An Interpretation of Petrotectonic Assemblage West of Western Himalayan Syntaxis in Dir District and Adjoining Areas in Northern Pakistan

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Abstract: A review of the geology of areas west of western syntaxial bend of Himalayas in Dir district and adjoining areas of northern Pakistan is presented. Several geotectonic regimes have been recognized and it is proposed that the well-known Indus ophiolite suture in this area is represented by amphibolite/ophiolite belt of Dir. These ophiolites are thought to have generated in an ocean and that their emplacement involved initially an ocean-continent type of plate interaction followed much later by continent-continent collision.

INTRODUCTION

Rock assemblage that characterises plate boundaries or specific plate interior settings has been defined as Petrotectonic Assemblage (Dickinson 1971). Because of complex internal geometry produced by extensive thrusting and mass transport, very dissimilar rock sequences are juxtaposed so that their original relationships are destroyed. It is, therefore, not possible to reconstruct early plate history by geometric matching or sea floor spreading. In case of collisional mountain belts, interpretation of the history of fossil plate margins whether convergent or divergent is potentially more complex than other orogens. The latest collision juxtaposes products of all the previous events, completely or partially destroying the evidence which can possibly lead to the reconstruction of plate margin history.

Plate tectonic models involving the collision of India with Eurasia have been put forth for the formation of Himalayas but the areas west of River Indus have rarely been referred to except very briefly by (Gansser 1974, Sillitoe 1975, Nowroozi 1972, Crawford 1974, Stonely 1975). This paper is an attempt to present an interpretation of the geology of Dir/Swat and parts of Indus Valley areas in the framework provided by ideas of the new global tectonics.

GEOLOGY OF DIR AND THE ADJOINING AREAS

The areas investigated are located in northwestern portion of northern Pakistan (Fig. 1). Geology of the area has been variously described by Chaudhry *et al.* (1973, 1974a, 1974b, 1976) and Chaudhry and Chaudhry (1974).

Geologically the area can be divided into the following NE–SW trending zones.

1. Alkaline Zone.
2. Blueschist Zone.
3. Ophiolite/Amphibolite Zone.
4. Volcanic/Volcanogenic Sedimentary Zone.

The Alkaline Zone

The alkaline microgranites containing aegirine, riebeckite and astrophyllite from northwest Pakistan were described by Coulson (1936) and Kempe and Jan (1970). They have suggested the existence of a fairly extensive alkaline igneous province in northern Pakistan trendng WSW–ENE. The intrusive age of these rocks has been suggested to be Tertiary i.e. towards the end of the Himalayan orogenic and metermorphic episode.

Here follows a summary of various intrusive and hypabyssal rocks of alkaline affinity encountered in the alkaline igneous province of northern Pakistan (Fig. 2).

Loe Shilman Alkaline Complex: These rocks are exposed in Loe Shilman, a valley in the northeastern part of Khyber Agency (Ahmed and Ali 1977). Sill like bodies of carbonatite have been reported from within the Landi Kotal formation which comprises of slates, phyllites and argillite with frequent basic sills and dykes. A number of alkaline intrusions are closely associated with these formations.

Warsak Alkaline Granites: The Warsak area, 24 km north-west of Peshawar contains a suite of alkaline granites intruded into low grade metasediments including slates, phyllites, quartzite and marbles possibly Precambrian to Palaeozoic in age. The alkaline granite occurs in arcuate exposures at the Warsak dam foundations. The granitic body is mildly deformed at the margins where it also shows some foliation (Ahmad *et al.*, 1969).

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Coulson (1936) described it as "biotite, aegerite, arfvedsonite gneiss" (soda granite).

Malakand Carbonatites: These occur in psammitic-pelitic rocks and are composed of calcite, arfvedsonite, siderite, ilmenite-magnetite, vermiculite, apatite, chlorite and some feldspar.

The rocks are coarse grained and porphyritic to subporphyritic. Calcite is the main mineral. Rare earths have been reported to be as follows :

Nb 100 to 300 ppm, Y 100 to 200 ppm, La 400 ppm (Ashraf and Chaudhry, 1977).

