrograph of carbonate cementation. (W1) Mag. x 10 (Crossed nicols).

CHAPTER - 3

LITHOFACIES AND ENVIRONMENTAL INTERPRETATION

A detailed field and laboratory studies of the Warchha Sandstone in the Salt Range and Khisor Range has revealed that the formation is composed of varied lithology, characterized by several sedimentary structures and bedforms. On the basis of field, textural and structural features, six lithofacies are recognized in the Warchha Sandstone. These facies range in thickness from 20 cm to 3.5 meters and are marked by repetition in all the described stratigraphic sections (Figure 3.1). In general, the Salt Range Section are dominated by relatively coarse grained fabric whereas, the Khisor Range Section predominantly displays medium-grained sandstones.

3.1 TROUGH CROSS BEDDED PEBBLY SANDSTONE LITHOFACIES:

This lithofacies is typically characterized by small to large scale trough cross beds within pebbly sandstones (Plate 3.1). The sandstones are texturally and compositionally immature. The dominant lithology is arkosic sandstone. The rocks are pink to yellowish brown to brick red in colour. This colouration is due to different degrees of oxidation of iron bearing minerals. The grain size vary from few mm to silt and sand size to clasts of several centimeter in diameter. The medium as well as the coarse fraction of these sandstone is generally poorly sorted and characterized by angular to subangular grains of various shape. The ratio of feldspar ,quartz and lithic fragments as well as grain size varies between beds. The lithic fragments include clasts of volcanic, igneous and recycled sediment. The thickness of the individual beds is 15 to 100 cm. The bounding surface of almost each trough is uniquely marked by pebble to cobble size clasts of several lithologies (Plate 3.2). The trough coarse bedded pebbly sandstone facies constitute about 1/3 rd of the formation in all the measured sections and occur in several, vertically repeated packages varying from 1.5 to 3.5 m in thickness.

3.2 PEBBLY SANDSTONE/CONGLOMERATE LITHOFACIES:

The pebbly sandstone/conglomerate lithofacies is the most distinct lithology of the Warchha Sandstone. The lithofacies is marked by poorly sorted, angular to subangular, coarse sandstone with intercalations or discontinuous layers of matrix-supported conglomerates. (Plate 3.3). This lithofacies characteristically display sharp base with the underlying beds and have wavy upper contact with the overlying beds. The concentration of large clasts at the top of each bed is a typical feature of this lithofacies (Plate 3.4). The thickness of individual bed within the lithofacies vary from 30 cm to 2.5 m. The lower contact of this lithofacies is marked by conglomeratic layer (Plate 3.5).

The textural and mineralogical composition of the rocks is generally the same as other lithofacies. Some beds however, display reddish colour due to abundance of clasts of pink granite (Plate 3.6). Except for greater abundance of coarse clasts (Pebble to Cobble size,Plate 3.7) and fine to medium-grained matrix, the rocks generally lie in the area of arkose on QFL plot.

3.3 CROSS BEDDED SANDSTONE LITHOFACIES:

This lithofacies is characterized by multiple sets of low angle small to large scale planar cross beds within fine grained sandstone (Plate 3.8) to medium (Plate 3.9) to pebbly sandstone (Plate 3.10). The rocks of this lithofacies are typically red in colour and occur in beds of 20 cm to 50 cm thick. Eventhough a wide range of grain sizes are present, the lithofacies is dominated by fine to medium sandstone. The overall sorting of grains is moderate with relatively few size classes as compared to general size variations within the Warchha Sandstones. The cross bed occur in several sets with some sets sharply truncated. It is the least abundant lithofacies in the Warchha Gorge section.

3.4 CLAY/SILTSTONE LITHOFACIES:

The clay/siltstone lithofacies is characterized by thin layers (few cm) to 50 cm thick beds. The lithology is dominantly red clays with silty intercalations but dark gray to black carbonaceous clays are also present in Zaluch and Saiduwali Sections. The beds lack internal organization and no sedimentary structures are discernible (Plate 3.11).

3.5 MASSIVE SANDSTONE LITHOFACIES:

The massive sandstone lithofacies occur in all the measured stratigraphic sections and is named on the basis of its total lack of discernible sedimentary structures (Plate 3.12). The sandstones are classified as arkose and are typically loosely cemented and disaggregate easily. The grain size variation are generally common with fine - medium and coarse-grained types. The lithic fraction of the rocks are dominated by a mix of wide variety of grain and clast compositions. The grains are angular to subangular.

3.6 FAINTLY LAMINATED TO LAMINATED SANDSTONE LITHOFACIES:

This lithofacies include beds with marked planar laminations (Plate 3.13) and faintly laminated beds where laminations are not clearly visible. In some cases the lamination may be present but their lateral continuity within the bed is not discernible. The rocks of this lithofacies are deep red in colour with yellowish to whitish irregular bands, displaying different degrees of oxidation. The beds in this lithofacies are relatively hard and intact. The laminated beds show planer 1-3 cm thick laterally continuous layers. The rocks are classified as arkose and are poor to moderately sorted with angular to subrounded grains. The typical feature of this lithofacies is the total absence of pebble-size clasts.

3.7 ENVIRONMENTAL INTERPRETATION:

The Warchha Sandstone is typically characterized by a unique set of features that has made its environmental interpretation relatively straightforward. These features include lack of carbonates, evaporite and fossils and presence of poorly sorted, texturally and compositionally immature sediments, angular to subangular grains and unidirected paleoflow. On the basis of these overall diagnostic criteria, the Warchha Sandstone is interpreted as alluvial fan deposit. While majority of the criteria support sediment deposition in an arid to semi-humid alluvial fan setting, the interpretation is not conclusive as this study is based on only three stratigraphic sections and the entire fan geometry can not be established. However, a unique lithology, sedimentary structures, debris flow units and typically red colour of the sediments strongly favour this interpretation (Nilsen, 1982).

The alluvial fan is a complex sedimentary environment which shares features with other alluvial settings. The development of a fan as well as stacking of fans is dependent upon, rate of sediment supply, uplift of the source area, movement along gravity faults and climatic conditions (Bull, 1972; Nilsen, 1982; Reading, 1986). The catastrophic flow are generally climatically controlled as is evident in modern alluvial fan and is regarded as the main cause of cyclicity within an alluvial fan. The Warchha alluvial fan show episodic sedimentation in the form of multiple debris flow units. The angularity of grains and poor sorting reflect nearby source area. The erosional contact of the formation with the Tobra Formation and similarities in grain composition show that the Tobra Formation represent a dissected river geomorphic area that ultimately provide paleoslope as well as sediment for Warchha alluvial fan.

3.8 RED COLOURATION OF BEDS:

During the field study it was noted that majority of beds in Warchha Sandstone were of deep red and reddish-brown colour (Plate 3.14). Most authors assume that the staining pigment of red beds is very fine-grained, uniformly dispersed hematite (Fe_2O_3), whereas hematite concentrated in large crystal or at certain spots does not cause red colour. Moreover, it is also believed that the red colour is produced by the special optical behaviour of tiny hematite clusters. The red colour of sandstone is caused by grains coating containing hematite. The hematite content required to generate red staining of clays and silts may be even less than 1% . Reddish coloured top layers of sandstones may also be caused by mechanical infiltration of detrital clay. It is also believed that oxidizing conditions within a sediment can be maintained for a long time when little or no organic matter or reducing pore waters are available to reduce the ferric to ferroan ion. Thus the Warchha Sandstone maintained its red colouration as the reducing agents like fossils and /or organic matters have not been reported so far.

