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GEOLOGY OF THE INDUS SUTURE ZONE IN THE MINGORA–SHANGLA AREA OF SWAT, N. PAKISTAN

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ABSTRACT

In the Mingora area the Indus suture zone is largely composed of metamorphosed ophiolites and melanges which have been wedged in between the Indo-Pakistan crustal plate and the Kohistan andesitic arc block. The Indo-Pakistan subcontinental sequence is made up of the twice metamorphosed Manglaur crystalline schists, the intrusive Swat granite gneiss, and the unconformably overlying once metamorphosed Alpurai and Saidu schists. The recognition of this unconformity requires major revision of the stratigraphic correlation of these units which were previously all considered to be Precambrian. Those above the unconformity are probably Phanerozoic, and the Saidu schist may be the local metamorphosed equivalent of the Indus flysch of Ladakh. The ophiolitic and related rocks of the Indus suture melange group are subdivided into three separate units. The Shangla blueschist melange is locally present in the north and represents a subduction complex developed adjacent to the Kohistan arc. The Charbagh greenschist melange crops out in the centre of the group and could be of either mid-oceanic island or island arc origin. The Mingora ophiolitic melange is obduction complex. It is characterized by metamorphism to talc-dolomite schist and emerald mineralization.

INTRODUCTION

The Indus suture which marks part of the collision zone between the Asian and Indo-Pakistan plates extends westwards from Ladakh through northern Pakistan to eastern Afghanistan, a distance of about 1500 kms. For the greater part of this long stretch, the suture zone either crosses extremely rugged terrain which defies access, traverses regions which are inaccessible for political reasons, or is poorly exposed. In Pakistan its best exposure is between Besham (on the Indus) and Mingora (Swat). A part of this region between Shangla and Mingora was mapped in detail by the authors from the Gemstone Corporation of Pakistan while prospecting for emerald deposits. This study has revealed new structural details and has revised the stratigraphy of the area.

Previous Investigations.

Pioneering work on the regional geology of the Swat area was done by Martin *et al.* (1962) who reported the following lithostratigraphic units in the Swat area:

Upper Swat Hornblendic group

Lower Swat-Buner schistose group

Greenschist

Phyllitic schist

Marble and calcareous schist

Amphibolite

Siliceous schist

Swat granite gneiss

Martin *et al.* (1962) reported a major thrust fault (now known as the Main Mantle Thrust or MMT) which brought the Hornblendic group over the Swat-Buner schistose group.

It was not until the early seventies when continental collision between Indo-Pakistan and Asia was confirmed by the plate tectonic model (Dewev & Burke, 1973; Molnar *et al.*, 1975). The significance of the MMT and the origin of these lithologic units were interpreted (Jan, 1977; Jan & Symes, 1977; Tahirkheli, 1979; Tahirkheli *et al.*, 1979) in accordance with these models. These authors have shown that the Hornblendic Group is mainly composed of rocks which once formed part of an andesitic arc, the Kohistan arc, within the closing Neotethys, and that the MMT is the location of a past subduction zone. North of the Kohistan arc is another major fault, the Main Karakorum Thrust (MKT; Tahirkheli, 1979). Together these are two of the most striking structural features of northern Pakistan (Kazmi & Rana, 1982). They both dip northward and surround the largely Cretaceous Kohistan arc sequence of calc-alkaline volcanics, metasediments, granulites, and amphibolites (Bard *et al.*, 1980; Bard, 1983). The MKT and MMT are characterized by outcrops of ophiolitic and metavolcanic rocks (Stocklin, 1977; Gansser, 1981) which record suturing of the Kohistan arc to the Asian continent in the north and to the Indo-Pakistan subcontinent in the south (Fig. 1). The southern suture, MMT, is characterized by several fault-separated tectonic terrains and is the western continuation of the Indus-Tsangpo suture zone (Lawrence *et al.*, 1983).

