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Phosphorite-bearing Cambrian Formations in the Himalayan Fold and Thrust Belt, Hazara Division, Northern Pakistan

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Abstract

The Abbottabad area is underlain by Precambrian to Cretaceous partially metamorphosed sedimentary rocks deposited on shelves surrounding Gondwana. The Cambrian formations are thrust southeastward over the Precambrian metamorphic rocks (Hazara / Tanawal Formation) along the Panjal Thrust, and are unconformably overlain by Jurassic to Cretaceous formations.

The Cambrian rocks in the study area are divided into two: the Abbottabad and Hazira Formations. The phosphorite deposits occur mainly in the uppermost part of the Abbottabad Formation and also in the Hazira Formation in a minor amount. The upper part of the Abbottabad Formation, Sirban Dolomite Member, is subdivided into three units: the Lower, Middle, and Upper. The Lower Unit consists of micritic dolomite, and the Middle Unit of dolomite and quartzite. The Upper Unit is characterized by numerous chert intercalations in the dolomite. The economically important phosphorite deposits are recognized at least three levels in the upper part of the unit. The phosphorite deposits show generally nodular or ooid-like structure, and are intercalated in dolomite. The phosphorite horizons are variable in thickness, reaching 5 m thick in maximum.

The Hazira Formation is 125m thick and overlies the Abbottabad Formation with a minor sedimentary gap. It is subdivided into two facies: Hazira and Galdanian Facies. The Hazira Facies consists of glauconite-bearing calcareous mudstone in the lower part, and sandstone in the upper part. The Galdanian Facies is composed of hematitic red mudstone, siltstone and chert breccia. Thin phosphorite beds occur in the lower part of the formation.

Many of the thrust faults developed in the area generally parallel to the Panjal Thrust and bedding planes. The faults strike NNE-SSW, and their inclinations are moderate to steep with westward or eastward direction. Folds are divisible into two type: symmetrical open folds and asymmetrical tight folds, and their half wavelengths are about 250 m and 100 m, respectively. Axial planes of the folds nearly parallel to the thrust planes.

The study area is divided into four structural domains: α, β, γ, and δ from west to east, bounded by persistent major faults. The Domain β is characterized by the abundance of phosphorite deposits and the prevalence of the Hazira Facies of the Hazira Formation. On the other hand, the Galdanian Facies-dominated domains, Domain α, γ, and δ, are generally poor in phosphorite.

The thrust sheets designated as structural domains and sub-domains have been overturned in the northern part of the study area. The fact indicates the two phase of deformations: the southward thrusting at the first and the shearing and overturning related to the formation of Hazara-Kashmir Syntaxis at the second.

Remarkable phenomena, such as a drastic facies change from carbonate to clastic rocks, and formation of phosphorite and ferruginous sediments like glauconitic and hematitic mudstone, are observed around the boundary between the Abbottabad and Hazira Formations. Such a drastic change between two formations might have resulted from a nutrient-rich condition in the sea water related to a rapid transgression.

INTRODUCTION

Phosphorite deposits were discovered by Latif (1970; 1972a) in the Abbottabad area, Hazara Division, northern Pakistan in the late 1960s. The area has been repeatedly studied by many workers (see next Chapter) not only for an economic interest in phosphorite and other mineral resources but also for an academic interest in the geologic structure of the area located in the Himalayan fold and thrust belt. Although detailed geologic maps in the Hazara area have been published on a scale of 1: 24,000 or smaller by many authors (Marks and Ali, 1961; Gardezi and Ghazanfar, 1965; Latif, 1970; Calkins et al., 1975; Ghaznavi and Karim, 1978; 1979; Hasan and Ghaznavi, 1980), about a half of them were published before finding of phosphorite deposits. The remainder are too insufficient for tracing of phosphorite deposits to evaluate ore reserve.

The Geoscience Laboratory, Geological Survey of Pakistan, have attempted to re-examination of mineral resources and geology in the Hazara Division including the Abbottabad area since 1991. The reports of such works were published in the Proceedings of the Geoscience Colloquium, Geoscience Laboratory (Mononobe, Karim and Khan, 1992; Mononobe, Hirayama and Karim, 1992; Hirayama and Mononobe, 1992). Subsequently, a mapping project including a field training of junior geoscientists of the Geoscience Laboratory was initiated in 1993. Part of the results were reported by Karim (1993), Warraich et al. (1994), Aslam and Kaneda (1994), and Karim and Kaneda (1994). The results were also presented in domestic and international meetings in Japan and Pakistan (Naka et al., 1995a, 1995b).

Though we were interested in utilizing the phosphorite ore in the Abbottabad area to manufacture the fused magnesian phosphate (FMP; Hirayama and Mononobe, 1992), the Sarhad Development Authority (SDA) did not published detailed geologic map compiled under a cooperation of the British consultant between 1977 and 1983 that the confirmation of their estimate of ore reserve became one of the purposes of our project. In the present work, detailed route maps on a scale of 1: 5,000 to 1: 6,000 were made along various traverses to describe lithological and structural observations. These field data were transferred onto a topographic map on a scale of 1: 10,000 prepared by SDA.

This paper summarizes the results of the mapping project. The attached geologic map and cross sections (Appendixes I and II) were reduced from an original scale of 1: 10,000 to a scale of 1: 25,000 for a technical constraint of publisher.

The Abbottabad city is located about 50 km north of Islamabad. The study area is of about 70 square kilometers and is situated between 73°15' E to 73°20' E longitudes and 34°10' N to 34°19' N latitudes, covering part of toposheet Nos. 43 F/8 and F/7.

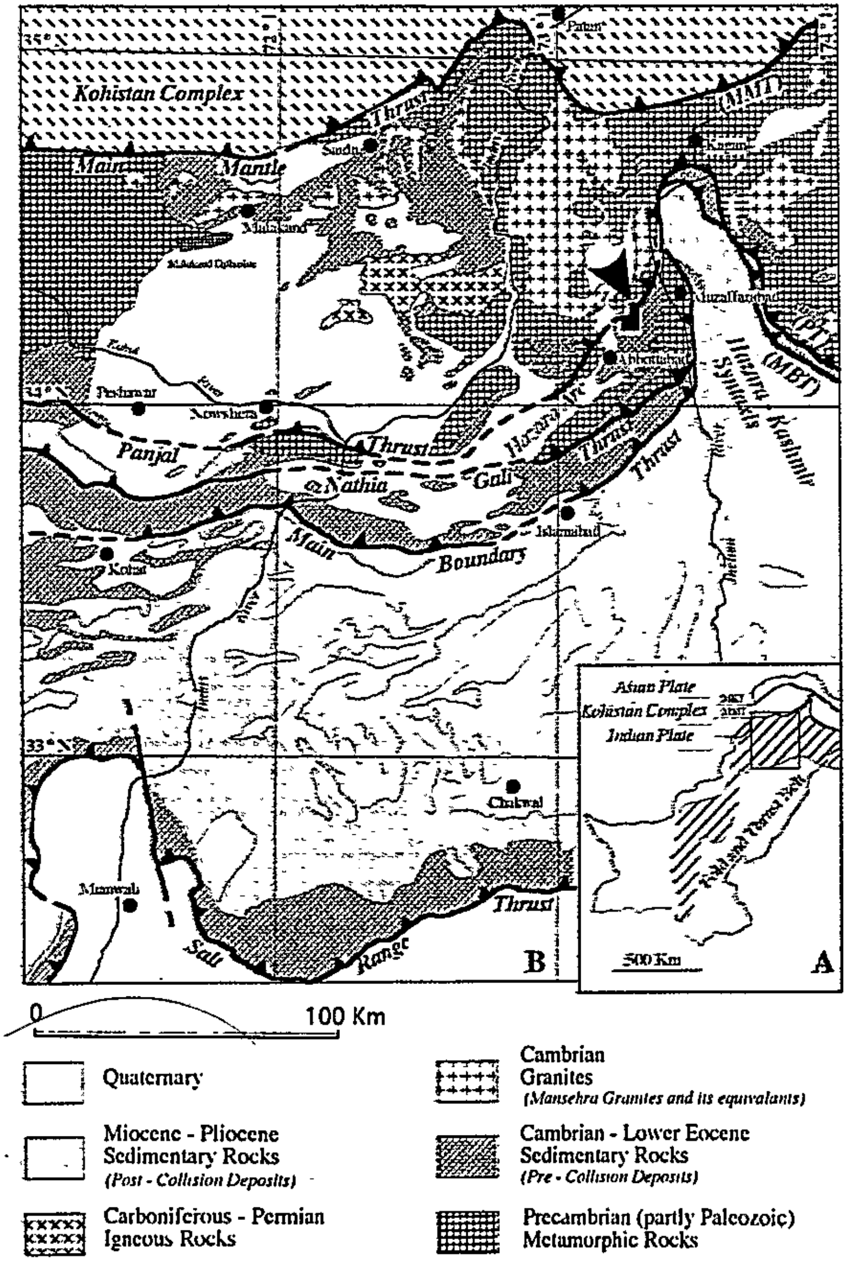


Figure 1 -A. A simplified tectonic map of Pakistan showing the Himalayan fold and thrust belt. The area of 1 - B is shown as a rectangle in the figure. MKT, Main Karakoram Thrust; MMT, Main Mantle Thrust.

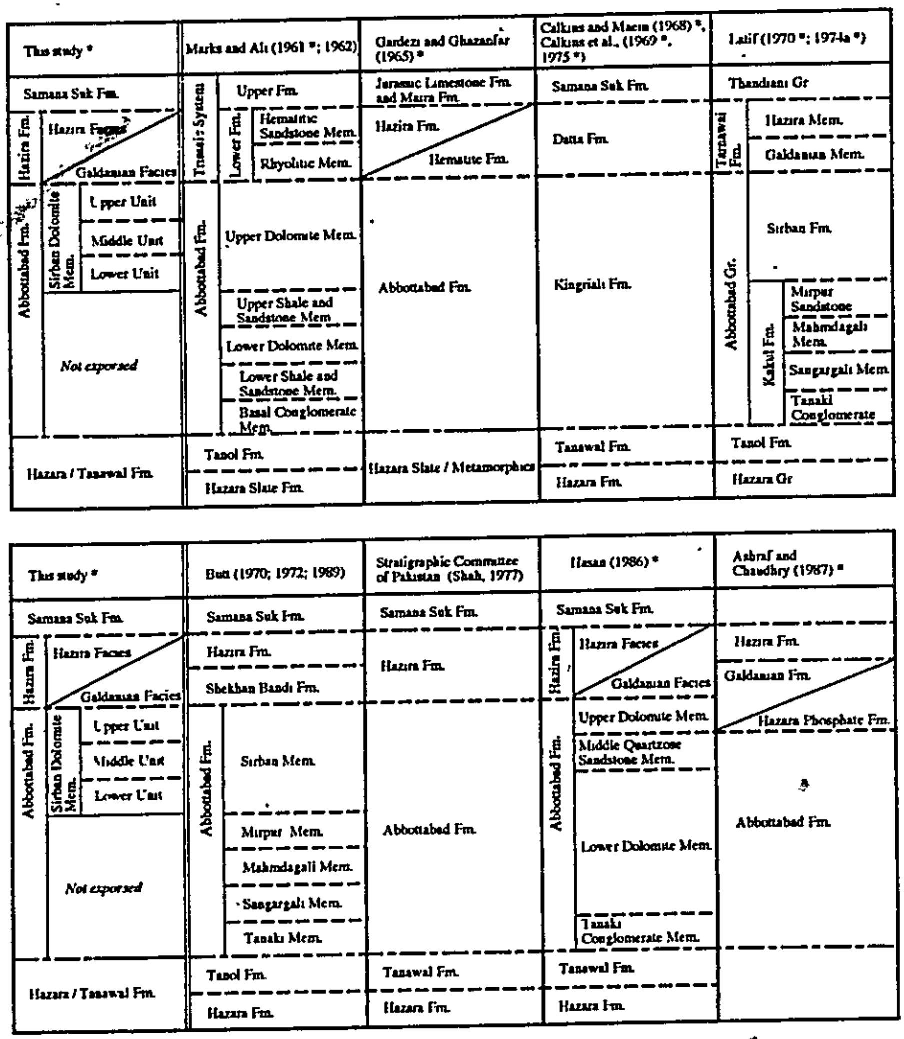
1 -B A geo-tectonic map of northern Pakistan showing major thrusts (barbs on hanging wall). The study area is indicated by a black arrow. Compiled from Qureshi et al. (1993), Khan and Humayun (1991) and Hylland et al. (1988).

GEOLOGIC SETTING AND PREVIOUS WORK

The collision between the Indian sub-continent and Asian continent occurred during the Late Eocene (Coward et al., 1986). After the collision, the sedimentary cover on the Indian sub-continent has formed an extensive southward-directed thrust-system, which is called the Himalayan fold and thrust belt, involving Precambrian to Early Eocene rocks (Figure 1). The Himalayan fold and thrust belt is bounded by the Main Mantle Thrust to the north and by the Salt Range Thrust to the south. The study area is located in the northwestern part of the Hazara Arc (Yeats and Hussain, 1987), which forms the western limb of the Hazara - Kashmir Syntaxis (Figure 1). The arc thrusts southward onto the Miocene to Pliocene post-collision sediments along the Main Boundary Thrust. To the north, the Hazara Arc is bounded by the Panjal Thrust with Precambrian strata and Cambrian granitic rocks.