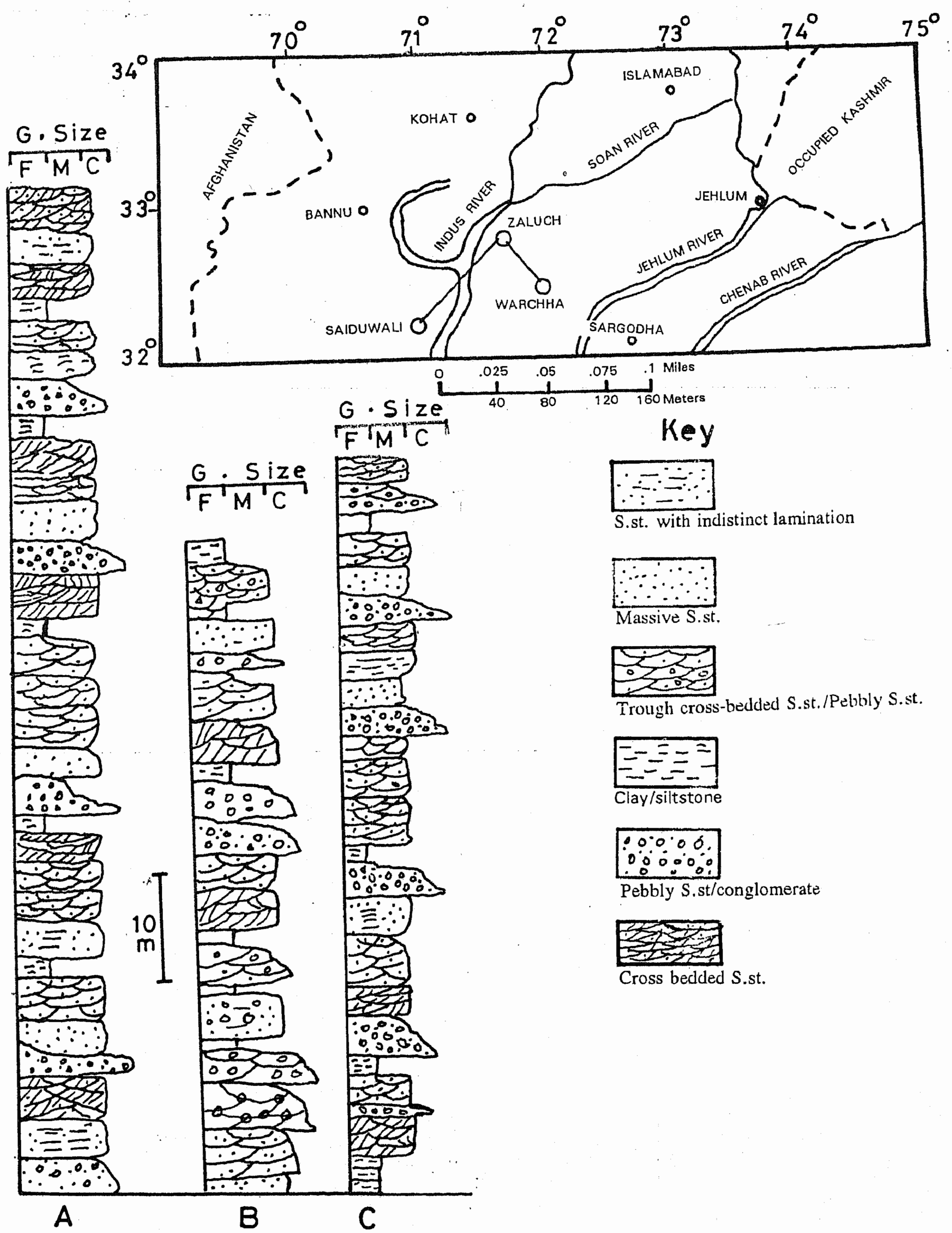

Figure 3.1 Graphic logs of Warchha Sandstone, Saiduwali (A) Khesor Range, Zaluch Nala (B) and Warchha Gorge (C) Salt Range.

Plate 3.1 Photogrpahs showing cross-bedding in Warchha Sandstone. Hammer is 27 cm long.

Plate 3.2 Same trough cross beds as above. Note pebble and cobble size clasts in pebbly sandstone.

Plate 3.3 Pebbly sandstone mixed with conglomeratic layers. The scale is 14 cm in length.

Plate 3.4 Photograph showing close up of weather surface of Warchha Sandstone. The conglomerate is characterized by matrix-to clasts-supported fabric, predominance of volcanic and plutonic clasts. Pencil is 15 cm in length.

Plate 3.5 Close-up photograph showing one of the conglomeratic bed with in Warchha Sandstone. Note medium grained cross bedded sandstone overlain by conglomerate of heterogeneous lithoclasts. Hammer is 27 cm long.

Plate 3.6 Photograph showing irregular layers of pebbles (clasts of pink granite) in coarse sandstone. Hammer is 27 cm long.

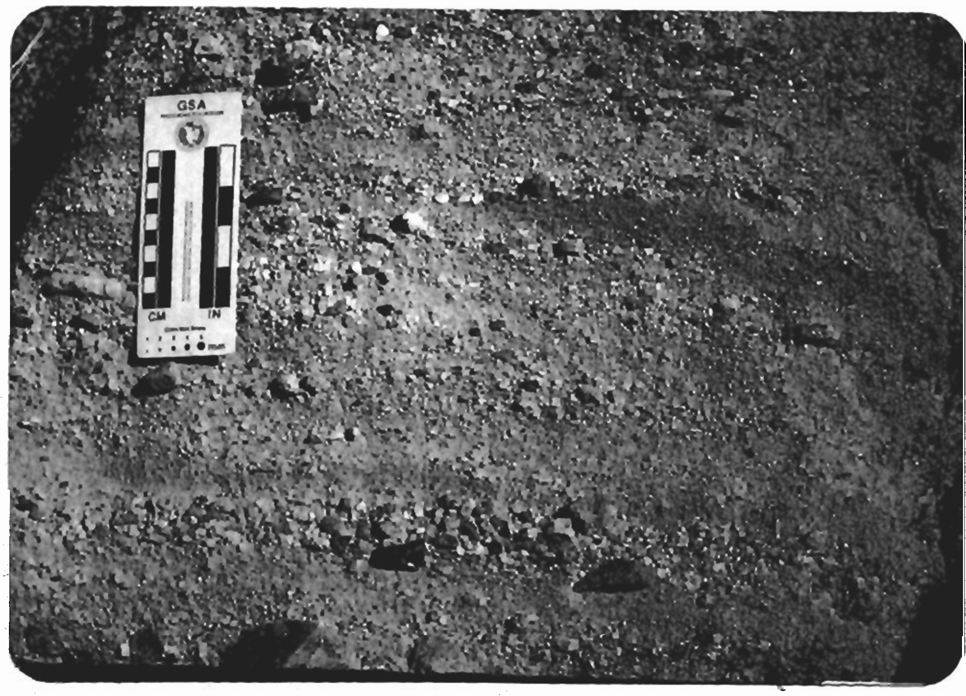

Plate 3.7 Photograph showing weathering surface of Warchha Sandstone. Note poor sorting, variation in grain sizes and composition. Scale is 14 cm in length.