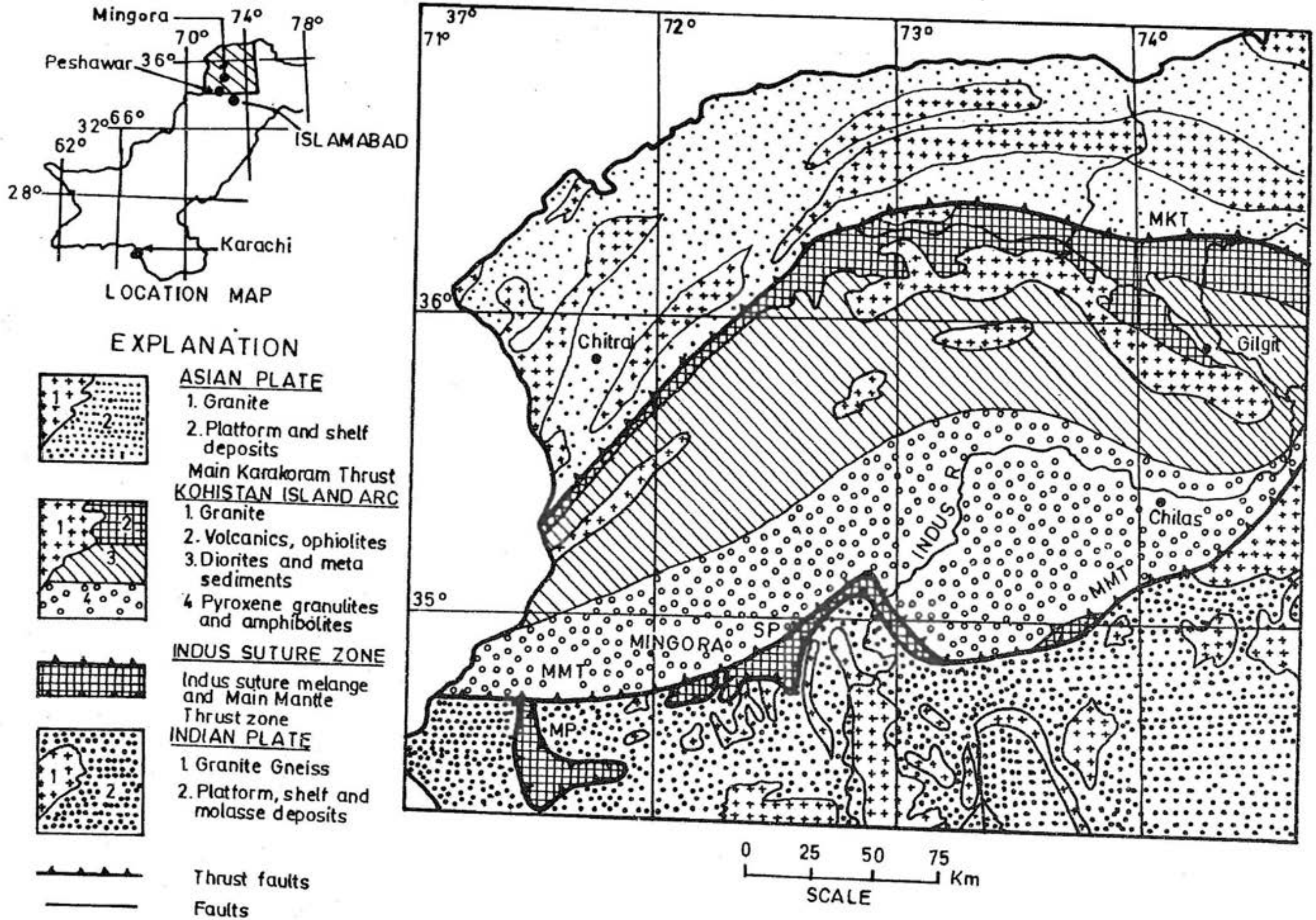

Fig. 1. Geological sketch map of Indus suture zone in northern Pakistan.