Pioneer works in the Hazara Division were made by Waagen and Wynne (1872) and Middlemiss (1896). They published geological descriptions with small-scaled geologic maps covering part of the Hazara Division, which served as a base for the subsequent work. Marks and Ali (1961) prepared a geologic map around Abbottabad, and divided the rock sequence into four units; the Hazara Slate Formation, Tanol Formation, Infra-Trias Group, and Triassic System. Their sedimentary environments and stratigraphic correlation to the adjacent region were discussed by them. Gardezi and Ghazanfar (1965) compiled a geologic map covering the area between Abbottabad and Lagarban, and designated the mudstone-dominated unit as the Hazira Formation. In the late 1960s to 1970s, phosphorite deposits and Cambrian fossils were discovered in the Abbottabad area (Latif, 1972a; 1972b; Fuchs and Mostler, 1972; Rushton, 1973). At the same time, the knowledge on stratigraphy and structure of the Hazara Division was rapidly increased mainly by Latif (1970; 1972a; 1972b; 1974a; 1974b), Calkins (Calkins and Matin, 1968; Calkins et al., 1969; Calkins et al., 1975), and the staff of Geological Survey of Pakistan (Bhatti et al., 1972; Ghaznavi and Karim, 1978; 1979; Hasan and Ghaznavi, 1980). Subsequently, intensive explorations of the phosphorite deposits, including topographic and geologic mapping, core drilling, aditting, and trenching, were carried out in the Kakul-Lagarban area between 1977 and 1983 by the Sarhad Development Authority (SDA) with a technical cooperation of the British Government. However, these data have remained unpublished. Besides the above-mentioned authors, new classification and nomenclature of rock units were proposed by many workers (Butt, 1970; 1972; 1989; Shah, 1977; etc.). Although stratigraphical, structural, and geochemical studies in this area were made by some authors between 1980 and 1990 (Coward et al., 1982; Ashraf and Malik, 1983; Bhatti, 1983; Bossart et al., 1984; Coward and Butler, 1985; Husain et al., 1987; Ashraf and Chaudhry, 1987; Ghazanfar et al., 1987; Treloar, 1989; Treloar et al., 1989; Husain et al., 1990), the geological interpretations established by Latif, Calkins, and GSP have undergone any basic change. Some reviews were also made on geology and phosphorite deposits by Hasan (1986), Butt (1989), and Khan and Humayun (1991).

Table 1. A comparison of the stratigraphy of selected previous workers with this study.



Abbreviation Gr., Group; Fm., Formation, Mem., Member,
* : attached with original geological map and/or stratigraphic column
Stratigraphic relationship : ——— fault ; — — — — conformity ;
—— - —— - unconformity or break of sedimentation

STRATIGRAPHY

The rock sequence in the study area is divided into the following three units: Precambrian, Lower Cambrian, and Jurassic to Cretaceous (Figure 2). Precambrian is composed of metamorphosed and/or weakly metamorphosed rocks, and is called the Hazara and Tanawal Formations. Lower Cambrian consists mainly of carbonate and clastic sedimentary rocks, and is divided into the Abbottabad and Hazira Formations. The overlying Jurassic to Cretaceous sedimentary sequence is divided into the Samana Suk, Chichali / Lumshiwal, and Kawagarh Formations in ascending order (Figure 2). The nomenclature of each rock unit in this paper basically follows the Stratigraphic Committee of Pakistan (Shah, 1977: refer to Table 1).

Phosphorite deposits are recognized in the uppermost part of the Abbottabad Formation and the Hazira Formations in the study area, and it can be traced to the north and south (Ashraf, 1974; Hasan and Ghaznavi, 1980).

1. **Hazara / Tanawal Formation** (Calkins and Matin, 1968)

Name : The formation names of Hazara and Tanawal derived from district and place, respectively.

Historical background: Several names have been given to the metamorphic rocks in the Hazara Division (see Table 1). The Hazara and Tanawal Formations were introduced by Calkins and Matin (1968), and Stratigraphic Committee has approved the names (Shah, 1977).

Stratotype : The stratotype have been not designated by any author.

Distribution : The Hazara / Tanawal Formation is distributed in the western part of the study area (Appendix I), and widely cropped out in the Hazara Division.

Thickness : Not measured, but more than several hundred meters are expected.

Lithology : The authors did not divide the Hazara and Tanawal Formations, and combined them as one unit. The formation consists of various kind of metamorphic rocks, including pelitic, psammitic, micaceous, and carbonaceous schists. In Banda Pir Khan, gneissose schists are found. Their metamorphic grade seems to decrease toward north in the study area.

Stratigraphic relationship : The formation is clearly truncated by the Panjal Thrust with the Cambrian and Jurassic rocks in the study area. The lower contact of the formation is not exposed. The contact between Hazara and Tanawal Formations is conformable (Latif, 1974a; Hasan, 1986) or disconformable (Calkins and Matin, 1968; Calkins et al., 1969; 1975).

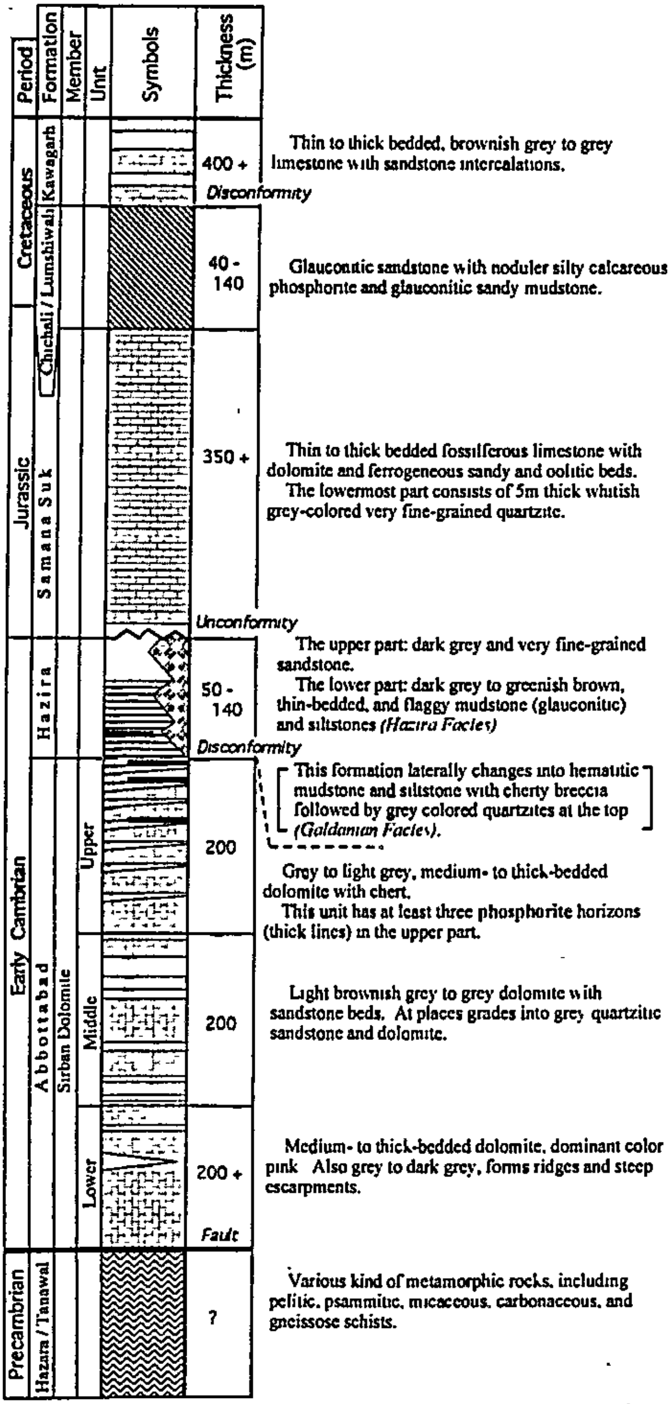


Figure 2. A generalized stratigraphic column of the study area, Abbottabad, northern Pakistan.

Age : No fossils have been reported from both formations. However, Crawford and Davies (1975; recalculated in Baig et al., 1988) reported Rb/Sr whole rock ages of 739±9 Ma and 951±8 Ma from the Hazara Formation. Moreover, to the south of Abbottabad, the Tanakki Conglomerate Member at the base of the Early Cambrian Abbottabad Formation unconformably overlies the Hazara Formation. Thus, the formation is assigned Late Precambrian. The Tanawal Formation is intruded by the Mansehra Granite near Mansehra (Calkins et al., 1975; see Figure 1). The Mansehra Granite has yielded a Rb/Sr whole rock age of 516±16 Ma (Le Fort et al., 1980). The age of the Tanawal Formations, therefore, is Early Cambrian or older.

2. Abbottabad Formation (Marks and Ali, 1962), **Sirban Dolomite Member** (Latif, 1970)

Name : The formation name is derived from the city of Abbottabad. The member name of the Sirban Dolomite was derived from hill, situated to the south of Abbottabad. Although the hill name is written as Sarbun Dhaka (Hill) in the toposheet No. 43 F/4, the member name has been spelled as Sirban since the member was established (Latif, 1970).

Historical background: Except Latif (1974a) who defined this formation as a group comprising two formation: the Kakul and Sirban Formations, the present formation has been defined as the Abbottabad Formation including Stratigraphic Committee of Pakistan (Shah, 1977). The formation has been divided into five members in ascending order: Tanakki Conglomerate, Sangargali Sandstone, Mahmdagali Dolomite, Mirpur Sandstone, and Sirban Dolomite Members (Table 1). However, Hasan (1986) divided the formation into three members: Lower Dolomite, Middle Quartzose sandstone, and Upper Dolomite Members. Comparison with stratigraphic columns between Hasan (1986) and Latif (1974a), the "Middle Quartzose Sandstone Member" of Hasan (1986) should be correspond with the middle part of the "Sirban Formation" of Latif (1974a: see Table 1).

Stratotype : The stratotype of the formation is in Sarbun Hill, south of Abbottabad (Marks and Ali, 1961; Latif, 1974a).

Distribution : The formation is widely distributed in the Hazara Division including the study area. In the study area, only the upper part of the formation, the Sirban Dolomite member, is exposed.

Thickness : The total thickness of the formation in the type section is estimated at 2200 feet (about 660 m) by Marks and Ali (1961), 1460 to 2630 feet (about 438 m to 789 m) by Latif (1974a), and 525.6 m by Hasan (1986). The Sirban Dolomite Member attains 600 m^+ thick in the study area. According to Latif (1974a), the member ranges from 800 to 1600 feet (about 240 to 480 m) in thickness.

Lithology : The formation is mainly composed of dolomite and sandstone. The upper part of the formation, the Sirban Dolomite Member, is subdivided into three units in this paper: the Lower, Middle, and Upper Units, on the basis of the proportion of dolomite / sandstone and presence of chert intercalations (Figure 2; Table 1).

Stratigraphic relationship : Outside the mapped area, the Tanakki Conglomerate Member of the Abbottabad Formation in Sarbun Hill unconformably overlies the Hazara / Tanawal Formation (Middlemiss, 1896; Marks and Ali, 1961; Latif, 1974a; Bhatti, 1983).

Age : The upper part of the member (Upper Unit) yield phosphatic fossils, which denotes Early Cambrian (see Discussion).

2- 1. Lower Unit

Distribution : The unit is distributed in the southwestern part of the study area, around Mirpur (Appendix I).

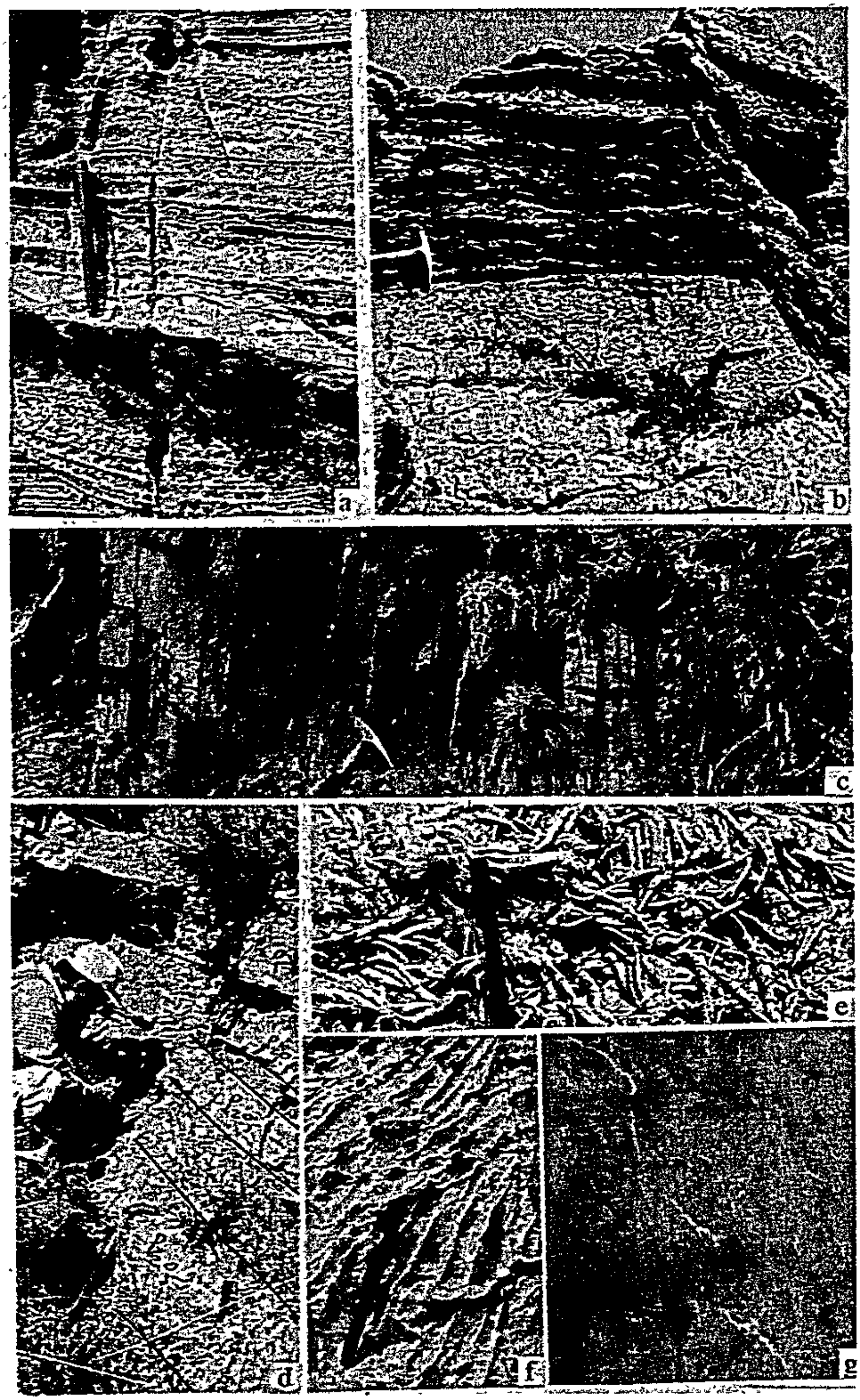
Thickness : The Lower Unit in the study area is 200 m^+ thick (Table 3).