This discovery fills the information gap about the continuation of the alkaline province.

Shewa Porphyry: The Shewa porphyry is composed of gneissic soda granite, aegirine / arfvedsonite bearing gneissic porphyries and undeformed intrusions of aegirine bearing acid porphyries. Shewa porphyry outcrops 12 mile northwest of Swabi in NWFP.

Genetic affinity of these porphyries with the alkaline rocks of Warsak area have been suggested (Coulson 1936).

Koga Alkaline Complex: Koga alkaline complex is situated on the border of Swat and Mardan Districts. The igneous complex is a granite syenite association intruding Swabi-Chamla sedimentary group of Mid-Palaeozoic age (Davies and Ahmed 1963).

The igneous complex has been divided into three main petrographic types by Siddiqui *et al.* (1968).

(i) *Chingalai Granodiorite Gneiss:* This group consists of granitic to granodioritic gneiss with dykes of aplite and dolerite. The rocks are typically peraluminous and are characterized by the abundance of biotite, K–feldspar phenocrysts, a crude foliation and hypidiomorphic granular texture.

(ii) *Babaji Syenites and Granites:* This group consists of a rather varied assemblage of alkaline granites, quartz bearing aegirine-augite and arfvedsonite nordmerkites, quartz-free aegirine-augite syenites and aplites. A general paraalkaline nature, granitoid texture and enrichment in soda is characteristic of this group.

(iii) *Koga Feldspathoidal Syenite:* These rocks are characterized by silica undersaturation enough for the development of feldspathoids, such as nepheline, cancrinite and sodalite. Various rock types described by Siddiqui *et al.,* (1968) and Ashraf *et al.* (1979) from this intrusion are :

1. Pulaskites.
2. Foyaites.
3. Litchfieldites.
4. Nepheline–cancrinite syenite.
5. Sodalite syenite.
6. Carbonatites and Fenites.
7. Pegmatite.

Tarbela Alkaline Microgranites and Carbonatites: Porphyritic microgranites containing aegirine and riebeckite occur on the northwest bank of river Indus at Tarbela. They are associated with gabbro sills intruding Salkhala series. One of the sills has been described as differentiated body containing a gabbroic composition at the base grading into a diorite to an oligoclase carbonate rock at the top (Kempe and Jan 1970). The carbonate bearing rock contains 0.012% Nb and 0.13% Zr.

Blueschist Zone

The areal distribution of this zone is given on Fig. 2. Following rock units have been encountered within this zone :

1. *Pelitic-Psammitic Schists:* These are extensively developed in the southern parts of the zone. The southern contact is not exposed but in the north they grade into garnet mica schists. At places these grade into graphitic schists. Biotite, muscovite, quartz, graphite, chlorite and chloritoid with accessory amounts of magnetite, sphene and limonite constitute these rocks. Occasional occurence of lime garnets have also been reported. These rocks belong to greenschist facies.

2. *Crystalline Limestones and Marbles*: The northern extremity of the "blueschists" zone is characterized by development of calcareous rocks. These marbles are black to almost pure white in colour and are well crystallized. Microscopic study of these rocks reveals the composition as calcite, quartz and mica as essential minerals whereas lime garnet, sphene, magnetite, limonite, epidote, apatite and tourmaline are present as accessories.

3. *Glaucophane Schists:* In view of the absence of detailed mineralogical work on these rocks, it is difficult to define very precisely the assemblages present in the area but the very existence of glaucophane in these rocks puts it under the broad category of "blueschist facies".

Metabasites in this zone contain the following mineral assemblages:—

a. Glaucophane-actinolite-quartz+sphene.
b. Glaucophane-chlorite-clinozoisite+quartz± sphene.
c. Actinolite-clinozoisite-quartz±sphene.