STRATIGRAPHY AND STRUCTURE

Structurally the Mingora area is composed of three tectono-stratigraphic groups of rocks (Table 1). From north to south these are (1) the Kohistan arc sequence which has been thrust over (2) the Indus suture melange group (MMT zone), which in turn has been obducted onto (3) the Indo-Pakistan subcontinent sequence (Figs. 1 & 2). The Kohistan arc sequence is relevant to this paper only to the extent that these rocks form the upper thrust slice which delimits the northern exposure of the Indus suture zone in this area (for details see Jan, 1977, 1980; Tahirkheli *et al.,* 1979; Majid & Paracha, 1980; Bard *et al.,* 1980; and Bard, 1983). We have revised the stratigraphy in the vicinity of Mingora to emphasize the complex structure and tectonic units of the MMT zone. We use the terms Indus suture zone, Indus-Tsangpo suture zone, and MMT zone interchangeably. We have given new unit names in an effort to clarify the complexities of the metamorphic stratigraphy. In the Mingora area we recognize three fault-bounded melange units of different tectonic origins that here comprise the Indus suture melange group. The MMT is not a single one of these bounding faults, but is the zone as a whole. The Indus suture melange group and the Indo-Pakistan subcontinent sequence are significant from the standpoint of stratigraphy and tectonics of this region and are briefly discussed as follows.

TABLE 1. STRATIGRAPHY OF THE MINGORA AREA

	Kohistan Arc Sequence	
	Kohistan Thrust	
Indian suture melange group	Shangla blueschist melange	Main Mantle Thrust Zone
	Shangla Thrust	
	Charbagh greenschist melange	
	Makhad Thrust	
	Mingora ophiolite melange	
	Charbagh-Kishora Thrust	
Indian subcontinent sequence	Saidu calc-graphite schist	Platform Sediments
	Alpuri calc-mica-garnet schist	
	unconformity	
	Swat granite gneiss / Manglaur crystalline schist	Basement