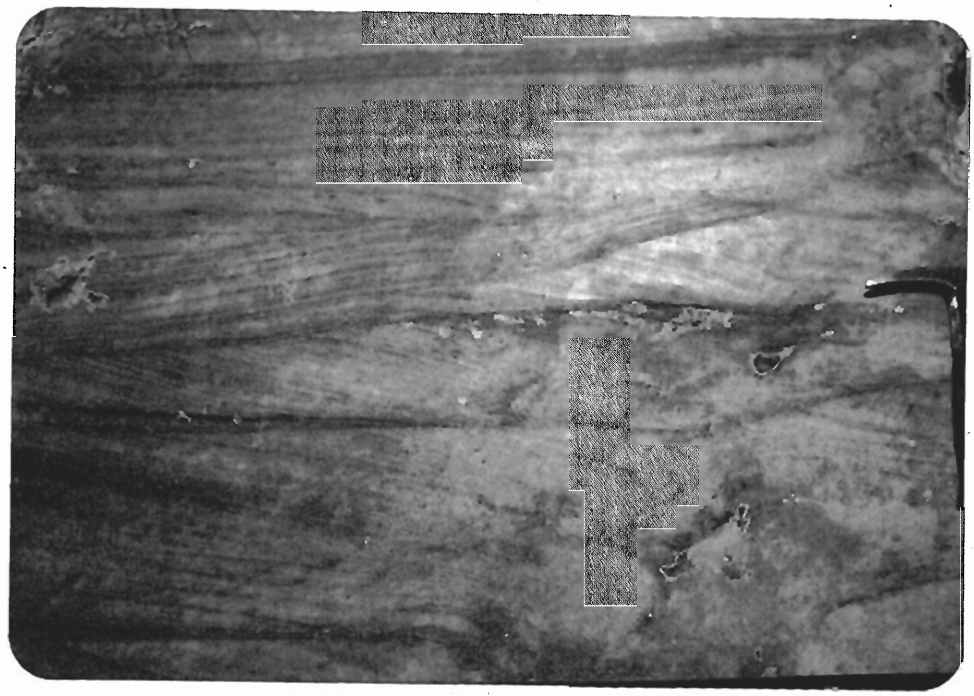

Plate 3.8 Photograph showing cross-bedding within fine grained sandstone.

Plate 3.9 Same cross-bedding as in plate 3.8, but in comparatively medium grained sandstone.

Plate 3.10 Photographs showing large scale cross bedding in Warchha sandstone. Note coarse-grained layers of sandstone. Hammer is 27 cm long.

Plate 3.11 Exposures of carbonaceous clays within highly weathered Warchha Sandstone in the Zaluch Nala section. Hammer is 27 cm long.

Plate 3.12 Photograph of Warchha Sandstone in Warchha Gorge Salt Range. Note prominent red colour, thick-bedded, massive sandstone.

Plate 3.13 Thick bedded, light red colour sandstone, characterized by cross-bedding.

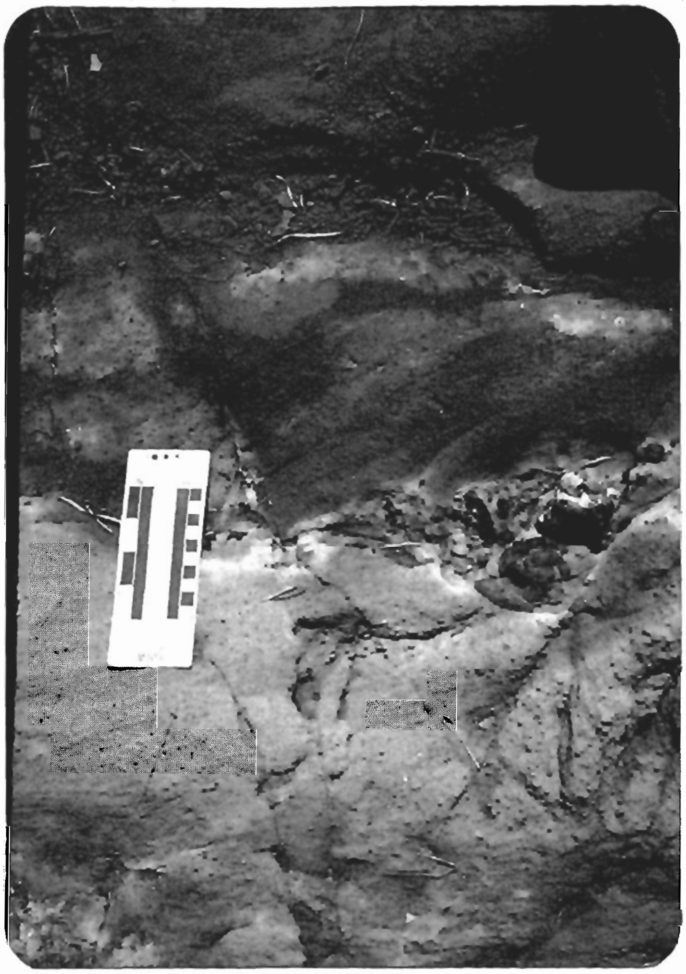

Plate 3.14 Photograph showing oxidized ironconcentrations along the wavy bedding plane. Note scattered centimeter-sized concretions in the upper reddish colour beds. Scale is 14 cm in length.

CHAPTER - 4

PROVENANCE

4.1 INTRODUCTION:

The word provenance has been derived from the French word "Provenir" and the Latin word "proveniens" meaning origin or the place where produced. In sedimentary petrology, provenance refers specifically to the nature, composition, identity and dimensions of source rocks, relief and climate in the source area. It also includes a transportation factor which is mostly understood to convey a sense of the distance and rigour of transport of sediments until deposition (Suttner, 1974). In other words, provenance is a combined term for source rock, relief, climate and transportation. The objective of provenance study is to work out the paleogeology of the Warchha Sandstone on the basis of quantitative study of mineral suites.

For this purpose point-count data are plotted on various QFL triangular diagrams of Folk and Dickinson. In the first two diagrams (Figures 4.1 to 4.2) the rock type is identified and it can be seen that the data occupy the field of arkosic sandstone. The remaining (Figures 4.3-4.7) are the QFL provenance discrimination diagrams of

Dickinson et al., (1983) which differentiate between various provenance fields of sandstone. These diagrams are discussed below separately.

4.2 CLASSIFICATION OF SANDSTONE:

The petrographic data is plotted in Folk's sandstone classification diagram (1980), it can be seen that except two or three samples, all the data comes under the field of arkosic sandstone (Figure 4.1). In point count data, the upper limit of quartz is up to 78% and the lower limit at least, in one sample is zero. Feldspars in one sample is 98% but generally it is between the range of 60 and 25%. Arkose in the literature is a controversial subject. There has been no general agreement on how little feldspar a sandstone can contain and still be designated arkose. Allen (1936) placed at the lower limit of feldspars 25 percent, Krynine once suggested 30 percent (1940) but (1948) proposed 25 percent. Pettijohn (1949, p.227) accepted 25 percent as the lower limit and proposed to restrict the term feldspathic sandstone to those sandstone with 10 to 25 percent (Of their detrital fraction). The term subarkose was then applied to this group of sandstones. Arkose has been redefined (Pettijohn 1954) as a sandstone characterized by 25 or more percent of labile constituents (Feldspars and rock fragments) of which feldspars form, one-half or more. By this definition arkose might contain as little as 12.5 percent feldspar. These definitions of arkose still fail to discriminate between true arkoses and the feldspathic graywackes which contain over 25 percent feldspar. Pettijohn and others described that in general, arkose is indeed derived by disintegration of granitic rocks and it is rich in potassium feldspar, while the feldspar of graywackes is sodium feldspars. Moreover graywackes are comparatively rich in rock fragments. Another compositional difference is that the matrix of graywacke is chloritic whereas in arkosic wacke the interstitial clay is kaolinitic and commonly red in colour.

In the light of the above discussion it is evident that in the Folk's classifications diagram (Figure 4.1), majority of the rock sample plot in the field of arkosic sandstone having upto 25% feldspars and lithic fragments less than 10%. One of the point counts data plots in the field of impure arkosic and five in the field of subarkosic. This minor deviation is probably the result of analytical (i.e. point counting) error. Similarly in the sandstone classification after Folk (1980) in figure 4.2, again the whole data come under the field of arkose. According to this classification in the arkosic field feldspars are up to 25% and lithic fragments, are less than 10%. Above 10% lithic fragments, the field area of lithic arkose starts in which only one point count is plotted. If the feldspars become less than 25% the subarkose field starts in which four point counts of the total data are plotted. According to these two triangular diagrams, the rocks of the Warchha Sandstone belongs to pure arkosic nature in which lithic fragments are less than 10% and with abundance of quartz, feldspar is above 25% in all thin sections.