Lithology : The Lower Unit is characterized by medium- to thick-bedded alternation of grey to dark grey dolomite and pink-colored dolomite, intercalated with thin sandstone. The former predominates over the latter. The dolomite is hard and micritic, displaying chop-board weathering surfaces. The pink-colored dolomite consists mainly of ferroan dolomite by XRD analysis (Aslam and Kaneda, 1993). In grey to dark grey dolomite, especially in weakly dolomitization part, algal mat is recognized (Figure 5-a). The chemical composition by XRF of the grey-colored dolomite is shown in Table 2. On the assumption that the loss of ignition (LOI) represents CO_2, the chemical composition of this sample indicates that minor amount of CaO and MgO remain unconsumed to form 97.02 % of dolomite. They probably come from other silicate minerals. Further, thin sandstone beds are intercalated in the upper part of this unit. The sandstone is fine- to medium-grained and shows a beige color on fresh part and a brownish grey color on the weathered surface.

2- 2. Middle Unit

Distribution : The unit is mainly distributed in the southwestern part of the study area, around Mirpur. Small outcrops of the member are also recognized to the north of Mohara (Appendix I).

Thickness : The Middle Unit in the study area is 200 m thick (Table 3). According to Hasan (1986), the "Middle Quartzose Sandstone Member", which is probably correlated with the Middle Unit, is 54 m thick.



Lithology : This member consists of medium- to thick-bedded alternations of dolomite, dolomitic sandstone and quartzite. The member is subdivided into the lower and upper parts. The lower part looks whitish grey to grey from far away, whereas the upper part looks brown-colored. The lower part of the unit is dominated by dolomite, whilst the upper part is prevailed by dolomitic sandstone and quartzite. The dolomite is micritic and grey-colored. The dolomitic sandstone is medium- to coarse-grained, occasionally showing cross-bedding (Figure 3-a) and protruded weathering surfaces. The boundary between the lower and upper parts is marked by a 20 m-thick band of medium- to thick-bedded quartzite, which is creamy white and fine- to medium-grained. The mineral species of dolomite and dolomitic sandstone identified by XRD consist predominantly of dolomite, ferroan dolomite, with small amounts of quartz and calcite (Aslam and Kaneda, 1993). Under the microscope, dolomite and dolomitic sandstone are composed of quartz grains of angular to sub-angular shape dispersed in matrix of dolomite associated with minor amount of goethite, hematite, and calcite (Figure 5-b). Altered minerals such as chlorite and sericite are also found. The quartzites display a perfect mosaic texture under the microscope, and are fine- to medium- grained (Figure 5 -c). A few microcline and tourmaline are observed in quartzites. The chemical composition of three samples from the unit are shown in Table 2. A norm- calculation of the mineral composition of sample KA-11 based upon an assumption of LOI represents CO_2 indicates that it consists of 60.97 % of quartz, 11.08 % of dolomite, and 22.49 % of calcite with minor remnants of CaO and MgO probably derived from other silicate minerals. Similarly, sample KA-13 is composed of 72.39 % of quartz and 24.37 % of dolomite with a minor amount of unconsumed CaO derived from other minerals, while sample KA-12 comprises 95.91 % of quartz less than 1 % of dolomite and calcite.

Figure 3. Field photographs.

a. A graded and cross-bedding dolomitic sandstone found in the Middle Unit, Sirban Dolomite Member of the Abbottabad Formation, NW of the Kakul Mine.

b. Chert bands in the Upper Unit, Sirban Dolomite Member of the Abbottabad Formation showing protruded weathering surfaces, Kakul Mine.

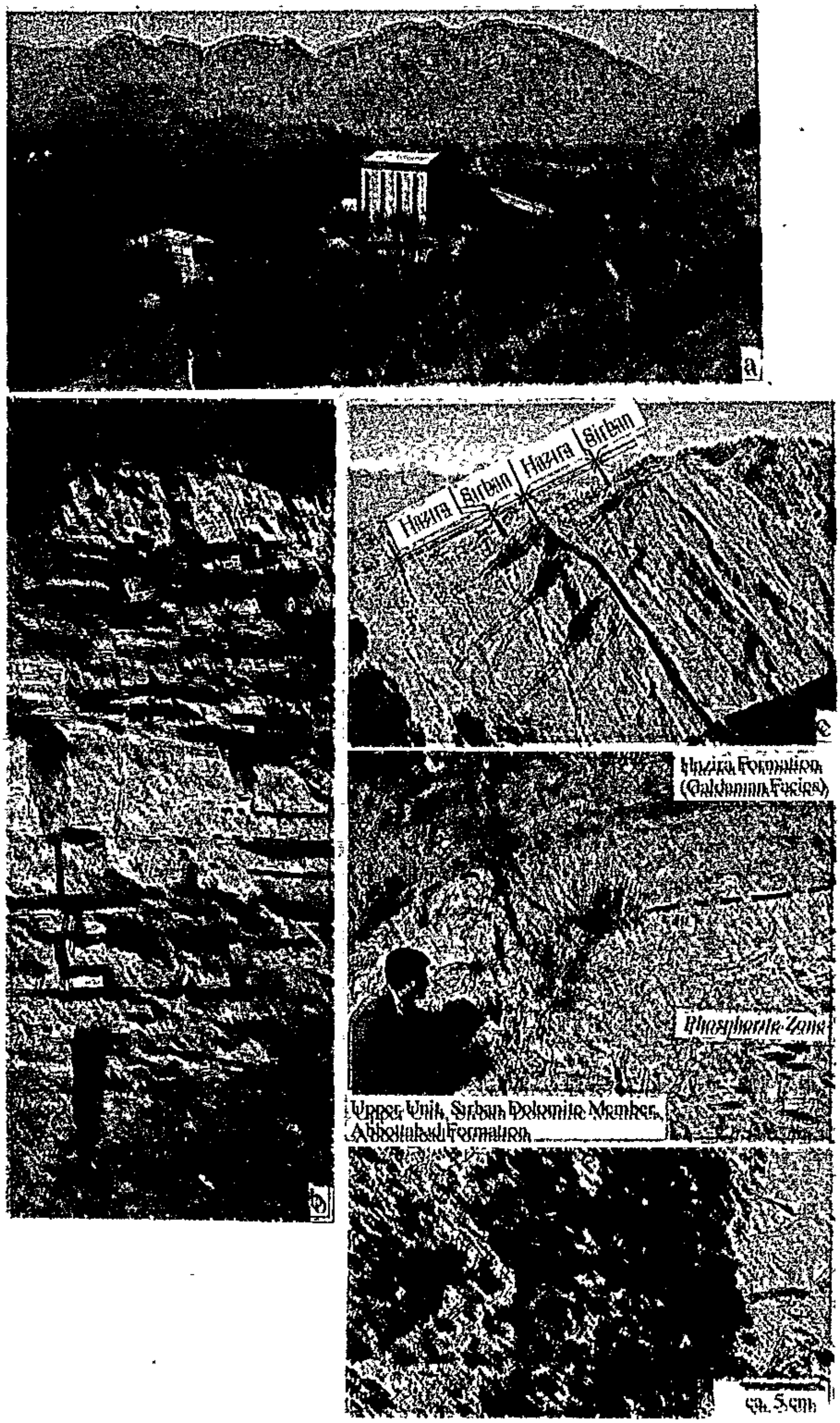
c. Medium-bedded and dark-grey colored siltstones intercalated with thin-bedded greenish-brown glauconitic mudstones (right side in the Figure) in the lowermost part of the Hazira Facies, Hazira Formation, near the Kakul Mine.

d. Phosphorite deposits in the Upper Unit, Sirban Dolomite Member of the Abbottabad Formation, Kakul Mine.

e. Burrows found in the bed surface of grey mudstone of the Galdanian Facies, Hazira Formation, Gali Beha.

f. Solutional grooves on the surface in the Samana Suk Formation, NE of the Kakul Mine.

g. Medium to thick-bedded Samana Suk Formation showing "yellow patches" and layers (sandy part: brownish yellow part), near the Kakul Mine.


a
b
Hazira
Sirban
Hazira
Sirban
c
Upper Unit, Sirban Dolomite Member,
ca. 5cm

2-3. Upper Unit

Distribution : The Upper Unit is widely distributed throughout the mapped area (Appendix I).

Thickness : The Upper Unit attains to 200 m in thickness, while Hasan (1986) reports the "Upper Dolomite Member" is 113.5 m thick.

Lithology : The Upper Unit is the most important phosphorite-bearing rock unit. The unit is composed of medium- to thick-bedded, grey to light grey and cliff forming dolomite interbedded with chert bands. The chert band varies in thickness from 3 cm to even 35 cm and form protruded weathering surfaces (Figure 3-b). The dolomite shows typical chop-board type of weathering. Sometimes thin intercalations of purple- to chocolate-colored siltstone are found within the cherty dolomite. The examination of cherty dolomite by XRD exhibits dolomite, ferroan dolomite, calcite, quartz, and phosphorite minerals (Aslam and Kaneda, 1993). Under the microscope, dolomite consists of fine-grained dolomite, with minor amount of quartz, hematite, goethite, and calcite (Figure 5-d). The chemical composition by XRF of the cherty dolomite is shown in Table 2. A norm-calculation of the mineral composition of the sample based upon an assumption of LOI represents CO_2 indicates that it consists of 10.53 % of quartz and 88.04 % of dolomite with minor remnants of CaO and MgO probably derived from other silicate minerals.

At least three to four sedimentary phosphate horizons are intermittently traceable in the upper part of this unit (Figures 2, Appendix I). A detailed stratigraphic column showing the uppermost horizon of phosphorite in the unit is given in Figure 6. Each of the phosphorite horizon varies from 1 to 5 m thick, composed of 1 to 15 cm thick phosphorite beds intercalated with dolomite, chert, and conglomerate containing chert granules (Figures 3-d, 4-b, and 4-d). The conglomerate containing chert granules is

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Figure 4. Field photographs.

a. A distant view of the Kakul Mine. The photograph was taken from N to S direction. Several adits for exploitation of phosphorite deposits can be seen on the right side of the photograph.

b. A close-up view of phosphorite deposits in the Kakul Mine. Black to greyish black phosphorite layers are rhythmically interbedded with the whitish grey dolomites. Upper Unit, Sirban Dolomite Member of the Abbottabad Formation.

c. A distant view of the part of the survey area, Tarnwai. The picture was taken from S to N direction. The Upper Unit, Sirban Dolomite Member of the Abbottabad Formation (Sirban) and the Hazira Formation (Hazira) are repeated by a thrust fault (green line). The Hazira mudstone forms small topographic depressions.

d. The contact between Abbottabad Formation and Hazira Formation (Galdanian Facies) in the Kakul Mine. Phosphorite layers (black color) occur just below the boundary.

e. A close-up view of a conglomerate containing chert granules of the Upper Unit, Sirban Dolomite Member of the Abbottabad Formation. Angular chert grains are dispersed in dolomite matrix.

comprised of angular to subangular chert grains dispersed in dolomite matrix (Figure 4-e). All of the phosphorite deposits show characteristic pelletal and oolitic texture under the microscope. The pellets and oolites vary in size from 0.1 -1 mm in length and 0.2 -0.5 mm in width. The oolites are often composite. The phosphate content in phosphorite layers and associated cherty dolomites vary from place to place (minimum 1 to 5 %, maximum 50 % or more; Latif, 1974b; Hasan and Ghaznavi, 1980; Hasan, 1986; Husain et al., 1990).

Table 2. Results of XRF analysis of some representative samples collected from the Kakul Mine (analyzed by Shehzad Hassan). Microscopic photographs of some samples are shown in Figure 5.

Sample No	KA-14	KA-11	KA-13	KA-12	KA-5	KA-6	KA-7	KA-8	KA-3
Lithology	dol	dol ss	dol ss	qz	ch. dol	ms	ms	ss	iron ms
Formation	Abb.	Abb.	Abb.	Abb.	Abb	Hazira	Hazira	Hazira	Hazira
Unit or Facies	Lower	Middle	Middle	Middle	Upper	Hazira	Hazira	Hazira	G
SiO_2	0.32	60.97	72.39	95.91	10.53	50.31	67.19	69.19	33.97
TiO_2	0.01	0.03	0.02	0.04	0.01	0.64	0.55	0.86	0.56
Al_2O_3	0.42	1.18	1.31	2.24	0.48	9.70	9.55	12.78	13.14
Fe_2O_3	0.81	0.60	0.53	0.18	0.17	4.86	6.85	3.98	36.45
MnO	0.07	0.08	0.07	0.02	0.06	0.15	0.08	0.08	0.01
MgO	22.07	2.58	4.66	0.07	19.89	5.89	1.86	2.17	0.56
CaO	29.94	17.69	8.69	0.06	26.82	9.27	3.77	0.93	4.22
Na_2O_3	0.00	0.01	0.07	0.09	0.00	0.04	0.05	0.05	0.00
K_2O	0.02	0.31	0.47	1.11	0.03	4.84	4.85	6.71	3.04
P_2O_5	0.03	0.19	0.17	0.01	0.01	0.38	1.39	0.50	4.73
LOI	46.31	16.37	11.63	0.29	42.01	13.94	3.87	2.75	3.31
Total	100.00	100.01	100.01	100.02	100.01	100.02	100.01	100.00	99.99

Sample No.	KA-9	KA-10	KA-1	KA-2
Lithology	qz	qz	ls	ls
Formation	Samana	Samana	Samana	Samana
SiO_2	96.88	96.98	5.65	2.49
TiO_2	0.01	0.26	0.12	0.04
Al_2O_3	0.76	1.26	2.30	1.11
Fe_2O_3	0.70	0.57	1.20	0.36
MnO	0.04	0.02	0.12	0.04
MgO	0.20	0.09	5.25	0.30
CaO	0.64	0.20	44.32	53.32
Na_2O_3	0.00	0.00	0.01	0.00
K_2O	0.06	0.24	0.57	0.23
P_2O_5	0.02	0.00	0.02	0.02
LOI	0.71	0.38	40.45	42.09
Total	100.02	100.00	100.01	100.00

Abbreviation:
dol ; dolomite
dol ss ; dolomitic sandstone
qz ; quartzite
ch. dol ; cherty dolomite
ms ; mudstone
ss ; sandstone
ls; limestone
Abb. ; Abbottabad
Samana . Samana Suk
G ; Galdanian

3. Hazira Formation (redefined from Gardezi and Ghazanfar, 1965)

Name : The formation is named after the village of Hazira, located in the northwestern part of the study area.