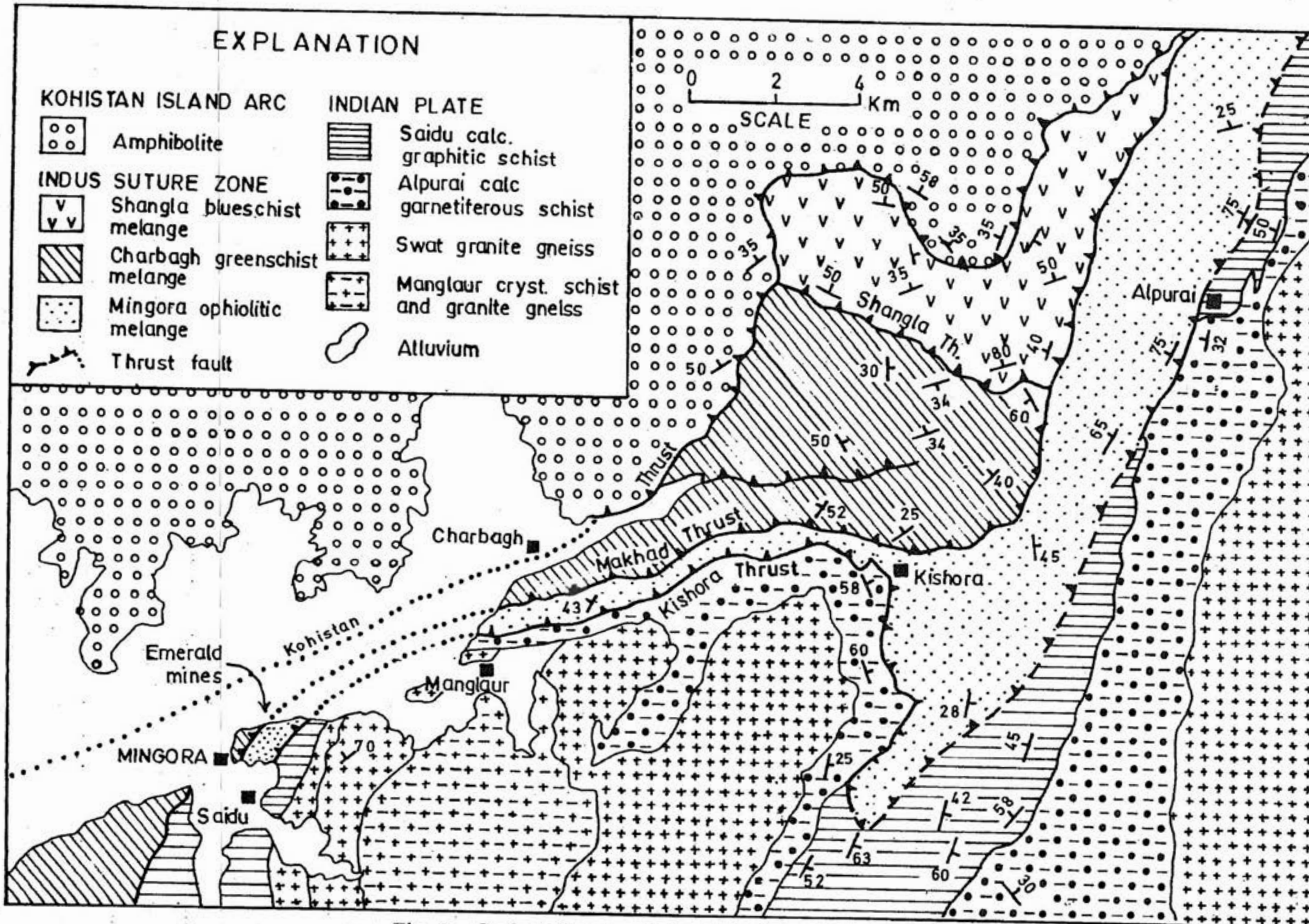

Fig. 2. Geological map of the Mingora-Alpurai area.

TABLE 2. MINERALOGY OF THE MANGLAUR CRYSTALLINE SCHIST

Formations / Main mineral assemblages					Mingora Ophiolitic Melange			Charbagh Greenschist Melange			Shangla Blueschist Melange	
								Greenschist		Greenstone		
	Manglaur Crystalline Schist	Swat Granite Gneiss	Alpurai Garnetiferous Schist	Saidu Graphitic Schist	Serpentinite	Talc-chlorite-dolomite Schist	Dolomite	Meta-tuff	Meta-basalt	Meta-mafic ign rks	Meta-basalt	Meta-tuff
Quartz	≡ ○	≡ ⬭	≡	=		—	—	=	—	—	—	≡
Plagioclase	—	—						=	=	=	=	=
K-Feldspar	—	= ⬭										
Biotite	=	=	=	=								
Muscovite	—	—	—	—				—				
Fuchsite						—	—				=	—
Hornblende												
Pyroxene					....							
Olivine					....							
Tourmaline	—	—										
Beryl		—				—e	—e					
Fe Ore	—	—	—	—	=	=	=	—	—	—	=	—
Chromite					—							
Sphene								—	=	=	=	=
Actinolite										=	=	=
Tremolite								—				≡
Epidote	—	—						=		—		—
Piedmontite												—
Zoisite											=	—
Clinozoisite									=		=	
Glaucophane											≡	=
Serpentine					≡	—	—			—	—	
Chlorite	—				—	≡	=	≡	≡	≡	≡	≡
Talc					—	≡	=					
Dolomite					— ⬭	= ⊂⊗	≡ ⊂⊗				—	—
Siderite					—	—	=				—	—
Calcite	—		—	—		—	—	—		—		—
Graphite	—		—	=								
Garnet	= ⊂⊗	— ⊂⊗	= ⬭									
Kyanite	—											
Sillimanite	=											

EXPLANATION

- ≡ Abundant
- = Common
- — Present
- ⬭ Porphyritic or porphyroblastic
- ○ Crushed porphyroblast
- ⊂⊗ Two-generations of porphyroblast
- .... Relicts
- —e Emerald

The Indo-Pakistan Subcontinent Sequence

(1) *Manglaur Crystalline Schists.* East of Mingora and south of Manglaur village, these schists crop out as tectonized and at places mylonitized non-calcareous granoblastic quartz-mica-garnet schist. At places these have been feldspathized and tourmalinized. These schists contain three main lithologic variants, namely quartz-feldspar schist, quartz-mica-kyanite schist, and quartz-mica-garnet schist (Table 2). Rare, thin layers of graphitic and hornblende schists (para-amphibolite)