4.3 PROVENANCE DISCRIMINATION DIAGRAMS:

Point-count data are plotted on QFL provenance-discrimination diagrams of Dickinson et al. (1983) in figures 4.3 to 4.7. The triangular diagram having $QmFL_t$ shows emphasis on source rock, QtFL is indicative of maturity, and emphasis on mineral grains is shown in QmPk diagram. Figures 4.3 and 4.4 show provisional compositional fields indicative of sand derivation from different types of provenance (Dickinson et al. 1983). Figures 4.5, 4.6 and 4.7 show the actual reported distribution of mean detrital modes for sandstone suites derived from different types of provenance plotted on standard triangular diagrams, after Dickinson and Suczek (1979) and modified by Dickinson, (1982, et al). Symbols for grain types are such that Qt is total quartz grains (Qm+Qp), where Qm is monocrystalline and Qp is polycrstalline quartz. F is the total feldspars which is the sum of plagioclase and potassium feldspars. L is the lithic fragments which represent the actual rock fragments plus accessory minerals. Lt is the total lithic fragments which is the sum of L and Qp. All the data occupy the field of continental block provenance. The continental block provenance includes two subfields, the stable craton and basement uplift. Majority of data plot in stable craton subfield of continental block provenance. Few samples come under the field of basement uplift, in figure 4.3, (QtFL triangular diagram). Three or four point count, plot in the field of recycled orogen provenance but there is no single point count coming in the field of magmatic arc provenance. According to Dickinson (1985) the tectonic setting of stable craton field is either continental interior or passive platform. The characteristics of derivative sand composition from this type of tectonic setting is such that it is always quartz rich with high Qm/Qp and K/P ratios. Similarly in basement uplift, the tectonic setting is rift shoulder or transform rupture (Dickinson 1985). The quartzo-feldspathic sand is low in total lithic fragments, same high K/P ratio and rich in total quartz compared to feldspar. As in figure 4.3 the data plotted in stable craton sub field of continental block provenance show high quartz content (Upto 77% Q) and low lithic fragments content. Few point count, which are high in quartz but having lithic fragment content more than six or seven percent, come under the field of recycled orogen provenance. These few point count may be due to analytical error because majority of samples strictly occupy the field of single continental block provenance. In figure 4.4 (QmFLt diagram) there is no deviation from continental block provenance and all the data has been plotted in both sub fields of the same provenance. On the basis of these two triangular diagrams (Figures 4.3 & 4.4) it is evident that the source of Warchha Sandstone is continental block provenance. Majority of the rocks fall under the subfield of stable craton, the tectonic setting of which is continental interior or passive platform.

In figures 4.5 and 4.6 the data is plotted on standard triangular diagrams, after Dickinson and Suczek (1979) as modified by Dickinson et al. (1982). In figure 4.5, the ratio between Qt (Total quartz) feldspars, and lithic fragments is such that majority of point counts again occupy the field of continental block provenance. In figure 4.5 few samples are out of the field and two come under recycled orogen provenance. In figures 4.5 and 4.6, upto seven point counts are out of field, one comes under the field of recycled orogen provenance and three point counts plot between the area of all three provenances. This minor deviation from continental block provenance is either analytical error or perhaps the three point counts coming in the central part between the fields of these three provenances show multiple sources and complex paleotectonic and paleogeographic relationships to the basin. Moreover the point count data plotted in these two diagrams (Figures 4.5 & 4.6) show and follow to some extent the maturity decreasing trend. As the feldspars content increases, the ratio of Q/F decreases and the chemical maturity of the framework grains is decreasing. Figure 4.7 is the QmPK triangular diagram (Shows emphases on mineral grains) after Dickinson and Suczak (1979) and modified by Dickinson et al. (1982). The petrographic data plotted on this diagram show the abundance of monocrystalline quartz compared to both potassium feldspars and plagioclase. Potassium feldspars exceed the plagioclase grains. As monocrystalline quartz are more stable than polycrystalline one and potassium feldspars are more resistant to weathering, erosional and transportation processes than plagioclase in all climates. Therefore this diagram shows the concentration of monocrystalline quartz and next the potassium feldspar grains abundance compared to plagioclase. The abundance of potassium feldspars compared to plagioclase indicates that either the source rock was rich in potassium feldspars or due to intense weathering, erosion and transportation, the plagioclase survival was difficult as a result there is concentration of potassium feldspars in total feldspar. Similarly the abundance of monocrystalline quartz compared to potassium feldspars show the stability of quartz to all environmental process i.e. to sedimentary cycle. From figure 4.7. It is clear that except few samples, majority of point counts plot above 50% range of quartz, with maximum value of plagioclase less than 20% in all thin sections. The point count data listed in table 2.2 also show that potassium feldspar plagioclase ratio is as high as 6:1 in average and also the Qm/Qp is 8:1 in average. Therefore in figure 4.7 these framework grains follow to some extent the trend of stability (i.e. maturity).

4.4 PROVENANCE STUDY:

As mentioned above in sedimentary petrology, provenance is the study of the nature, compositions identity and dimensions of source rocks, relief and climate in the source area, and to some extent includes the transportation. In short words, provenance is the study of source rock, relief, climate and transportation. The triangular diagrams shown in figure 4.1 to 4.7 place prime emphasis on the role of provenance tectonics in controlling the source and nature of framework grains in sandstone, but secondary influences of weathering, transport, and diagenesis also affect provenance interpretations. Thus for provenance study, both paleoclimatic and poleotectonic changes should be considered.

4.5 PALEOCLIMATIC AND PALEOTECTONIC CHARACTERISTICS:

Surficial processes of weathering and sediment transport are largely a function of paleoclimate, whereas subsurface diagenensis is controlled mainly by trend in basin evaluation. These surfacial and subsurface effects both tend to eliminate chemically less stable and physically less resistant grains, and thus to increase the proportion of quartz in the remaining grain population (Mack 1984) Climate of an area is independent of any direct tectonic control. The rate of erosion of a highland is controlled by relief and climate in the area. Uplift and erosion gradually unroof the rocks and expose them in the core of the highland. Exposure and duration of exposure of a rock type in the source area is a function of relief and climate, which provide a certain degree of topographic maturity to the area. Both the Alps in Europe and the Appalachian in North America are product of continent-continent collisions, i.e. they have same paleotectonic characteristics. But as they are different in degrees of unroofing and in their topographic maturities, therefore they shed sand of different compositions (Basu 1985). In weathering of rock, rainfall and temperature are also two important parameters which have profound effect on the rate of rock-weathering and rate of erosion. Rainfall and temperature also control the growth of vegetation and the attendant biomass in a highland area, and thus significantly contribute to biochemical alteration of original rock material. Genesis of sediments begins with regolith and/or soil formation on a bedrock. The composition of the bedrock is controlled primarily by plate tectonics and the processes of alteration of the bedrock material are the result of climatic effect.

Although process of weathering and sediment transport clearly modify the composition of sedimentary detritus, recent analysis imply that the fundamental imprint of provenance tectonics is preserved in the final sedimentary products. For example, sand collected from beaches around the periphery of South America display bulk composition expected for their respective tectonic settings despite the fact that topography and climate of that large continent is varied in different areas. Recent studies show, however, that detailed variations in proportions of quartz, feldspars and rock-fragments within sandstone suites derived from the same provenance are sensitive to combined influence of mechanical abrasion during transport and hydraulic sorting during deposition.

In the light of this discussion, it is not impossible to conclude some details about the paleoclimatic and paleotectonic record of each provenance type. If the source of any rock is investigated and proved to exist in a particular provenance, then the paleotectonic and significantly contribute to biochemical alteration of original rock material. Genesis of sediments begins with regolith and/or soil formation on a bedrock. The composition of the bedrock is controlled primarily by plate tectonics and the processes of alteration of the bedrock material are the result of climatic effect.