Historical background : The present formation has been called by two names: the Hazira Formation and the Galdanian (or Shekhan Bandi) Formation (Table 1). The Hazira Formation was first introduced by Gardezi and Ghazanfar (1965) for a predominantly shale-siltstone unit exposed near the village of Hazira. The Galdanian Formation was proposed by Latif (1970) for hematitic shales distributed near the village of Galdanian in the middle eastern part of the mapped area. Because both of the formations are underlain by the Sirban Dolomite Member of the Abbottabad Formation and unconformably overlain by the Samana Suk Formation, Shah (1977) and Hasan (1986) included the Galdanian Formation into the Hazira Formation. As a lateral change between hematitic mudstone and grey mudstone is observed near Lagarban, the present authors apply "Galdanian" as a facies name to hematitic mudstone in this formation.

Stratotype : The type section has not been defined by any authors.

Lithofacies : The formation consists mainly of weakly undulated mudstone and sandstone, and forms valleys and saddles as shown in Figure 4-c. The formation can be divided into two facies: Hazira and Galdanian Facies (Figure 2). The two facies mostly separated by faults from each other, but a lateral change is observed between red hematitic mudstone and grey to dark grey mudstone and siltstone near Lagarban (Appendix I and Figure 7).

Stratigraphic relationship : The formation disconformably overlies the Abbottabad Formation (see Discussion).

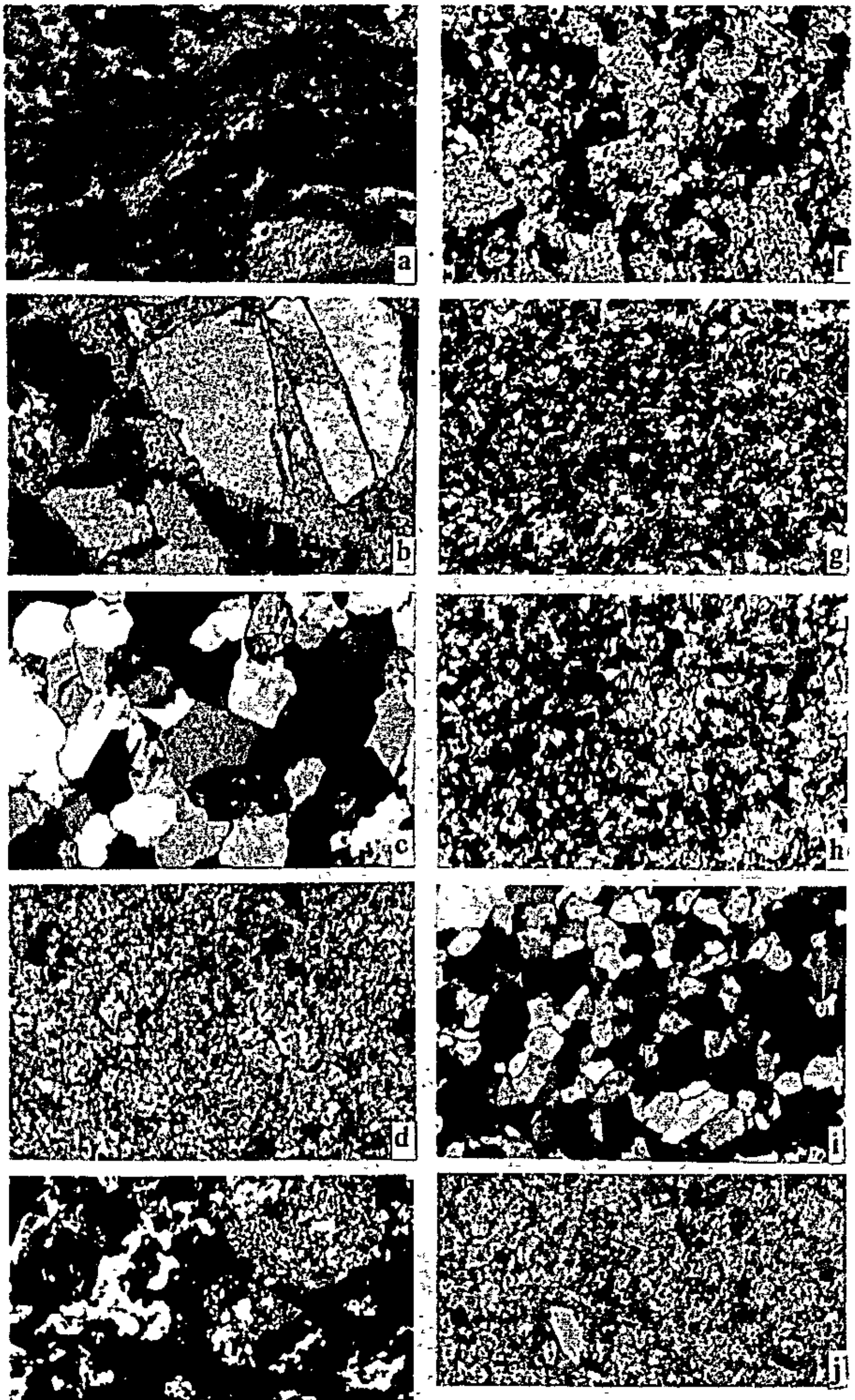
Age : The formation yield phosphatic fossils, which indicate Early Cambrian (see Discussion).

3-1. Hazira Facies

Distribution : This facies is mainly distributed in the western part of the study area (Appendix I).

Thickness : The facies varies from 50 to 140 m thick (Table 3). The previous workers estimate it at 1000 feet thick (about 300 m; Gardezi and Ghazanfar, 1965) and 91 m thick (Hasan, 1986).

Lithology : The Hazira Facies mainly consists of dark grey to greenish brown, finely-laminated calcareous mudstone and siltstone in the lower part (Figure 3-c) and dark grey-colored, very fine-grained sandstone in the upper part. The mudstone and siltstone are flaggy and glauconite along the bedding planes (Figure 3-c). The glauconites are pelletal in shape and range from 0.1 to 1 mm in long (Figure 5-f). The


a
b
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1 mm

dark grey sandstone in the upper part is dark grey- to brown-colored and blocky on the weathering surfaces. The mudstone and sandstone consist fine-grained aggregate of quartz, calcite, and small amounts of hematite and mica in a clayey matrix (Figures 5-g and 5-h). Chemical compositions of the rocks in this facies and the Galdanian facies are shown in Table 2. It indicate that the Hazira Facies is richer in SiO_2 and poorer in Fe_2O_3 than the Galdanian Facies.

3 -2. Galdanian Facies

Distribution : This facies is mainly distributed in the eastern part of the study area (Appendix I).

Thickness : The thickness of the facies varies from 50 and 80 m (Table 3).

Lithology : The Galdanian Facies is characterized by red- and chocolate-colored hematitic mudstone and siltstone in the lower part and grey to reddish brown, fine- to medium-grained quartzite in the upper part. Massive, compact and hard breccias are occasionally found in the upper part, composed of cherty to quartzitic fragments in a matrix of red siltstone. The mudstone occasionally contains a lot of worm burrows (Figure 3-e).

Figure 5. Microscopic photographs (Thin sections are prepared by Shehzad Hassan). Scale bar shows 1 mm for all photographs. Chemical composition of samples are listed in Table 2.

a. An upward-curved algal mat in dolomite. Lower Unit, Sirban Dolomite Member of the Abbottabad Formation. Open nicol. Sample No. KA-14.

b. Dolomitic sandstone. Fractured quartz grains filled with dolomite. Middle Unit, Sirban Dolomite Member of the Abbottabad Formation. Crossed nicol. Sample No. KA-11.

c. Quartzite. Quartz grains display a typical mosaic texture. Matrix is very poor. A few grains of microcline and tourmaline can be observed. Middle Unit, Sirban Dolomite Member of the Abbottabad Formation. Crossed nicol. Sample No. KA-12.

d. Dolomite. Fine-grained dolomite associated with rhomboid shaped crystals. Upper Unit, Sirban Dolomite Member of the Abbottabad Formation. Open nicol. Sample No. KA-5.

e. Hematitic rock. Irregular shaped hematite (black color) and quartz (white color) are observed. A glauconitic ooid is also contained (upper right). Galdanian Facies of the Hazira Formation (lower part). Crossed nicol. Sample No. KA-3.

f. Glauconitic mudstone. Ooids and pellets of glauconite occur in a quartz-hematite-clay minerals matrix. Hazira Facies of the Hazira Formation (lower Part). Crossed nicol. Sample No. KA-7.

g. Siltstone. Sub-angular to sub-rounded detrital grains of quartz and feldspar dispersed in a clayey matrix. Micas are also observed. Hazira Facies of the Hazira Formation (lower part). Crossed nicol. Sample No. KA-6.

h. Sandstone. Fine-grained sandstone of quartz- to lithic-wacke type. Hazira Facies of the Hazira Formation (upper part). Crossed nicol. Sample No. KA-8.

i. Quartzite. Subrectangle to polygonal quartz grains weakly tectonized. At the base of Samana Suk Formation. Crossed nicol. Sample No. KA-10.

j. Limestone. Some micro-fossils and detrital quartz grain (lower left) are observed. Samana Suk Formation. Open nicol. Sample No. KA-1.

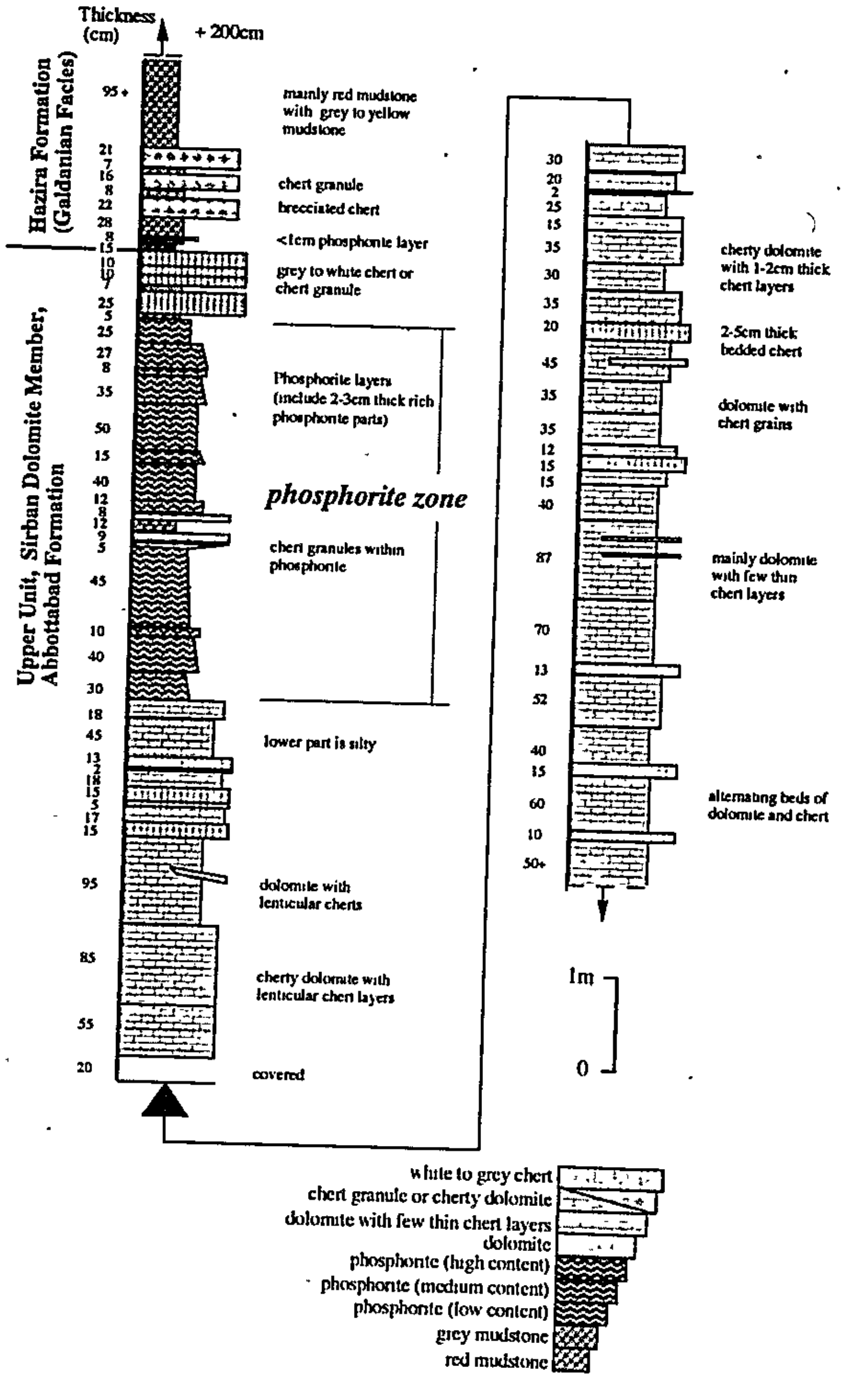

Figure 6. A columnar section of the KM-I Section, Kakul Mine, showing a lithologic change from the Abbottabad Formation to Galdanian Facies of the Hazira Formation. The location of the section is shown in Figure 7.