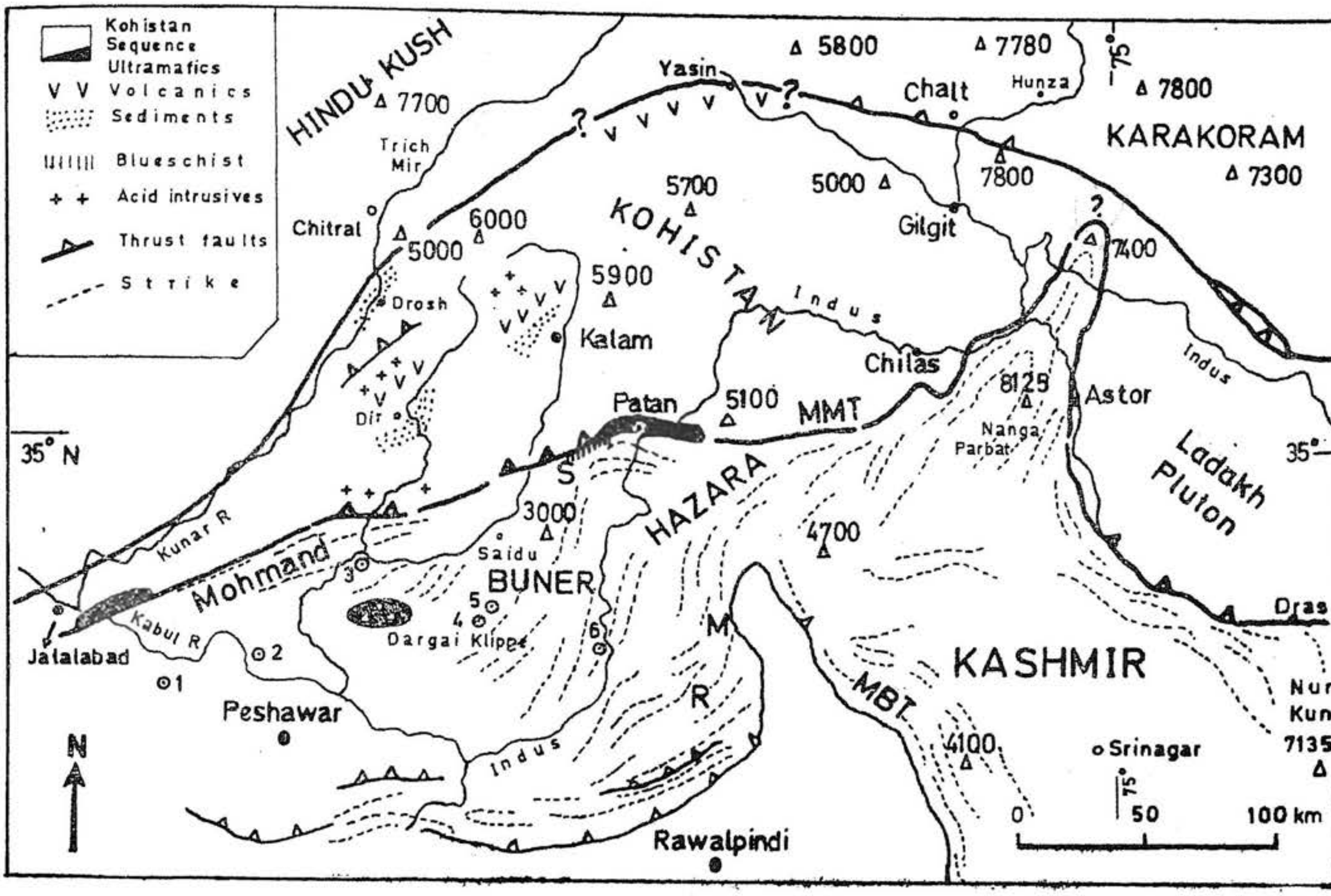

Fig. 2. Geological sketch map of the India-Eurasia zone in Northern Pakistan and adjacent area showing also occurrence of alkaline zone (1 to 6). (After Tahirkheli *et al.* 1979).