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In the light of this discussion, it is not impossible to conclude some details about the paleoclimatic and paleotectonic record of each provenance type. If the source of any rock is investigated and proved to exist in a particular provenance, then the paleotectonic and paleoclimatic details of the source area of the rock can be investigated. The rocks of Warchha Sandstone are arkosic and occupy the field of continental block provenance as is clear from figures 4.1 to 4.7. Majority of point count data cover the stable craton subfield of continental block provenance and few point counts come under the basement uplift, subfield of same provenance block. Tectonic setting for stable craton is continental interior or passive platform. The sources for craton-derived quartzos sands are low-lying granitic and gneissic exposures, supplemented by recycling of associated flat-lying platform sediments (Dickinson 1982). The most quartzose sands are derived from stable craton interiors having low relief, somewhat more feldspathic sand (arkoses) from a transitional group, (Figure 4.3 and 4.4) and the most feldsphathic sands or arkoses derived from basement uplifts where erosion has cut deep into the continental crust. High Qm/Qp and K/P ratios with low Lt (Total lithic fragments) is characteristic of this provenance, which is clear from figures 4.1 to 4.7 and point count data listed in table 2.2. Although most quartz arenites are probably multicyclic in origin (Suttner et al. 1981), they can also be derived from intensely weathered tropical cratons during only one cycle of erosion (Franzinelli and Potter 1983). Conversely, cratons exposed in arid or glaciated regions might conceivably yield quartz-feldspathic sands to form arkosic petrofacies whose origin could be attributed erroneously to active tectonism. The quartz content of sand derived from tectonically active highlands is influenced by intensity of local weathering. Where relief is great enough, erosion into fresh bed rock may yield quartz-poor sands (Ruxton 1970). Low relief and tectonic stability of cratonic landmass promotes the degree of weathering and/or reworking to produce quartz-rich sands. In continental block provenance the intensity of weathering for the concentration of quartz-rich sand is more important compared to fluvial transport alone (Dickinson 1985). The Warchha Sandstone has high content of quartz but is somewhat more feldspathic. Therefore some of the point counts come under the subfield of basement uplift. Fault-bounded basement uplifts characterized by the rift belts and transform ruptures within continental blocks shed arkosic sand into adjacent linear trough or local pull-apart (Dickinson 1985). Generally the lithic fragments of this source rocks are less than 10% and quartz are 40-45%. About 35-40% feldspar is present. Both, triangular diagrams and point count data listed here show these characteristics of the continental block provenance. Now the paleoclimatic and paleotectonic characteristics of Warchha Sandstone provenance can be expressed as:

1. It was the area of low relief with plutonic and/or volcanic igneous and sedimentary rocks.

2. The climate was either humid or definitely semiarid which allowed intense weathering.

3. The area was not well vegetated because from potassium feldspar bearing minerals, potassium quickly move from the soil into plants (Paton 1978) and conversely there is the high ratio of K/P in total feldspars of these rocks.

4. Perhaps tectonic stability of the cratonic mass promoted the degree of weathering needed to produce quartz-rich sand.

5. Paths of sediment transport was short and direct from the provenance to adjacent or nearby basin. Because transitional tectonic setting and dispersal transport system show scatter plots and no simple correlations can be obtained like in data plotted here.

6. The Warchha Sandstone resembles lithology their Tobra Formation of Lower Permian age. This formation has been interpreted as of Glacial origin (Teichert1980). At places the lower disconformable contact of the Warchha Sandstone is with the Tobra Formation. The erosional upper surface of the Tobra Formation and Similarities in clast lithology points either towards a common source rock for both the formation or indicate reworking of and incorporation of Tobra into the Warchha Sandstone.

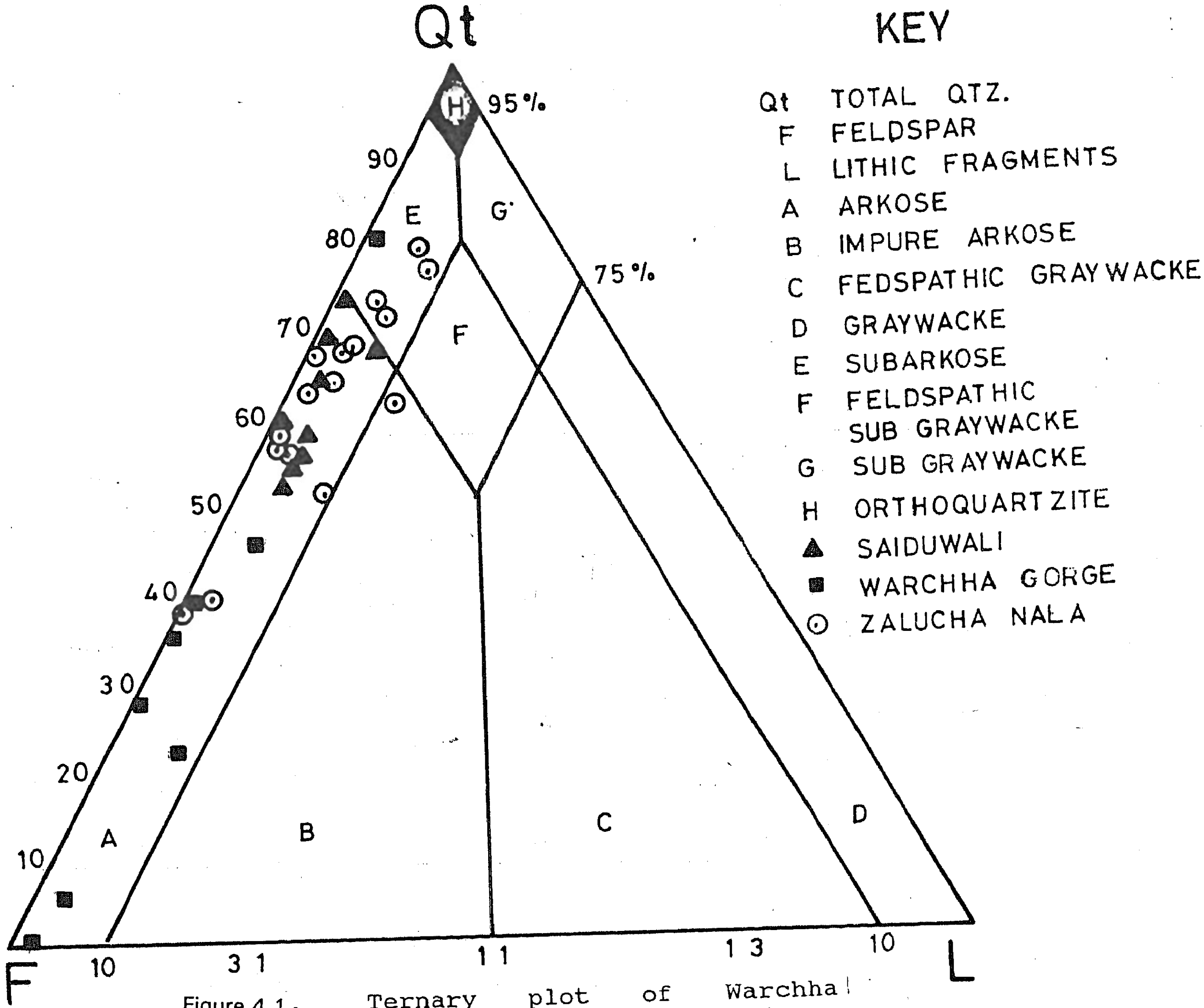

Figure 4.1. Ternary plot of Warchha Sandstone compositional data on Folk's (1954) triangular classification.