A few phosphorite layers are intercalated in the lower part near Galdanian (Appendix I). The phosphorites in this facies are microscopically close to those in the Sirban Dolomite Member. Though rhyolite is reported from the facies (Middlemiss, 1896; Marks and Ali, 1961; Hasan and Ghaznavi, 1980), the authors could not find any volcanic materials in the facies. Under the microscope, the red mudstones are highly oxidized and quartz grains are floated in a matrix of hematite and goethite, associated with chlorite, glauconite, and sericite (Figure 5-e). The chemical composition is marked by a high content of Fe_2O_3 and low content of SiO_2 (Table 2).

4. Samana Suk Formation (Fatmi, 1977)

Name : The formation name is derived from Samana Range, N.W.F.P. Province.

Stratotype : The type section of the formation is in Shinawari, Samana Range.

Distribution : The formation is widely distributed in the study area (Appendix I).

Thickness : It is estimated at 350 m in the study area (Table 3). In the type section, the formation is 190 to 366 m thick (Iqbal and Shah, 1980).

Lithology : The formation consists of thick-bedded fossilferous limestone and oolitic limestone with dolomite, calcareous sandstone, and ferruginous sandy limestone. The basal part of the formation is marked by a 5 m-thick whitish grey and very fine-grained quartzite beds. The quartzite is intercalated with calcareous sandstone, and shows mosaic texture under the microscope (Figure 5-i). The overlying limestone ranges in thickness from 10 to 30 cm or more, whereas the calcareous sandstone varies between 1 and 7 cm thick. The limestone is light grey to dark grey and micritic, containing a lot of shell debris and gastropods. It is characterized by groove-shaped weathering surfaces (Figure 3-f). Detrital quartz and feldspar grains are also found in limestone under the microscope (Figure 5-j). The calcareous sandstone is fine- to medium-grained and yellowish brown-colored, occasionally showing graded bedding and cross-laminations (Figure 3-g). Intense bioturbation has transformed the sandstone intercalations to yellow-colored patches floating in a grey-colored matrix of limestone (Figure 3-g).

Stratigraphic relationship : The Samana Suk Formation unconformably overlies the Hazira Formation. Despite a large time gap, the boundary between the Hazira and Samana Suk Formations is nearly parallel to the bedding planes of the both formations.

Age : Well preserved micro- and mega-fossils are found in the study area. The age of the formation has been assigned to Middle Jurassic (Fatmi, 1977).

Table 3. Thickness of rock units measured along various cross-sections in the study area. Section lines and distribution of structural domains are given in Figure 7. Fm., Formation; C / L Fm., Chichali and Lumshiwal Formation; Abb., Abbottabad; Dol., Dolomite.

Domain		Section	Kawagah Fm.	C / L Fm.	Samana Suk Fm	Hazira Fm		Abb Fm., Sirban Dol. Mem.		
						Galdanian	Hazira	Upper	Middle	Lower
α	α-1	M-N						# 70		
		E-F						# 70		
		X-Y						# 100		
	α-2	E-F			# 240					
		G-H			? 20	**80**		# 50		
		X-Y			# 220	**80**		? 0 - 200		
β	β-1	I-J			? 250		**140**	# 30		
		A-B			# 180		# 100	# 20		
		K-L			# 300		# 60			
		C-D			? 120		? 100			
	β-2	I-J			# 80		**100**	? 120		
		A-B			# 40		**100**	? 100 - 200		
		K-L					# 100	# 100 - 200		
		C-D			? 330		? 100			
		M-N			? 240					
		G-H			# 70		**120**	? 200	? 200	
		O-P					? 120	**200**	? 200	
		X-Y					# 120	**200**	**200**	? 200
	β-3	I-J			? 130 -280	**50**		? 50-100		
		A-B			? 60		**50**	? 160-200		
		K-L					# 50	# 200		
		C-D			? 120		? 50	# 100		
		M-N			? 220		# 50			
		E-F			? 150		**100**	? 60 -200		
		G-H			# 80		**120**	# 200		
		O-P						? 200		
γ	γ-1	A-B				# 70		# 90 - 200		
		K-L						# 120		
		C-D				# 20		# 180		
		M-N			# 350	? 70				
		E-F			? 80	**80**		# 120		
		G-H			? 120	**80**		# 200		
		O-P			# 20	# 20		# 60		
	γ-2	K-L				# 60		? 200		
		C-D			? 20	**80**		# 180		
		M-N			? 150	? 80				
		E-F			# 110	**60**		# 120		
		G-H			# 20					
δ	δ-1	I-J		?	? 300					
	δ-2	A-B				**30 - 70**				
	δ-3	A-B			# 300	70		? 100		
		K-L			? 140	**60**		# 140		
		C-D				? 70		# 80		
		M-N			? 350	# 70		# 20		
	δ-4	K-L			# 200	**80**		? 80		
		C-D			# 60	**80**		# 50		
		M-N				# 60		# 80		
	δ-5	C-D	?	**40**	? 150					
		M-N	? 400	**50**	? 120					
	δ-6	E-F	? 180	**140**	? 300					
		G-H			? 300					

Gothic : confirmed thickness, # : bounded by fault, ? : estimated

5. Chichali / Lumshiwal Formation (Fatmi, 1977)

Name : The formation names are derived from the name of a pass located in the Surghar Range, and a nala (river) name in the Salt Range, Punjab Province, respectively.

Stratotype : The type sections of the formations are in Chichali Pass, Surghar Range, and Lumshiwal Nala, Salt Range, respectively.

Historical background : The Chichali and Lumshiwal Formations in the study area were described as the Spiti shale and Giumal sandstone by Latif (1970). But Calkins et al. (1975) and Hasan and Ghaznavi (1980) combined the both formations into one unit, the Chichali / Lumshiwal Formation. The authors follows the opinion of Calkins et al. (1975) and Hasan and Ghaznavi (1980).

Distribution : The formation is exposed near Lagarban, Maira, and Balolia in the western part of the study area (Appendix I).

Thickness : In the study area, the formations are 40 to 50 m thick in Maira and 140 m in Balolia (Table 3). Hasan and Ghaznavi (1980) estimates it less than 15.4 m.

Lithology : The formation consists mainly of glauconitic sandstone, associated with some nodular silty calcareous phosphorite and glauconitic sandy mudstone. The sandstone is greenish grey to light grey in color, soft, and massive. The sandy mudstone is black to grey in color, very soft, and massive.

Stratigraphic relationship : The Chichali / Lumshiwal Formation conformably overlies the Samana Suk Formation.

Age : Poorly preserved ammonites and belemnites are found in sandy mudstone. The age of the formations is assigned to Tithonian (Latest Jurassic) to middle Albian (Early Cretaceous) by Fatmi (1977).

6. Kawagarh Formation (Fatmi, 1977)

Name : The formation is named after the name of a hill located in Punjab Province.

Stratotype : The type section of the formation is in Kawagarh Hill, Punjab Province (Fatmi, 1977).

Historical background : The Kawagarh Formation in the study area was designated the Chanali limestone by Latif (1970). Subsequently, Calkins et al. (1975) and Hasan and Ghaznavi (1980) correlated this unit to the Kawagarh Formation.

Distribution : The formation is distributed near Maira and Balolia area in the eastern part of the study area (Appendix I).

Thickness : The thickness of the formation exceeds 400 m (Table 3).

Lithology : The formation is composed largely of thin- to thick-bedded, brownish grey to grey limestone, intercalated with sandstone. As mentioned by Hasan and Ghaznavi (1980), it is rather difficult to distinguish the Kawagarh Formation from the Samana Suk Formation in the field. However, the Kawagarh Formation lacks "yellow patches" of bioturbated sandstones and oolites characterizing the Samana Suk Formation.

Stratigraphic relationship : Though the relationship between the present formation and the underlying Chichali / Lumshiwal Formation looks conformable, Hasan and Ghaznavi (1980) regard it as disconformable on the basis of the missing of fossils representing Cenomanian and Turonian.

Age : The authors could not find mega-fossils from the formation. Latif (1970) found foraminifers ranging from late Coniacian to Campanian (Late Cretaceous).

STRUCTURE

The study area is sandwiched by two major faults, the Panjal Thrust on the NNW side and the Nathia Gali Thrust on the SSE side (Figure 1). The metamorphic and sedimentary sequences in the study area are strongly deformed, and form complicated structure by many faults and folds. By a detailed mapping, however, the study area can be structurally divided into four major domains, namely the Domain α, β, γ, and δ, from west to east separated by the Nare Di Gali, Kakul and Galdanian Faults (newly proposed). The simplified structural map showing the distribution of structural domains and major faults is given in Figure 7.

1. Fault

Many of the faults developed in the study area generally parallel to the two major faults, Panjal and Nathia Gali Thrusts. The faults strike NNE-SSW nearly parallel to the bedding planes. They are mostly thrust faults, but their inclination is moderate to steep with westward or eastward direction. High angle normal faults are also recognized in the study area, and clearly cut the thrust faults. Amplitude of dislocation by the faults could not be estimated except a few faults, because the fault planes are generally parallel to the bedding planes. The followings are major faults separating the structural domains described below.

1-1. Panjal Thrust (Calkins and Martin, 1968)

The Panjal Thrust, which is one of the most important thrusts in the Hazara Division, separates the Hazara / Tanawal Formation in the hanging wall from Cambrian

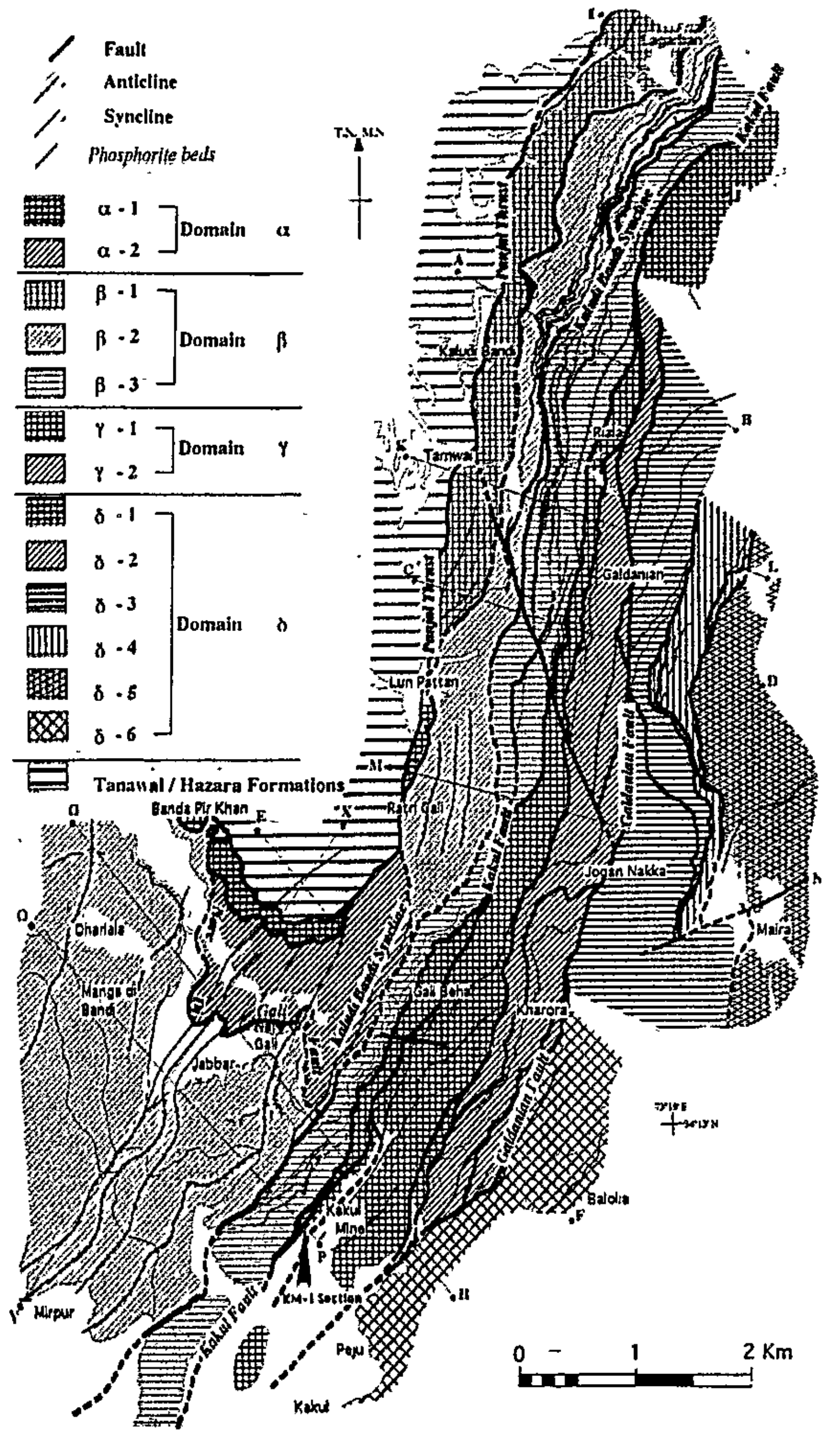

Figure 7. A diagram showing the distribution of structural domains in the study area.

to Cretaceous sedimentary rocks in the foot wall. The fault has been called by various names such as the Panjal Thrust (Calkins and Martin, 1968; Latif, 1970; 1974b; Yeats and Hussain, 1987), Tarnawai Fault (Hasan and Ghaznavi, 1980), and Tarnawal Fault (Hasan, 1986). In the southwestern part of the study area, the Panjal Thrust strikes NW-SE to E-W, and dips moderately to the north. Thus, the thrust forms a convex shape toward south. Then, the thrust abruptly changes the trend from E-W to NNE-SSW or N-S in the northern part of the area (Appendix I). Moreover, the thrust has been entirely overturned by subsequent deformations. The thrust plane observed on a road side in Tarnwai strikes N 60° E, and dips 60° SE. The Hazara / Tanawal Formation looks like forms a foot wall of a normal fault. However, the younger sequence distributed to the east of the fault is totally overturned to the southeast, paralleling to the fault planes of the Panjal Thrust. Therefore, this fault plane is considered to have been overturned along with the overlying rock sequence in the northern part of the area.