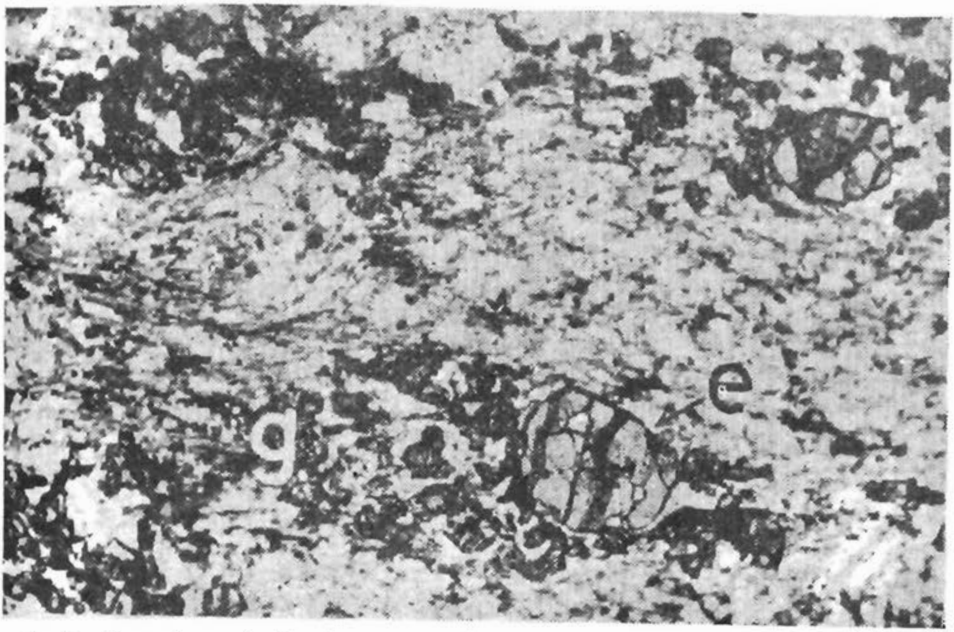

Fig. 3. Photomicrograph showing garnets of two generations in Manglaur crystalline schist; fresh euhedral crystals (e) growing across earlier crushed granoblasts (g). (Field 2.3 x 3.3 mm).

are present. These schists contain relicts of garnet porphyroblasts, largely as crushed pseudomorphs replaced by penninite and mica, stretched parallel to foliation or as scattered grains in the matrix. Fresh, undeformed garnet porphyroblasts have grown across these and form a second generation (Fig. 3). Thus the Manglaur schists have experienced at least two periods of metamorphism separated by a retrograde episode.

East of Mingora, the Manglaur schist is exposed in the core of a badly faulted antiform surrounded by outcrops of Swat granite gneiss. The schist has been extensively tectonized by several intersecting gravity faults which fall in two groups, one trending NW or NE, the other, EW or NS. The latter group is more prominent. The schist has been pervasively intruded by the Swat granite gneiss. Xenoliths of Manglaur schist (from a few centimeters to several hundred meters across) are commonly present in the gneiss and vice versa.

Martin *et al.* (1962) mapped the Manglaur schist as part of the Swat gneiss or included it in the siliceous schists of the Lower Swat-Buner schistose group (here subdivided into Saidu and Alpurai schists, see below). Subsequent investigators assumed that the Manglaur schist represented a mass of extensive roof pendants and slivers in the Swat gneisses. Our study finds the Manglaur schists to be significantly different from the Lower Swat-Buner schistose group and identifies an unconformity between them. The distinctive characteristics are as follows :

Manglaur schist	Alpurai schist
1. Largely siliceous unit;	1. Largely calcareous unit;
2. Kyanite metamorphic grade;	2. Upper greenschist metamorphic grade;
3. Two metamorphic events;	3. One metamorphic event;
4. Intruded by Swat gneiss; and	4. Unconformably overlies Swat gneiss; and
5. Cross-cutting tourmaline granite dikes and sills.	5. No cross-cutting intrusions

(2) *Swat Granite Gneiss.* This gneiss occurs as a massive sheetlike body intruded into the Manglaur schist and has been folded subsequently into an antiform. The upper and outer part of the antiform is largely composed of a leucocratic siliceous gneiss (see Table 2) ranging from a finely foliated and banded gneiss to a coarse augen gneiss with porphyroblasts of microcline (and occasionally of quartz). The inner part of the antiform is largely Manglaur schist. The common occurrence of beryl in these rocks is significant from the standpoint of emerald paragenesis. In these rocks garnet has been crushed and fragmented and its pseudomorphs of penninite are widespread indicating post-intrusive deformation. Shams (1963) has reported contact metamorphic minerals in the Manglaur schist adjacent to the augen gneiss near Manglaur. The granite gneiss and the Manglaur schist contain intrusions of a relatively fresh, medium- to coarse-grained, leucocratic tourmaline granite largely in the form of dikes and sills. At places this granite is pegmatitic, for example, near Banjot village, south of Manglaur and east of Jambil. The augen gneiss has a lensoidal to tabular weathering pattern, while the granite has a typical spheroidal weathering habit.