It is only in the northern most part of the glaucophane schist zone, where metabasites occur, that characteristic glaucophaneschists assemblage is found. In the south, however, the area is composed of slates of possible Precambrian age with a few limestone and sandstone intercalations at places. These metasediments host a number of intrusives most important of these are Malakand granitic rocks.

Two types of granitic rocks have been defined by Chaudhry *et al.* (1976).

(i) *Malakand Granite Gneiss:* These are medium to coarse grained foliated rocks. Gneissic structure is well developed and is a manifestation of parallel alignment of crystals.

The general trend of the gneiss is NE-SW and dips towards north in the northern part and towards south east in the southern part.

(ii) *Malakand Granite:* The Malakand granite is an undeformed to mildly deformed, non porphyritic leucocratic granite, local deformation is due to movement along shear zones. The granitic intrusion exhibits a sharp contact against metasedimentary rocks and granite gneiss and also produces a visible contact aureole. Age of these intrusive rocks is regarded as early to Mid. Mesozoic but no basis has been quoted for the age (Chaudhry *et al.*, 1976).

Amphibolite/Ophiolite Zone

The exact areal extent of the amphibolite belt is not defined as yet. However, the best studied part of amphibolite belt is exposed in Panjkora river valley and is shown on Fig. 1. The belt shows an apparent tendency to pinch in the southwest while along the strike towards north-north east the belt shows relatively broader exposed area.

This zone consists essentially of amphibolites containing exotic pieces of eclogites, serpetinites, dunites and peridotites. In addition to the exotic blocks the amphibolite belt also hosts a varied intrusive sequence ranging in composition from diorites to noritic gabbros with some granites and tonalite.

Chaudhry *et al.* (1974) have defined two categories of amphibolites from this belt. Their classification based largely on petrographic, chemical and field criteria divides these rocks into:

1. *Northern Dir Amphibolites:* These are medium to coarse grained rocks with a dominantly xenoblastic texture. Other textural variations are also observed. The variability in the amount of hornblende and felsic minerals is obvious from thin section studies. The rocks with higher colour index contain hornblende and epidote as their major constituents with accessory amounts of chlorite, sphene, quartz, plagioclase and magnetite. Lighter coloured varieties not only have lesser hornblende but their felsic mineralogy is also very different. In these rocks quartz and plagioclase take over as major minerals whereas chlorite, garnet, epidote, muscovite, orthoclase, sphene, calcite and apatite represent accessories.

2. *Southern Dir Amphibolites:* These rocks have fine to medium grained, hypidiomorphic and granular texture. Allotriomorphic and idiomorphic textures are also seen.

Amphibole, plagioclase, quartz and orthoclase are the main constituents while garnet, epidote, chlorite, sphene, calcite and biotite are the accessories. The southern Dir amphibolites are much more uniform in texture and rarely show banding which is characteristic of northern Dir amphibolites.

3. *Hornblendites:* Black hornblendite patches, dykes and sills are present both in the southern and northern amphibolites of Dir area. These rocks usually grade into more typical amphibolites. A general hypidiomorphic granular nature is characteristic of these rocks. They are composed chiefly of hornblende with minor cummingtonite and plagioclase.

At places gradational contacts between hornblendite and peridotite/dunite have been observed. The cores of hornblendite bodies contain fresh peridotite and or dunite.

4. *Eclogites:* These rocks occur as exotic screens within the amphibolites. There is apparently no relationship of these rocks with the surrounding amphibolites. Such eclogites form under exceptionally anhydrous conditions (Fry and Fyfe, 1969).

These rocks contain quartz and have clinopyroxene-garnet-quartz assemblage characteristic of eclogite facies.

5. *The Intrusive Sequence:*

(i) Dioritic Intrusives. The dioritic intrusives occur in one belt like body trending NE-SW. This rock unit is not uniform in mineralogy, texture or composition. It's compositional span ranges from diorite through quartz diorite to tonalite. However, typical diorite composition is the most dominant variety. Diorites, generally contain a fabric which trends NE-SW. The extension of this intrusion is also reported from Swat and Chilas areas.