1-2. Nare Di Gali Fault (newly proposed)

The fault is located to the south of the southerly convex of the Panjal Thrust and forms a border between the Domain α on the north and the β on the south. The fault plane generally dips to N, and nearly parallel to the bedding planes of both walls (see cross section G-H of Appendix II). The Nare Di Gali Fault plane has been deformed by open and symmetrical folds.

1-3. Kakul Fault (newly proposed)

The fault is a boundary between the Domain β and γ. The fault runs in a NNE-SSW direction and dips moderately to steeply to the northwest. The Kakul Fault, which shows an inclined trend to the Panjal Thrust in the southern area, parallels it toward the north.

1-4. Galdanian Fault (newly proposed)

The Galdanian fault separates the Domain γ on the west from the Domain δ on the east. The fault plane steeply dips to the east or west. In the northern part of the area, the fault joins with the Kakul Fault.

2. Fold

Two type of folds are recognized in this area: tight and open ones. The tight folds are developed in the eastern and northern parts of the study area, and show asymmetrical profiles. The half wavelength of the folds varies from 100 to 300 meters. Their fold axes are generally parallel to the thrust planes, trending NNE-SSW. The eastern or

Table 4. A comparison of characteristic features of the four structural domains.

Domain	α	β	γ	δ
Abundance of phosphorite	very poor	abundant	moderate (Kakul Mine)	none
Facies type of Hazira Formation	Galdanian Facies	Hazira Facies partly Galdanian Facies	Galdanian Facies	Galdanian Facies
Fold type	open	open (southern part) tight (northern part)	tight	tight

southeastern limbs of folds are mostly truncated by the thrust faults. Their fold axes plunge moderately to the north or south. The fold planes dips to the east or west, and are sometimes affected by subsequent deformations leading to overturning (see cross section A-B in Appendix II).

In marked contrast to the tight fold, the open folds recognized in the southwestern part of the area display symmetrical profiles and their axial planes are mostly vertical. Their full wavelength is about 500 m (see cross-section G-H of Appendix II). Their axes plunge gently to the north. The open folds have obviously deformed the Panjal Thrust and Nare Di Gali Fault.

3. Structural domain

The study area can be divided into four structural domains (thrust sheets); Domain α, β, γ, and δ (Figure 7). Each of the domains is characterized by the abundance of phosphorite and the facies of the Hazira Formation (Table 4).

The Domain α sandwiched between the Panjal Thrust and the Nare Di Gali Fault is marked by very poor occurrence of phosphorite, the predominance of the Galdanian facies in the Hazira Formation, and open folds. The Domain α is subdivided by a thrust into two sub-domain: α -1 and α -2.

The Domain β is characterized by the abundance of phosphorite deposits and the prevalence of the Hazira Facies. Tight folds are developed in the northern part of the domain, while open folds are observed in the southern part. The domain is subdivided by thrust faults into three sub-domain: β -1, β -2, and β -3.

The Domain γ is marked by a moderate development of phosphorite deposits including the Kakul Mine, predominance of the Galdanian Facies, and tight folds. The domain is divided into two sub-domain: γ -1 and γ -2.

The Domain δ is featured by the lack of phosphorite, predominance of Galdanian Facies, and tight folds. The domain is subdivided into six: sub-domain δ -1 to δ -6.

Thus, it is noticeable that the phosphorite deposits are abundant in a domain characterized by the Hazira Facies like in the Domain β, whereas the Galdanian Facies-dominated domains are generally poor in phosphorite.

DISCUSSION

1. Ages of the Abbottabad and Hazira Formations

The ages of the Abbottabad and Hazira Formations have been determined by the occurrences of phosphatic micro-fossils. Shah (1977) reports the occurrence of phosphatic tube *Hyolithellus* spp. with *Hyolithes* spp. from the upper part of the Abbottabad Formation, which probably corresponds to the Upper Unit of the Sirban Dolomite Member in the study area. However, the exact location and stratigraphic horizon of the fossils are unknown. On the other hand, *Allonnia tripodophora* and other many phosphatic fossils are found in the lower part of the Hazira Facies of the Hazira Formation in the Sarbun Hill (Latif, 1972b; Fuchs and Mostler, 1972; Rushton, 1973).

Brasier (1989) reports the occurrence of fauna similar to those of the Hazira Formation from the Zone III to V of the Meishucun section, China, suggesting the upper part of the Abbottabad Formation and the lower part of the Hazira Formation are correlative to the Zone I and Zones III to V of China standard section (Figure 8). The base of the Zone I is probably correlated to Precambrian - Cambrian boundary, and Zones I to III and IV to V are correspond with Meishucunian (Chinese stage = Tommotian, Earliest Cambrian) and Quiongzhusian (Chinese stages = Atdabanian, Early Cambrian), respectively (Brasier, 1989; Brasier et al., 1990).

2. Stratigraphic relationship between the Abbottabad and Hazira Formations

The stratigraphic relationship between the Abbottabad and Hazira Formations have been argued (Table 1). Hasan and Ghaznavi (1980) and Hasan (1986) regard the stratigraphic relationship as conformable, whilst Latif (1974a) regards it as disconformable (Latif, 1974a). Marks and Ali (1961) and Ashraf and Chaudhry (1987) consider it as unconformable.

Based on (i) an abrupt facies change between the Abbottabad and Hazira Formation, (ii) a close similarity of the lithostratigraphical sequence between the present area and the Meishucun section (Figure 8) in China, where extinction of some taxa and negative isotopic (δ ^{13}C and δ ^{18}O) change representing a sedimentological break are recognized (Brasier 1989; Brasier et al., 1990), (iii) occurrence of glauconite indicative of a sedimentary break at the base of the Hazira Formation, the authors prefer a disconformable relationship.

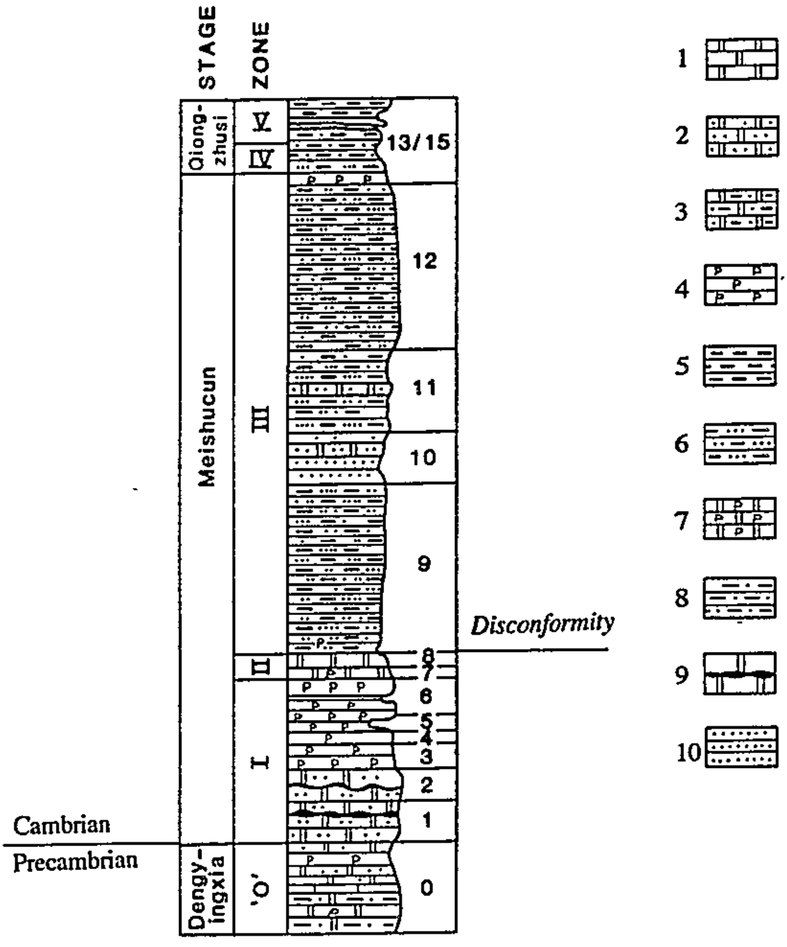

Figure 8. A stratigraphic column of the Meishucun section, Yunnan in China (slightly modified from Brasier, 1989; Figure 3.2). See the text for discussion. 1, dolomite; 2, sandy dolomite; 3, sandy argillaceous dolomite; 4, phosphorite; 5, argillite; 6, argillaceous siltstone; 7, phosphatic dolomite; 8, sandy argillite; 9, dolomite with chert bands; 10, sandstone.

3. Environmental change between the Abbottabad and Hazira Formations

A remarkable facies change from a carbonatic formation to a clastic formation is recognized at the boundary between the Abbottabad and Hazira Formations (Figure 2). Besides, the change is accompanied by the formation of peculiar sediments, such as phosphorite, and hematitic and glauconitic mudstones (Figure 7).

A similar lithologic change from calcareous to clastic sediments associated with phosphorite has been recognized along Gondwana from China to Iran during the transitional period from Precambrian to Cambrian age (Cook and Shergold, 1986;

Shergold and Brasier, 1986; Brasier, 1989). A comparison with the Meishucun section (Figure 8), representing a standard section of Gondwana region, with the stratigraphic section of the study area (Figure 2) indicates a marked similarity between both areas.

Brasier (1992) suggested that a change from "icehouse" condition in Precambrian age to a "greenhouse" condition in Cambrian age triggered a widespread transgression, which brought, in turn, un-mixed, nutrient rich bottom waters onto the shelf to form phosphorite and ferruginous mudstone.

Thus, the facies change found from the Abbottabad to Hazira Formations and its close association with the formation of phosphorite and ferruginous sediments probably represent a widespread rapid transgression that occurred along the Gondwana including the study area in Early Cambrian age.

4. Structural Development

As previously mentioned, the study area is divided into a plenty of thrust sheet designated as structural domains and sub-domains. The thrust sheets are overturned in the northern area, whereas they maintain the original mode of occurrence in the southern part.

As for such a structural difference, there have been proposed two school of interpretations. One of them (Coward and Butler, 1985; Butler and Coward, 1989), who studied the structure of northern Pakistan, argued that overturned thrusts could be simultaneously generated with gently dipping thrusts by introducing a mechanism of a passive back-rotation that an obstacle causes at the frontal part of the thrust sheets. Another school of interpretation is proposed by Bossart et al. (1984) who interpreted the generation of the Hazara - Kashmir Syntaxis by at least two phase of tectonic movements: (i) formation of a series of thrust sheets, (ii) the secondary deformation of these thrust sheets by a left-lateral shearing.

The fact that the trend of the Panjal Thrust in the study area and the Nathia Gali Thrust abruptly changes from E-W to NE-SW or N-S (Figures 1 and 7), suggests the interpretation by Bossart et al. (1984). Because the mechanism proposed by Coward and Butler (1985) and Butler and Coward (1989) can not change the trend of the thrusts. The fact that the study area is located in the western limb of the Hazara - Kashmir Syntaxis implies such an abrupt change in trend of these major thrusts associated with overturning formations is attributed to the formation of the Hazara - Kashmir Syntaxis.

CONCLUSIONS

Based upon the detailed geologic mapping, the authors have attained to the following facts:

(1) The Sirban Dolomite Member is subdivided into three units; the Lower, Middle and Upper Units.

(2) The Hazira Formation is divided into two facies, the Hazira and Galdanian Facies. The both facies laterally changes each other.

(3) The economically important phosphorite deposits are recognized at least three levels in the upper part of the Upper Unit of Sirban Dolomite Member. Thin phosphorite beds also occur in the lower part of Galdanian Facies of the Hazira Formation. The phosphorite deposits show generally nodular or ooid-like structure, and are intercalated in dolomite. The phosphorite horizons are variable in thickness, reaching 5 m thick in maximum.

(4) The mapped area can be structurally divided into four major domains (thrust sheets): Domain α, β, γ, and δ. The Domain β is characterized by the abundance of phosphorite deposits and the prevalence of the Hazira Facies of the Hazira Formation. On the other hand, the Galdanian Facies-dominated domains, Domain α, γ, and δ, are generally poor in phosphorite.

(5) Stratigraphical relationship between the Abbottabad and Hazira Formations is disconformable. An abrupt lithological change from carbonatic facies to clastic facies occurred at the boundary. This change is associated with deposition of phosphorite and ferruginous sediments indicative of a widespread rapid transgression along Gondwana.

(6) The overturning of thrust sheets in the northern part of the study area indicates the two phase of tectonic movements : (i) Southward thrusting to form a series of E-W trending thrust sheets and (ii) a secondary deformation of the thrust sheets probably derived from a left-lateral shearing related to the formation of Hazara-Kashmir Syntaxis.

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Preliminary Results of Study on Genesis of Kumhar Magnesite, Hazara, Pakistan

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ABSTRACT

The 14 lenticular bodies of the magnesite ore are found in Kumhar, Sherwan area. Lense Nos. 1 & 2 are the biggest and have been studied in relatively more detail. The total reserves are 6.2 million tons and the proved reserves of lense No. 1 & 2 are 2.98 million tonnes with an average of 45% MgO content.

Preliminary result show that the magnesite is formed due to hydrothermal activity. The solutions rich in Mg replaced Ca from the host dolomitic limestone of Abbottabad Formation and enriched Mg to form magnesite. The homogenization temperature of fluid inclusions varying from 150°C to 350°C suggest close relationship of hydrothermal activity with the mineralization of magnesite ore.

INTRODUCTION

The Geoscience Laboratory of the Geological Survey of Pakistan started a project on the genesis of Kumhar magnesite ore deposite using the latest analytical facilities. The project was also aimed to see the suitability of this magnesite for its use for making refractory bricks and to replace serpentinite in manufacture of fused magnesium phosphate fertilizer (FMP). This is a preliminary report dealing with the genesis of the magnesite.