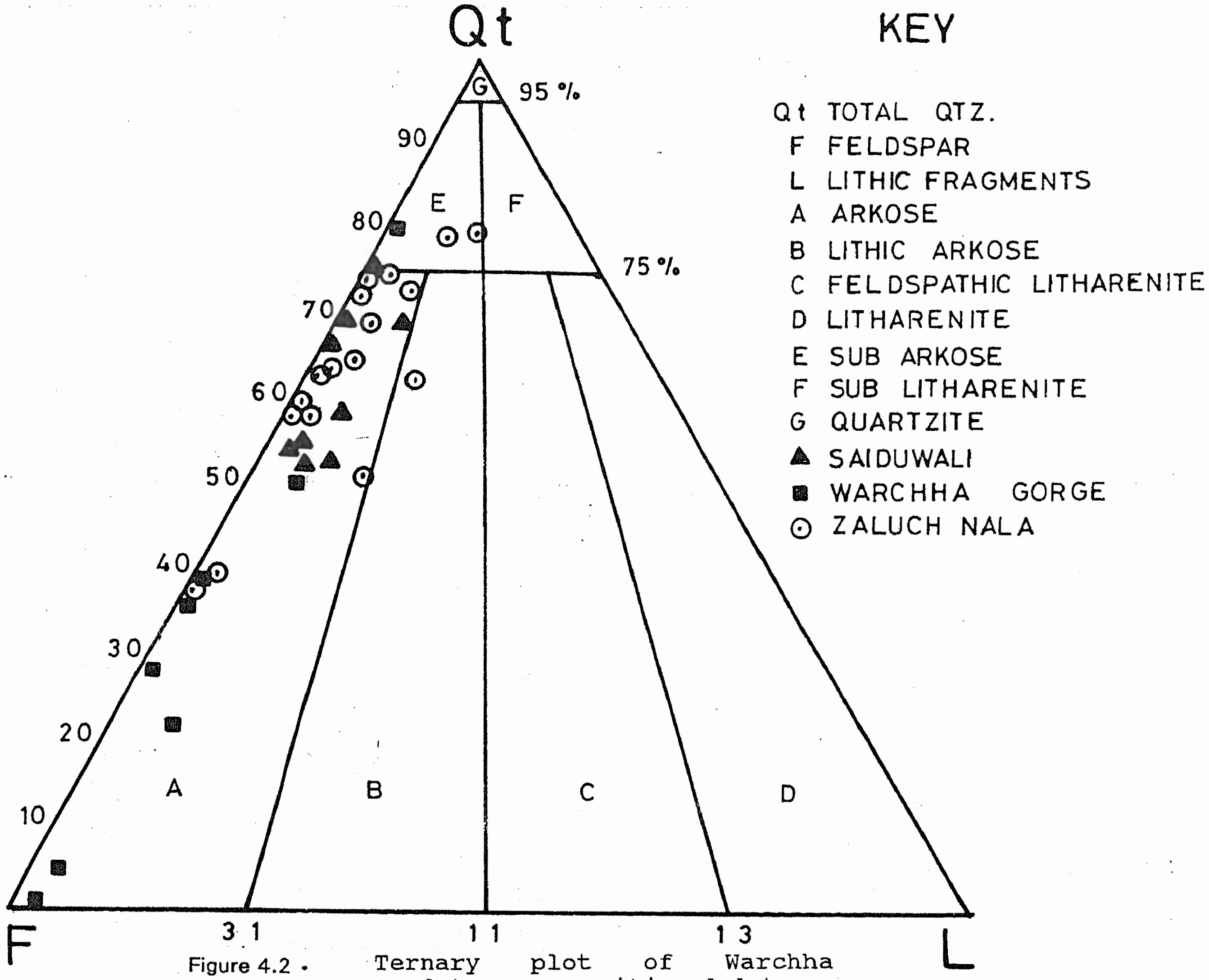

Figure 4.2 . Ternary plot of Warchha Sandstone compositional data on Folk's (1980) triangular classification.

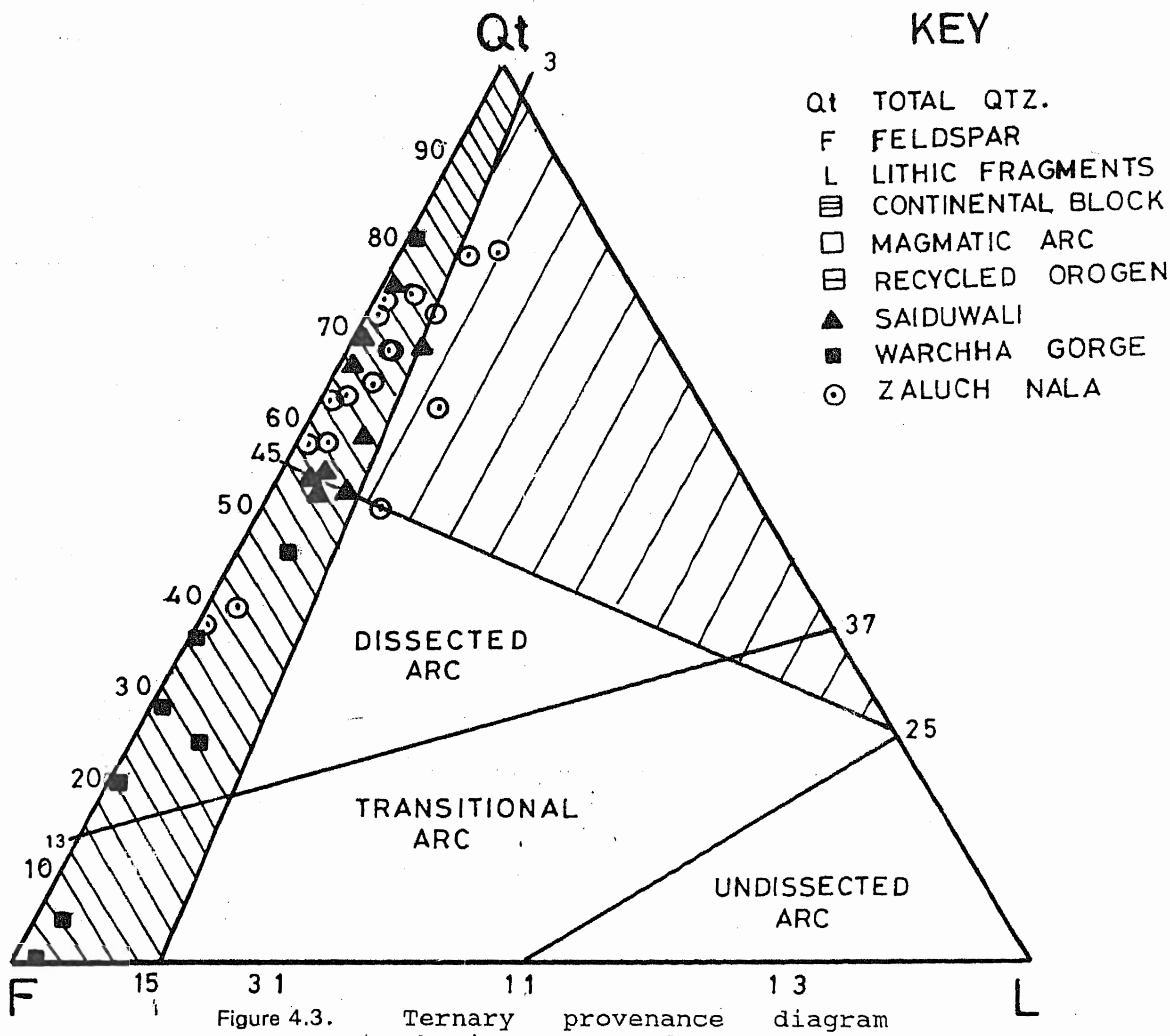

Figure 4.3. Ternary provenance diagram showing range and mean of Qt F L in the Warchha Sandstone. (Provenance fields from Dickinson, 1983).