The diorite body is intrusive into the main amphibolite mass. Xenoliths and screens of amphibolites are very common in the intrusive diorite whereas their occurrance within the tonalites of quartz diorites is relatively rare. Mineralogical variation within the intrusive complex of amphibolite zone is described in detail by Chaudhry and Chaudhry (1974).

(ii) Noritic Intrusions. These intrusions range in composition from norite, melanorite, quartz norite, quartz-hypersthene gabbro, to quartz-hypersthene diorite.

The noritic rocks contain xenoliths and screens of dunite, peridotite, pyroxenite. These rocks are younger than the dioritic complex as evidenced by their cross cutting relationships. Contact relations between amphibolites, norites and diorites are as follows:—

1. Amphibolites are cut by both norite and diorite.
2. Xenoliths of amphibolites occur in norite intrusions.
3. Apophyses of norite cut amphibolite.
4. Contact of diorite and amphibolites is sharp with a contact metamorphic aureole.
5. Amphibolite occurs as xenoliths in diorite.
6. Apophyses of norite cut diorite.

(iii) Trondhjemite Intrusions. The trondhjemitic intrusion occurs within the northern Dir amphibolites and shows a chilled contact against the amphibolites. It is a coarse grained hypidiomorphic granular rock composed essentially of plagioclase and quartz with some biotite, hornblende, chlorite and epidote as accessory minerals (Chaudhry and Chaudhry, 1974).

In addition to these intrusions minor bodies of granitic porphyry, aplites and pegmatitic dykes are also reported from the area.

Volcanic/Volcanogenic Sedimentary Zone

Concordant with the previously described rock unit in the northern parts of the Panjkora river valley, a thick sequence of sedimentary/volcanogenic sedimentary rocks occurs (Fig. 1).

The sequence contains sandstones, graywackes and slates and intercalation of marl to limestone interbedded with acid lavas. In addition, a few ash flow and ash fall horizons have also been encountered. The volcanic rocks range in composition from rhyolites to andesites.

DISCUSSION

In Himalayas, the ophiolites are believed to be the line of closure of eastern part of the southern Tethys (Dewy and Bird, 1970; Powell and Conaghan, 1973; Gansser, 1974). The western continuation of the ophiolite belt marking the Indus suture line, west of river Indus, before its southward swing is not clearly defined. The ophiolite belt is considered to be represented by poorly defined "Greenstone Complex" of Bakr (1965) in Chitral.

The detailed geological anatomy of the amphibolite belt is presented in a series of publications i.e. Chaudhry and Chaudhry (1974), Chaudhry *et al.* (1974, 1974a, 1974b and 1976). These workers have produced critical geological data for the recognition of overall structural regimes for geotectonic reconstruction of this part of the mountain belt.

The structural regimes now recognized in Dir and adjoining areas are an alkaline zone, a blueschist zone, an amphibolite/ophiolite zone and a volcanic/volcanogenic sedimentary zone.

A brief geological description of these zones has already been given. Here follows a synthesis of their geotectonic significance.

The alkaline province trending WSW-ENE in northern Pakistan has now been defined. This belt of alkaline intrusives and hypabyssal rocks extends over a distance of 200 kms. The belt contains several independent centres of alkaline magmatism including carbonatite plugs. These rocks have not been radiometrically dated but from the geological criteria most of the rocks are very young. A possible Tertiary age has been indicated from one syenite sample in Koga (Siddique *et al.*, 1968). Warsak alkaline granite has been interpreted to be as Lower Teritiary by Ahmad *et al.* (1969).

Most strongly alkaline rocks are generally known to be associated with the rift systems, i.e. zones of tension within the continental crust. Many of these rocks contain (Na_2O+K_2O) more than 10%. Chemical data on Koga alkaline complex shows that the (Na_2O+K_2O) in the rocks average more than 15% (Siddique *et al.*, 1968; Ashraf *et al.*, 1979). Similarly in Warsak alkaline granite (Na_2O+K_2O) averages upto 10% of the rock (Ahmed *et al.*, 1969).