The Kumhar magnesite ore deposit is located in Hazara at about 35 Km west of Abbottabad at 34°11'23" latitude and 73°05'45" longitude (Figure 1). Rugged mountainous terrain characterizes the area. Sherwan is main town in the investigated area and is famous for the soapstone and barite mining. There are also indications of sulphide mineralization in this area. Lead-zinc mineralization in Soban Gali (Figure 1) and barite near Sherwan have been repoted (Ali, et al.,1964, 1969).

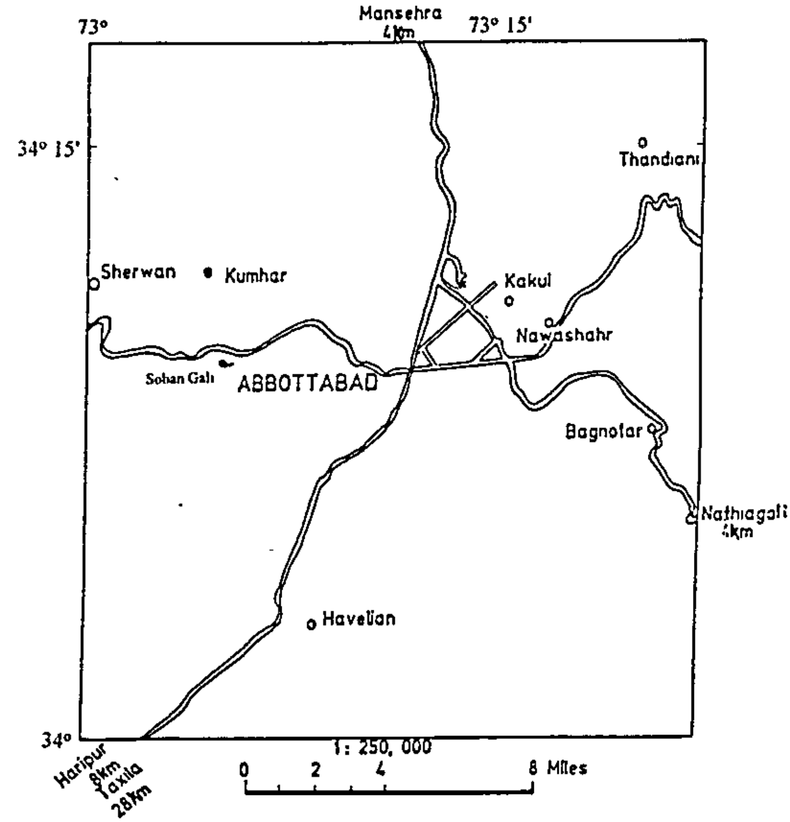

Figure 1. Location map of study area.

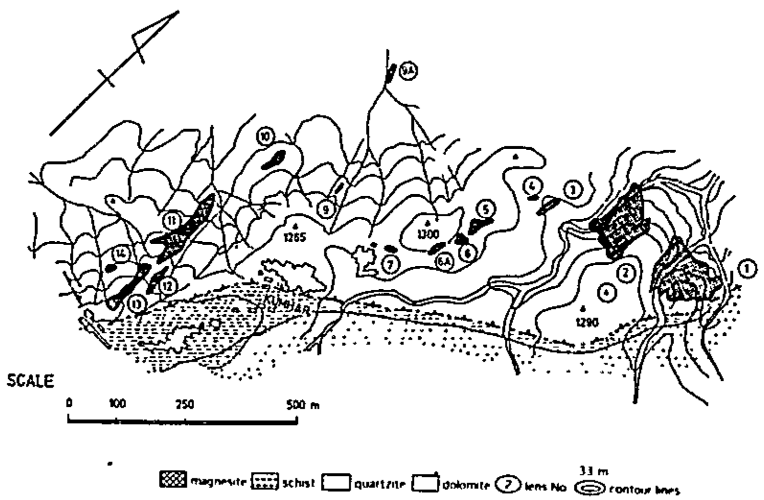

Figure 2 Distribution map of magnesite lenses in Kumhar mine

HISTORY OF MINE

Pakistan Industrial Development Corporation started the work in 1968 and mapped the magnesite bearing area on 1:600 scale, (Siddique and Alam, 1968). They showed the distribution of the magnesite in the area and estimated the inferred reserves of the magnesite. In 1971 an agreement between PIDC and the Ministry of Metallurgical Industry, People's Republic of China was signed to conduct plant tests for manufacturing refractory bricks using Kumhar magnesite and Malakand chromite. The results were quite encouraging, and it was reported that the magnesite and chrome-magnesite bricks could be manufactured with the Kumhar magnesite. Later on Min-Koh International Consultant, a Chinese geological consultant, made another contract in 1979 with PIDC for the exploration of lens No.1 & 2. During this study detail mapping with aditing for the reserves estimation were done and 3 million tons proved reserves were reported. Based on their recommendations later on 10 drill holes with total run of 1000 m were drilled. In 1981 another contract was signed with the Japan Consulting Institute for the feasibility study for construction of manufacturing plant for refractory bricks. The feasibility study was made for an annual output of 15,400 tons. Mononobe et al., (1992) and Karim & Kaneda (1994), did some work on the reserves calculation and the genesis of the magnesite ore respectively.

The PIDC started mining of the ore in 1990 with an average of 500 tons per month, and the average grade is about 45% MgO. The ore is supplied to different agencies in Hasanabdal and Rawalpindi. The magnesite is mainly used for making refractory bricks. The production of the ore varies and depends upon the demand. Similarly the labor is also hired on demand. Normally 7 to 10 laborers are working at the mine site.

REGIONAL GEOLOGIC SETTING

Hazara area is part of Indian plate and is situated between two main tectonic boundaries, the Main Mantle Thrust (MMT) in the north and the Main Boundary Thrust (MBT) in the south. It lies on the western flank of the famous Hazara-Kashmir syntaxial bend. The area is characterized by exceedingly complex structures and regionally metamorphosed rocks with northward increase in metamorphic grade (Calkins, et al., 1967).

In the Hazara area the rock facies of Cambrian to Cenozoic age overlie the late Precambrian Tanawal and Hazara Formations. The rocks are thrusted southward in a series of imbricated sheets and duplexes. Most of the contacts between the formations are faulted. Three major unconformities are developed in the Hazara area. The base of Cambrian sequence is marked by a bed called Tanakki conglomerate, which has clasts of metasedimentary rocks, derived from the underlying Hazara Formation of Precambrian age

(Baig et al., 1988). The second unconformity is between the Hazira Formation of Cambrian age and Samana Suk Formation of Jurassic age (Ghaznavi et al., 1983). The Cretaceous-Tertiary boundary is marked by laterite and ferruginous pisolite, known as Longrial iron ore (Khan & Ahmad 1967).

Local Geology

In the investigated Kumhar area only two formations are exposed, Tanawal and Abbottabad Formations. The Abbottabad Formation has a faulted contact with the Tanawal Formation. Only the upper member of the Abbottabad Formation is exposed in the area. The upper part of the Abbottabad Formation is not present here, probably eroded, because in the nearby Barkot area, south west of Kumhar, phosphorite is found at the contact of Abbottabad and Hazira Formations (Hasan et al., 1985). The general description of the two formations is given below.

Tanawal Formation

The Tanawal Formation was originally named as Tanol group by Wynne (1879) for a sequence of quartzite schist overlying the Hazara Formation. The Tanawal Formation is only found on the west of Panjal fault. It is composed of thinly laminated and low to medium-grade schist containing quartz and mica as major constituents, with quartzite and quartzose schist.

The Tanawal Formation is overlain unconformably by the Abbottabad Formation near Haripur (Ali, et al., 1964). In the Kumhar magnesite mining area, only cross bedded quartzite with interlayered quartz-mica schist is exposed and has faulted contact with the Abbottabad Formation. The age of the Formation is uncertain because no fossil has been found. In Mansehra and the surrounding area, Mansehra granite of Cambrian age has intruded the Tanawal Formation, therefore Precambrian age is assigned to this Formation.

Abbottabad Formation

The Abbottabad Formation was named by Marks and Ali (1962) to the sequence of dolomite and quartz sandstone exposed in Sarban hill area. The complete section with all the four members, Sangar gali, Mohammada gali, Mirpur Sandstone and Sarban member of the formation is exposed in the Sarban hill, Abbottabad (Latif, 1974). In the magnesite bearing area only lower part of Sarban member of Abbottabad Formation is exposed and is composed of mainly cherty dolomitic limestone. The lower contact of dolomite is faulted with Tanawal Formation.

On the basis of Hyollithes species, (Latif, 1974; Shah, 1977) found in the upper part of the Abbottabad Formation, an Early Cambrian age is assigned to this formation. In the upper part of the formation phosphorite deposition is found in Sherwan and Abbottabad areas (Hasan & Ghaznavi, 1980).

MINERALIZATION OF KUMHAR MAGNESITE DEPOSITE

The magnesite mineralization is classified into two groups, one is carbonate rock-hosted ore mineralization and another is ultrabasic rock-hosted ore mineralization. The carbonate rock-hosted mineralization is subdivided into two categories, sedimentary and hydrothermal type. Kumhar magnesite belongs to carbonate hosted ore mineralization formed by hydrothermal solutions.

The magnesite ores in the Kumhar mining area are restricted to dolomite of Early Cambrian age, and is distributed in about 2 sq km. area with 14 different lenticular bodies. The general trend of these lenses is NS in the western part, NE-SW in the central part and is EW in the eastern part. The distribution of the magnesite lenses show some alignment.

Out of the 14 lenses No.1 & 2 are the biggest and this study is based on the data of these two lenses. Lens Nos.1 & 2 are distributed on the both sides of a ridge 1290 m high. The Lens No. 1 is 110 m long and 87 m wide with a general E-W trend and dipping 60° northward. The lens No.2 is 150 m long and 82 m wide having general trend of NE-SW with northward dip of 65°. The depth of both these lenses is about 60m which is based on the data of drill hole No.10 which was deepest and was drilled to the depth of about 100m. This may be mentioned that the drill hole does not give the actual depth of magnesite, because it did not penetrated through the bottom of the lense.

The quality of the ores is not uniform through out the area. The northern lenses are good in quality with MgO more than 45%. The magnesium content vary from 25% to 45% in the southern lenses. The overall silica content is quite low but the southern lenses have higher percentage of silica as compared to the northern lenses. Good quality magnesite is crystalline, milky-white to whitish-gray in colour.

Reserves estimation

The subsurface data is not sufficient to give the true reserves. The total estimated reserves for all the 14 lenses at the Kumhar are about 6.2 million tons with 45% MgO on average. The proved reserves estimated by the Min Koh International Consultants (1980) are 1.84 million tons for the Lens No.1 and 1.14 million tons for the lens No.2, in total about 3 million tons.

The reserves are much more than the given ones but more systematic drilling is needed in the area to prove these reserves.

The mineralogical and geochemical examination of host dolomite and the magnesite ores have been carried out using XRD, DTA/TG, microscopic observation and fluid inclusion study, to know the ore-forming mechanism.

The magnesite is found both as amorphous and crystalline varieties. The analytical results show that the MgO content in magnesite is almost same in different samples (Table 1) and average is about 46.5 %. The FeO is very low (0.33% to 1.03%) in the magnesite.

The magnesite is formed by the replacement of Ca and enrichment of Mg in the dolomitic limestone by the Mg rich hydrothermal solution. The source of hydrothermal solution can be the Mansehra Granite which is in the north not very far from the main magnesite body. In the magnesite bodies the relic of unaltered bodies of dolomite are found. The homogenization temperature of fluid inclusion varies from 150°C to 350°C which suggests the magnesite mineralization was closely associated with the hydrothermal activities (Karim & Kaneda, 1994). The late stage hydrothermal solutions were rich in Mg and silica therefore at places along the fractures and joint planes the soapstone is formed which also confirms the hydrothermal origin.

Table 1: Chemical analysis of the magnesite , dolomite and soapstone from Kumhar area.

Sample No.	@1	•2	•3	+4	•5	•6	•7	@8	@1A
SiO_2	2.19	2.24	2.01	62.41	0.63	0.35	2.03	1.47	0.58
TiO_2	0.017	0.043	0.011	0.016	0.013	0.009	0.010	0.013	0.014
Al_2O_3	0.30	0.86	0.21	0.30	0.21	0.13	0.16	0.17	0.21
Fe_2O_3	0.45	0.44	0.33	0.26	0.36	1.05	0.36	0.50	0.39
MnO	0.039	0.031	0.027	0.006	0.028	0.051	0.029	0.041	0.032
MgO	22.23	46.29	46.79	32.11	46.90	46.52	47.11	22.06	23.66
CaO	28.88	0.74	0.88	0.04	0.78	0.29	0.49	29.55	28.84
Na_2O	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
K_2O	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
P_2O_5	0.043	0.042	0.011	BDL	0.009	0.002	0.012	0.005	BDL
LOI	45.86	49.31	49.74	4.86	51.07	51.60	49.80	46.19	46.26

@ Dolomite; • Magnesite; + Soapstone

Analysis carried out in the GeoLab by Iffat Jabeen & Muhammad Zafar.

CONCLUSION

Based on fluid inclusion studies and the field evidences, it is concluded that the Kumhar magnesite deposit was formed by hydrothermal activity which caused the replacement of the host dolomitic rocks. The mineralogical features are (1) the ore consists of magnesite, calcite, talc and small amount of quartz, and (2) dolomite, the host rock, is weakly disseminated with secondary calcite, quartz and talc.

The fluid inclusion studies showed that the geochemistry of ore-forming fluids of the Kumhar deposit is quite similar to that of hydrothermal vein type deposits. This suggests that the related igneous rocks might have existed in the nearby area (Mansehra granite ?). In the surrounding area, lots of other mineralized showings such as barite, soapstone, and Pb-Zn sulphides have been observed. In order to examine the mineralization in this area, the study of ore-forming fluids and related-igneous rocks should be carried out in more detail through the regional geochemical grid sampling and fluid inclusion studies.