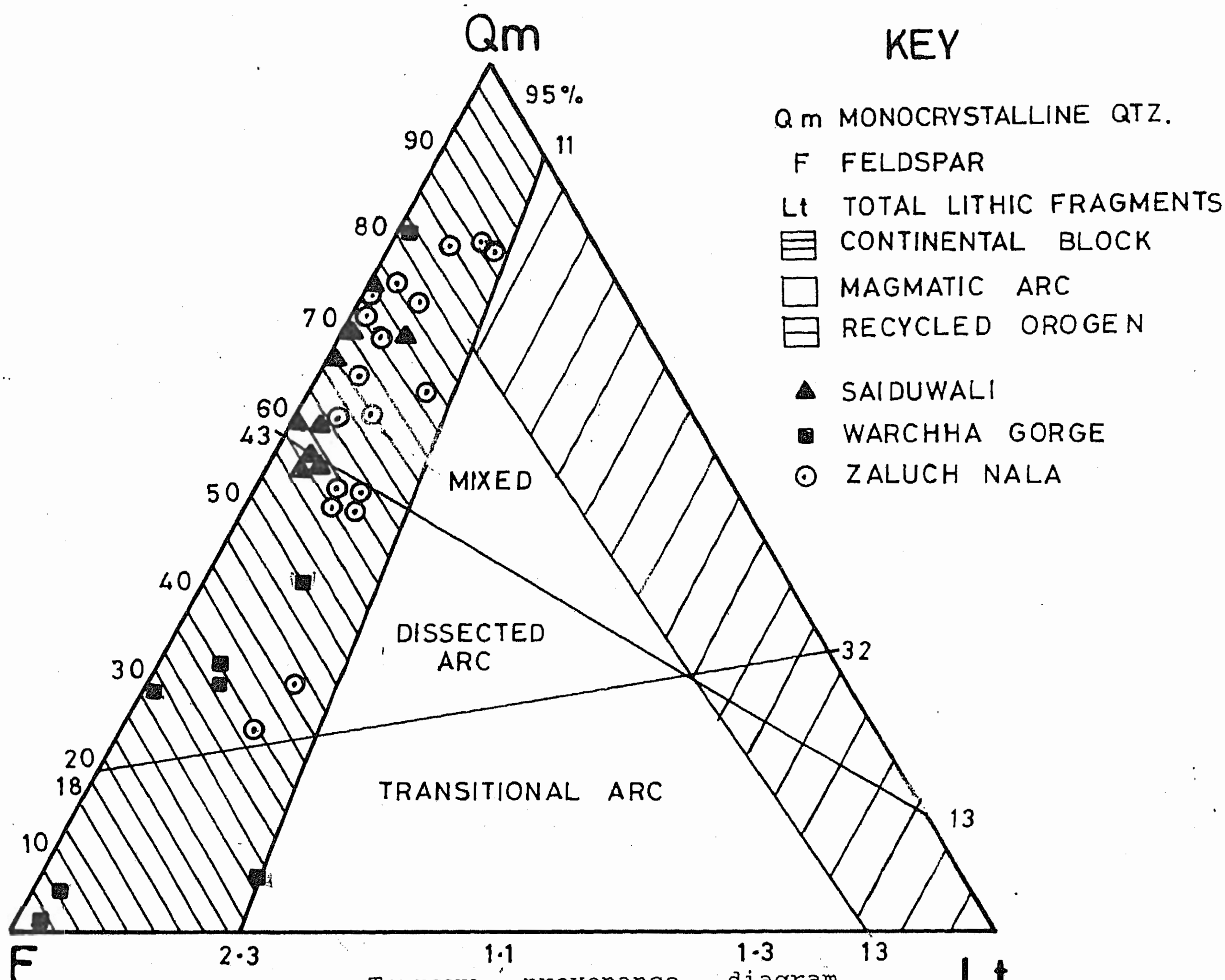

Figure 4.4. Ternary provenance diagram showing range and mean of Qm F Lt in the Warchha Sandstone. (Provenance fields from Dickinson et al 1983).

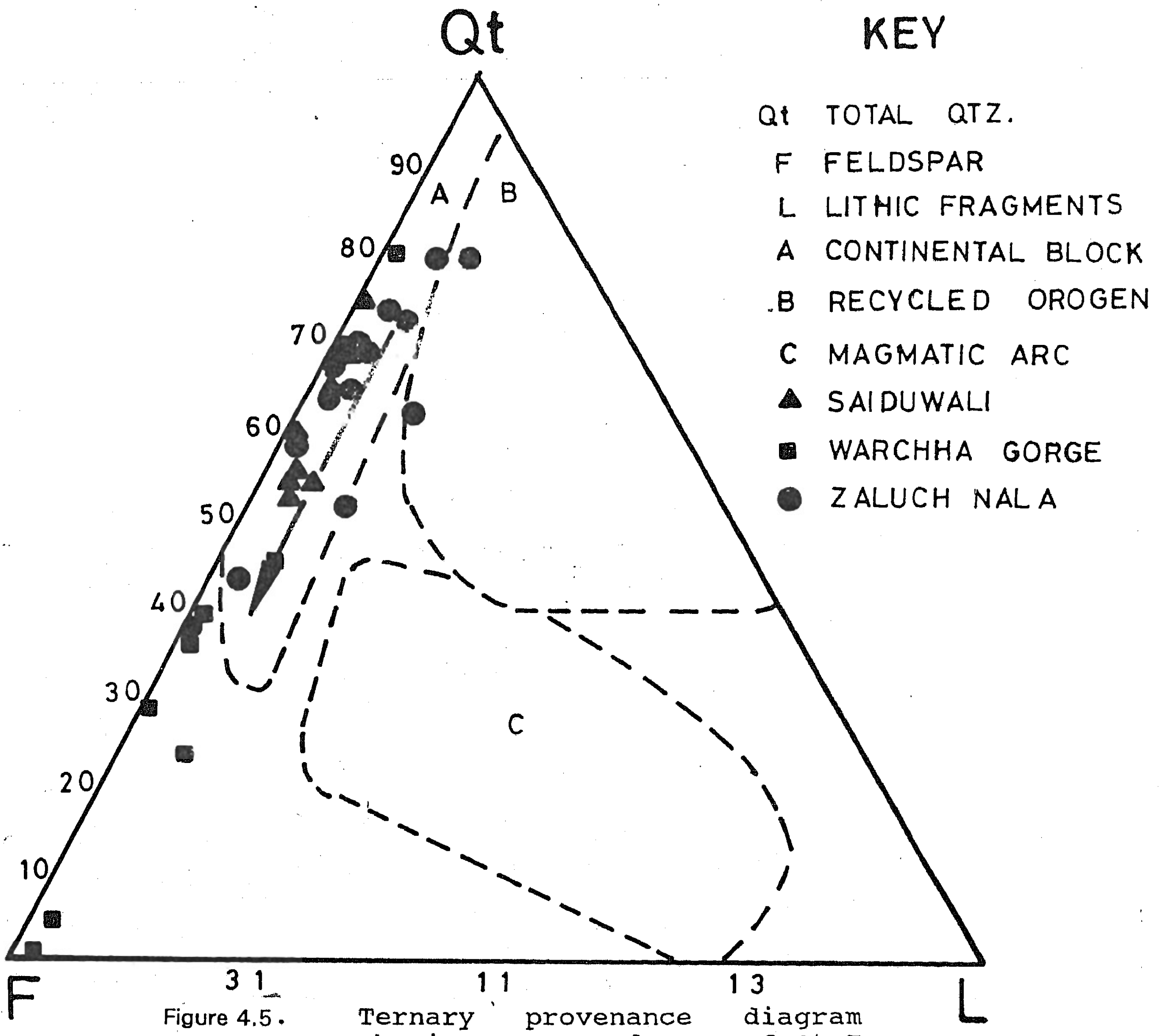

Figure 4.5. Ternary provenance diagram showing range and mean of Qt F L in the Warchha Sandstone. (Provenance fields from Dickinson and Suczek 1979).