From the petrological data and the geographical distribution these centres of alkaline magmatism within a narrow belt suggest a zone of crustal weakness during the Tertiary period.

Powell and Conaghan (1973) have suggested that a fundamental crustal fracture developed within the Indian block during Late Eocene/Oligocene and that the Indian subcontinent was underthrusted along this fracture. The fracture zone suggested above is represented by schists and gneisses and was developed under the influence of compression. Underthrusting of the incident plate is bound to produce compressional environment within the zone of plate interaction whereas a complimentary zone of tensional forces would be created behind the underthrusted portion of the incident plate. Relative rigidity of the continental crust as opposed to the oceanic crust can account for the formation of such a zone. In an ocean-continent type of situation, the underthrusting of oceanic plate into a subduction zone is not likely to produce similar tensional environments within an oceanic plate due to its different rheological behaviour as opposed to the continental crust.

It is proposed that while the leading edge of the Indian continent was being collided with the Asian block producing compressional features within the zone of deformation, a complimentary zone of tension was created within the Indian block. The downbuckling of the underthrust portion of the leading edge produced a large scale monocline type of structure where tensional fracture developed at the crest of this structure. This fracture zone provided for the sites of intrusion of highly alkaline magmas. This hypothesis would explain the intrusion of alkaline magma in orogenic environments, which were previously known only from the stable blocks of the crust (Gilluly, 1971).

Baring the structural discontinuities and displacements by later movements, the extension of such a zone of tension is suggested towards west in Afghanistan and in the Himalayan ranges in the east.

Collision of India with Asia commenced in Pakistan and Afghanistan in Late Cretaceous Early Palaeocene and in the Himalayas in Pre-Mid Eocene times (Powell and Conaghan, 1973). Thrusting remained inactive from Mid. Eocene to Early Miocene (Powell and Conaghan 1973). Renewal of underthrusting and uplift of the Himalayas during Mid. Miocene is indicated by thick molasse sequence. This event coincided with the intrusion of alkaline rocks. The rapid uplift of the Asian block was accompanied by an overall uplift due to bouyancy of the colliding crustal blocks. This rapid uplift caused extremely rapid erosion and exposed batholithic alkaline rocks at places.

The alkaline rocks in Koga alkaline complex contain a gneissic unit which shows intense deformation, a relatively mildly deformed syenite and undeformed fenitized rocks with carbonatite plugs at their centres. This sequence suggests a continued intrusion/extrusion of the alkaline magmas along the zone of weakness since its formation. Isotope studies on these rocks will reveal the exact chronology of the alkaline intrusive/extrusive sequence.

The rocks metamorphosed in the blueschist facies have been reported by Arif (1972). These rocks are exposed only as thin slices close to and apparently stratigraphically beneath the ophiolite bearing amphibolite zone. Blueschist zone of Dir/Swat area is parallel to the ophiolite/amphibolite zone. In this respect they are similar to several other blueschist areas of the world (Black *et al.*, 1969). The ophiolites were tectonically emplaced in the Himalayan Indus suture and its possible extension in Dir area in Late Cretaceous (Stoneley, 1974). Where ages based on radiometric dating in blueschist zones are available, it is found that blueschist metamorphism is related in time to deformation whereas the igneous age of the ophiolites is older than the enclosing sediments and their metamorphic equivalents (Cogulu, 1967; Coleman, 1967). It is, therefore, concluded that the blueschist metamorphisin in Dir/Swat area is younger than Cretaceous, and is, therefore possibly Early Tertiary.

Blueschist metamorphism results when the sediments are trapped in a trench environment (Ernst, 1970 and Dickinson, 1968). In New Caledonia and New Guinea blueschists lie directly under the oceanic crust. Such a situation cannot be explained by a model suggesting continuous plate consumption in a subduction zone (Coleman, 1971). It has been, therefore, suggested that the older oceanic crust was obducted onto the underlying metasediments deformed and metamosphosed in blueschist facies.