As regards research of magnesite in the area, they appear adequate enough to meet all the foreseeable needs of Pakistan. The quality of magnesite is also generally of industrially acceptable grades.

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Appendix I :
Geologic Map of the Kakul - Lagarban Area, Abbottabad, Northern Pakistan
(Naka, Hirayama and Tahir Karim, 1995)

T.N. M.N.

45 Strike and Dip

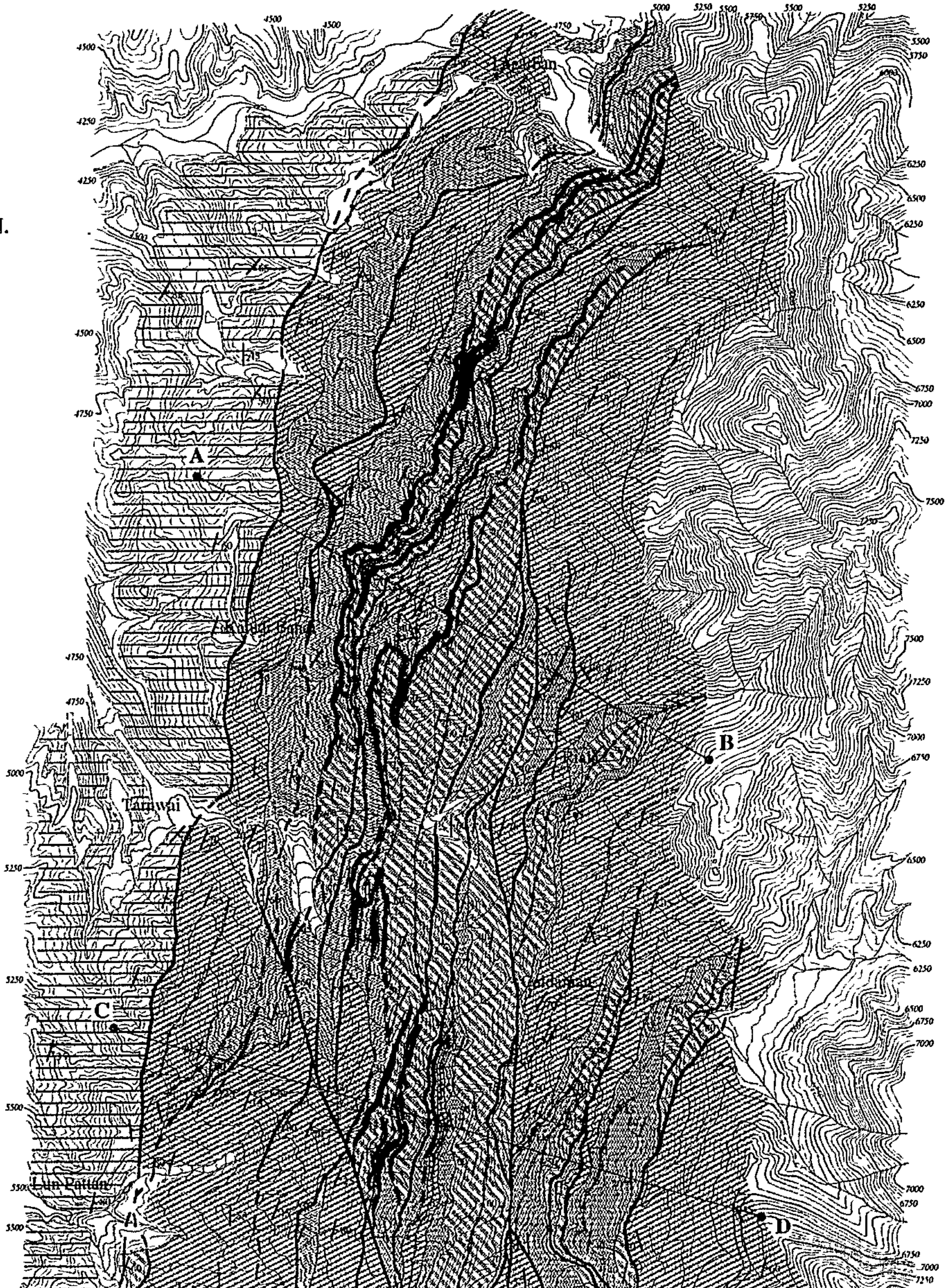
Fault

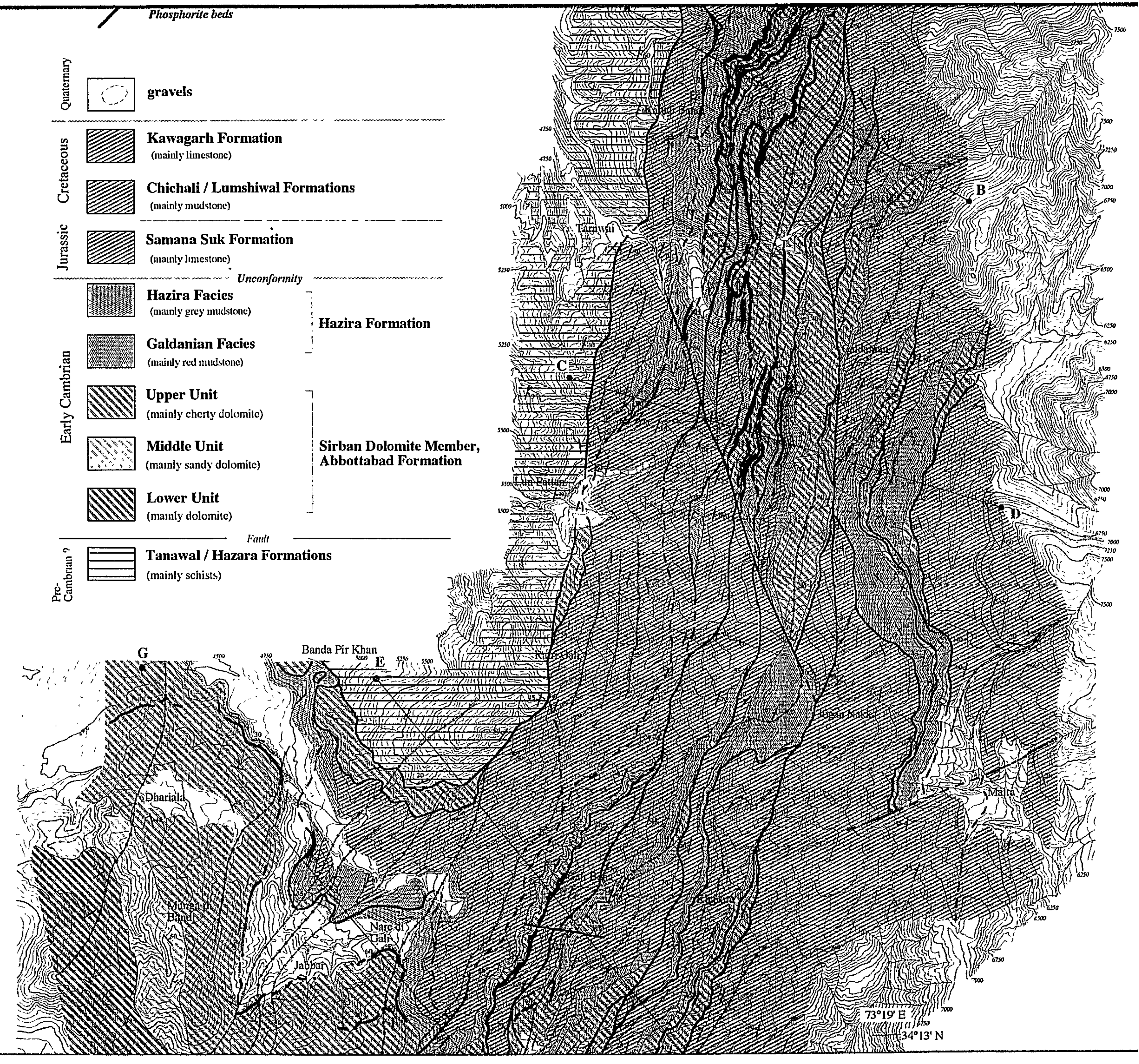
Anticline

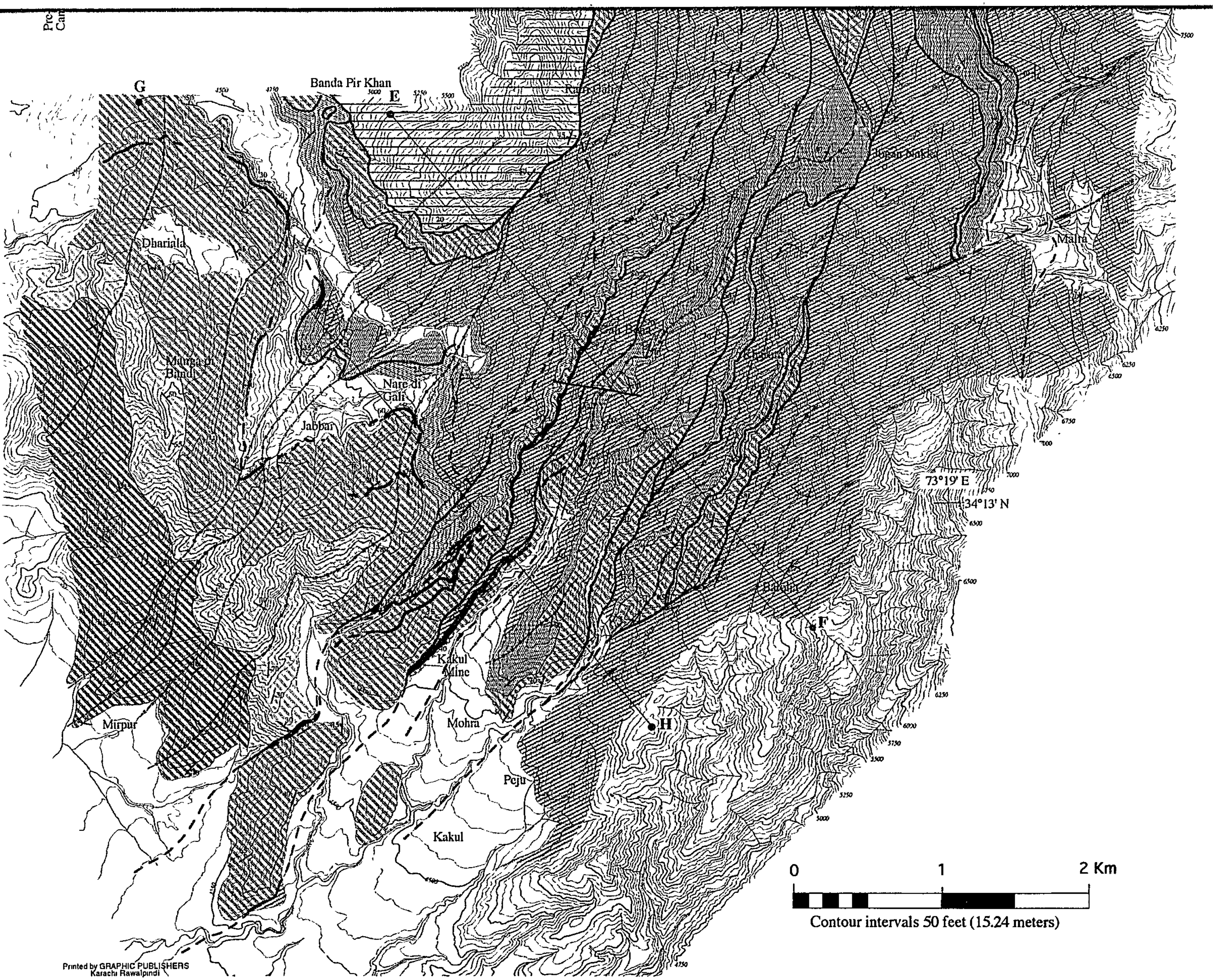
Syncline

Phosphorite beds

Quaternary	**gravels**		
Cretaceous	**Kawagarh Formation** (mainly limestone)		
Cretaceous	**Chichali / Lumshiwal Formations** (mainly mudstone)		
Jurassic	**Samana Suk Formation** (mainly limestone)		
	Unconformity		
Early Cambrian	**Hazira Facies** (mainly grey mudstone)	**Hazira Formation**	
Early Cambrian	**Galdanian Facies** (mainly red mudstone)	**Hazira Formation**	
Early Cambrian	**Upper Unit** (mainly cherty dolomite)	**Sirban Dolomite Member, Abbottabad Formation**	
Early Cambrian	**Middle Unit** (mainly sandy dolomite)	**Sirban Dolomite Member, Abbottabad Formation**	
Early Cambrian	**Lower Unit** (mainly dolomite)	**Sirban Dolomite Member, Abbottabad Formation**	
	Fault		
?	**Tanawal / Hazara Formations**		




Phosphorite beds
Quaternary
gravels
Cretaceous
Kawagarh Formation
(mainly limestone)
Chichali / Lumshiwal Formations
(mainly mudstone)
Jurassic
Samana Suk Formation
(mainly limestone)
Unconformity
Early Cambrian
Hazira Facies
(mainly grey mudstone)
Galdanian Facies
(mainly red mudstone)
Hazira Formation
Upper Unit
(mainly cherty dolomite)
Middle Unit
(mainly sandy dolomite)
Lower Unit
(mainly dolomite)
Sirban Dolomite Member, Abbottabad Formation
Fault
Pre-Cambrian ?
Tanawal / Hazara Formations
(mainly schists)
B
C
D
E
G
Tarnwai
Banda Pir Khan
Dhariala
Malra
Nare di Gali
Jabbar
73°19' E
34°13' N



Banda Pir Khan
G
E
F
H
Dhariala
Mirpur
Jabbar
Nare di Gali
Kakul Mine
Mohra
Peju
Kakul
Malra
73°19' E
34°13' N
0
1
2 Km
Contour intervals 50 feet (15.24 meters)
Printed by GRAPHIC PUBLISHERS Karachi Rawalpindi

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