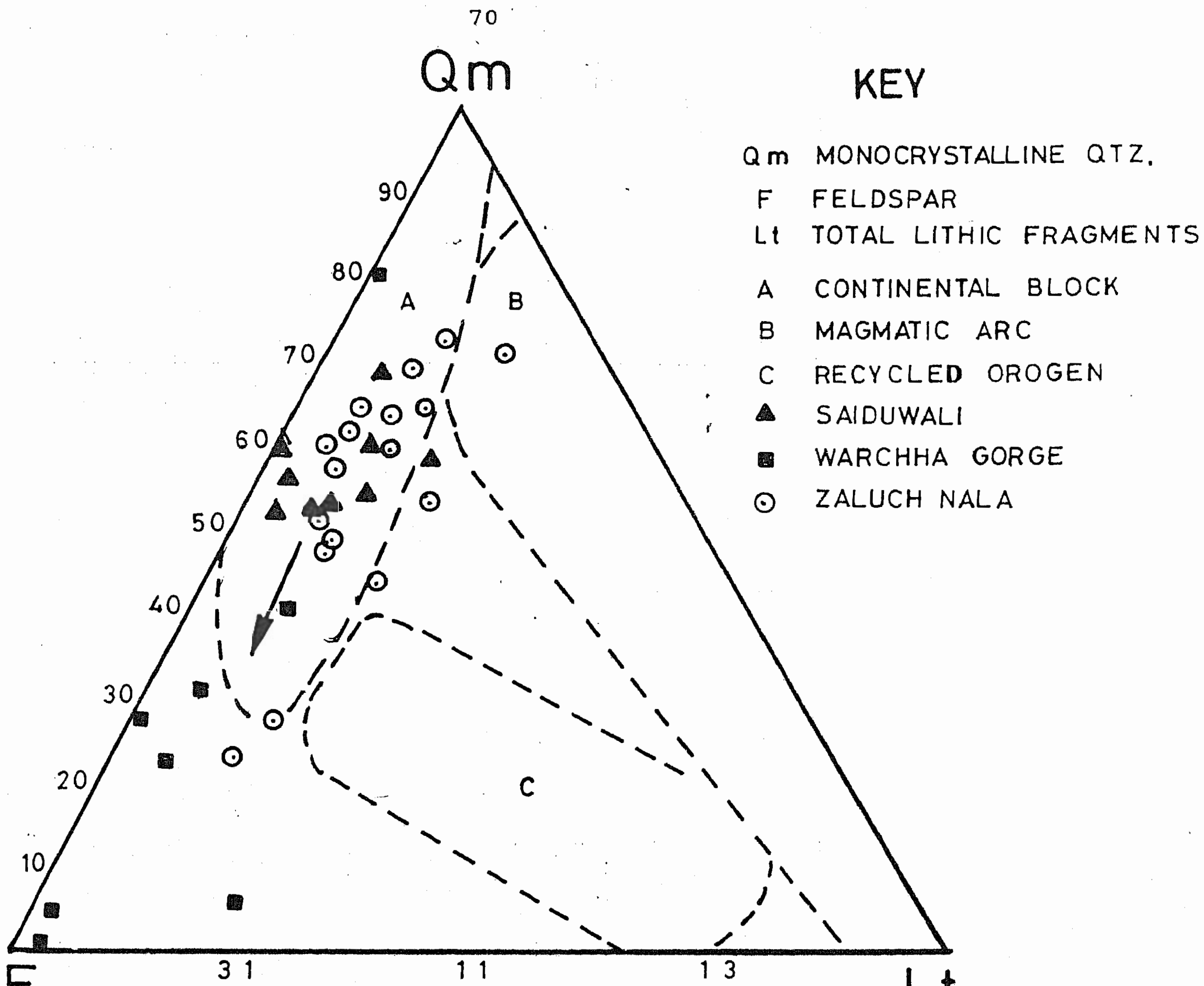

Figure 4.6. Ternary provenance diagram showing range and mean of Qm F Lt in the Warchha Sandstone. (Provenance fields from Dickinson 1985).

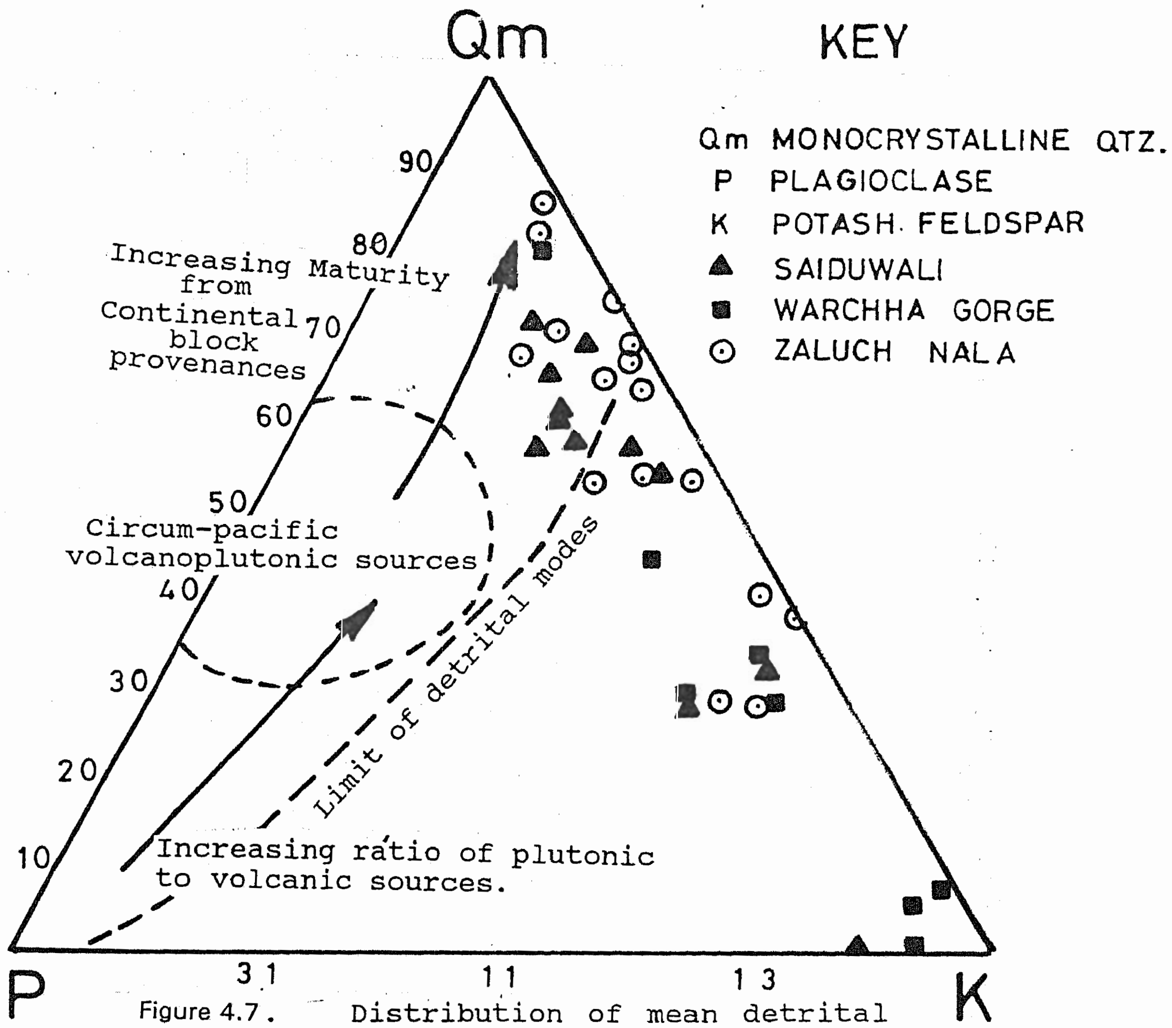

Figure 4.7. Distribution of mean detrital modes for sandstone suites derived from different types of provenances plotted on standard triangular diagram; after Dickinson and Suczek (1979) as modified by Dickinson (1982; et al, 1982).

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