Prior to the complete closure of the Tethys ocean in this area the existence of an active subduction zone is indicated by the high pressure type metamorphic assemblage. The present day geology of amphibolite/ophiolites overlying blueschists indicate early subduction producing blueschist facies followed by obduction of the oceanic crust onto these metamorphosed sediments.

Amphibolites, ultramafics and eclogites of Dir area probably represent a subduction melange produced in a northward dipping subduction zone of the former Tethys ocean. The existence of north dipping subduction is indicated by magmatic rocks in northwest Baluchistan (Hunting Survey Corporation, 1960). Southern Dir area and adjoining Malakand area contains a slate and phyllite (greenschist facies) sequence as the oldest sediments. The top of the sequence contains crystalline marbles. The whole metasedimentary sequences is intruded by various kinds of granites (Chaudhry *et al.*, 1976). The northern end of this sequence contains a blueschist bearing allochthonous block near Shangla and Bar Bandai in Swat separated by a thrust from the amphibolite belt. The base of the amphibolite complex contains deformed garnet bearing amphibolites.

The southern part of the amphibolites have been interpretted by (Chaudhry *et al.*, 1974) as ortho-amphibolites while the northern part of the belt contains evidence to indicate their origin from a calcareous sequence, with some contribution from the volcanic sources. This sequence is overlain by quartzites. It is proposed that the ortho-amphibolites were formed by metamorphism of ocean basalts whereas the para-amphibolites and quartzites represent ocean floor pelagic sediments, cherts and submarine volcanics interbedded within these sediments.

The intrusive sequence encountered within this zone ranges in composition from norite to noritic gabbros, diorites and trondhjemites. Such rocks when plotted on FMA diagram show a calc-alkaline trend typical for an oceanic suite (Thayer, 1969). The ultramafic fractions include harzburgite and dunite with minor plagioclase bearing Iherzolites. At places the gabbroic and ultramafic rocks show a cumulate texture and banding (Chaudhry and Chaudhry, 1974), which indicate their development in shallow magma chambers feeding to the basalts now represented by southern Dir amphibolites.

Geophysical studies have revealed three distinct layers in oceanic crust. Layer I consists of sediments (Shor and Raitt, 1969). Layer II is considered to be basalt (Vine and Mathews 1963) and the third layer consists of serpentinites and peridotites (Hess 1962). There is a controversy about the composition of the third layer which has also been postulated to be gabbro/amphibolite (Christensen 1970; Cann 1968). Below the third layer, it is generally accepted, is mantle peridotite.

Considering the above stated sequence established on the present day oceanic crust, it is not difficult to conclude that the amphibolite/ophiolite zone exposed in Dir represents a section of the ancient ocean floor. Ecologites represent a piece of the depleted mantle picked up by basalts and other intrusives/extrusives.

The area north of amphibolite zone consists mainly of a detrital sequence of shales, graywackes and sandstones. The top of the sequence also contains a zone of volcanic flows and tuffs of acidic affinities. This sequence is indicative of an arc-trench gap. The graywackes and shales were probably deposited in the uplifting basins between the trench and the main volcanics are probably represented by the "greenstone complex" of Chitral.

The "greenstone complex" is generally light to dark green and consists of epidiorites, dolerite, basalts andesites, hornblende gneiss and hornblendites (Bakr, 1965). In the volcanic component, basalt-andesite type of association indicates a volcanic arc type of environment. Further studies may reveal the exact nature of this complex.

CONCLUSIONS

We propose that ophiolite belt in the western syntaxial bend of Himalayas is represented by the amphibolite/ophiolite complex of Dir area as opposed to the previously held views that the "greenstone complex" of Chitral represents the ophiolitic suture. These ophiolites were generated in ocean floor environments (possibly along the mid ocean ridges).

The emplacement of these ophiolites involved initially an OCEAN-CONTINENT type of plate interaction, as indicated by the metamorphic zonation, followed by continent-continent collision.

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