The age of the Manglaur schist and Swat gneiss is uncertain; no useful radiometric dates are yet available from this area. The crystalline rocks of the Swat area closely resemble those of the Mansehra area to the east. Le Fort *et al.* (1980) have published a 516 m.y. Rb/Sr isochron date on the Mansehra granite which they consider as the age of intrusion. The Mansehra granite intrudes siliceous schists of staurolite to sillimanite grade called the Tanawal Formation by Calkins *et al.* (1975). These schists closely resemble the Manglaur schist. If this correlation is correct, the Manglaur schist is Precambrian and the Swat gneiss intruded it in the early Paleozoic. The earliest metamorphism was probably synchronous with this intrusive event.

(3) *Alpurai calc-mica-garnet schist.* This name has been introduced to denote the lower three subdivisions of the Lower Swat-Buner schistose group of Martin *et al.* (1962). These schists unconformably overlie the Swat granite gneiss and Manglaur schists. In the Alpurai and Charbagh areas the contact is sheared. We interpret this as an unconformity on three grounds. First, the stratigraphic situa-

tion is very widespread; from at least Alpurai to Malakand Pass, a distance of over 100 km, the same units of the Alpurai schist overlie the Swat gneiss in the same order with an abrupt contact. Second, only one major metamorphic event affected the Alpurai and younger schists, but two metamorphisms separated by retrogression and cataclasis affected the Manglaur Schist. Third, in the Bhesham area, Fletcher, C. and the geologists of the Sarhad Development Authority (personal communication, 1984) have recognised a major unconformity between an upper calcareous schist and marble unit (?Alpurai schist) and underlying quartzose metasediments (?Manglaur schist). This is probably the same feature as we have recognised in Mingora. Recognition of this unconformity will have great importance in clarifying the currently confused state of metamorphic stratigraphy in northern Pakistan (Yeats & Lawrence, 1983).

The Alpurai schist is composed of several hundred meters of siliceous schist and calcareous quartz-mica-garnet schist (Table 2). At places relics of former sedimentary structures such as cross-bedding and graded-bedding are preserved in quartzites. Near the base it contains 20 to 50 meters of para-amphibolites in quartzites overlain by marble beds of variable thickness (15—30 meters) interbedded with garnetiferous calc-schists. The upper part of the unit is less siliceous and more calcareous and is largely composed of calcareous and garnetiferous mica schist with large idioblastic porphyroblasts of garnet. Along faults and shear planes quartz lenses are boudinaged. Boudins 5 to 40 centimeters across are common.

(4) *Saidu calcarous graphite schist.* In the Mingora area and elsewhere these schists overlie the Alpurai schists. The contact appears to be gradational, but great variation in thickness of the two units and in the number of marble horizons in the Alpurai schist below the Saidu schist strongly suggest the presence of an unconformity. East of Alpurai on the road to Besham there is a thick unit of graphitic schist with a conglomerate at its base (Jan & Tahirkheli, 1969), apparantly resting uncomformably on quartzose schists. We tentatively interpret this as Saidu schist resting directly on Manglaur schist with the Alpurai schist entirely removed. The Saidu schist is gray to dark gray, calcareous and pelitic. Most of the unit is graphitic, but the chlorite schists are locally present (see Table 2). The chlorite schists are easily confused with parts of the Mingora ophiolite malange and have caused mapping errors in the past. The metamorphic grade is upper greenschist to lower amphibolite. The unit is equivalent to the phyllitic schist of the Lower Swat-Buner schistose group of Martin *et. al.* (1962) and to part of the greenschist unit. Most of the greenschist unit is equivalent to the Indus suture melange group.

In the Mingora-Alpurai region, the upper part of the Saidu schist has been overthrust by the Indus suture melanges. An intensely tectonized imbricate zone has formed with several overlapping slices of talc-dolomite schist and greenschist of the Mingora ophiolite melange (Figs. 4 & 5). The thrust emplacement of thin slices of the overlying unit into the over-ridden substrata requires that successive faults cut through into the section as the fault system develops. Thus the faults

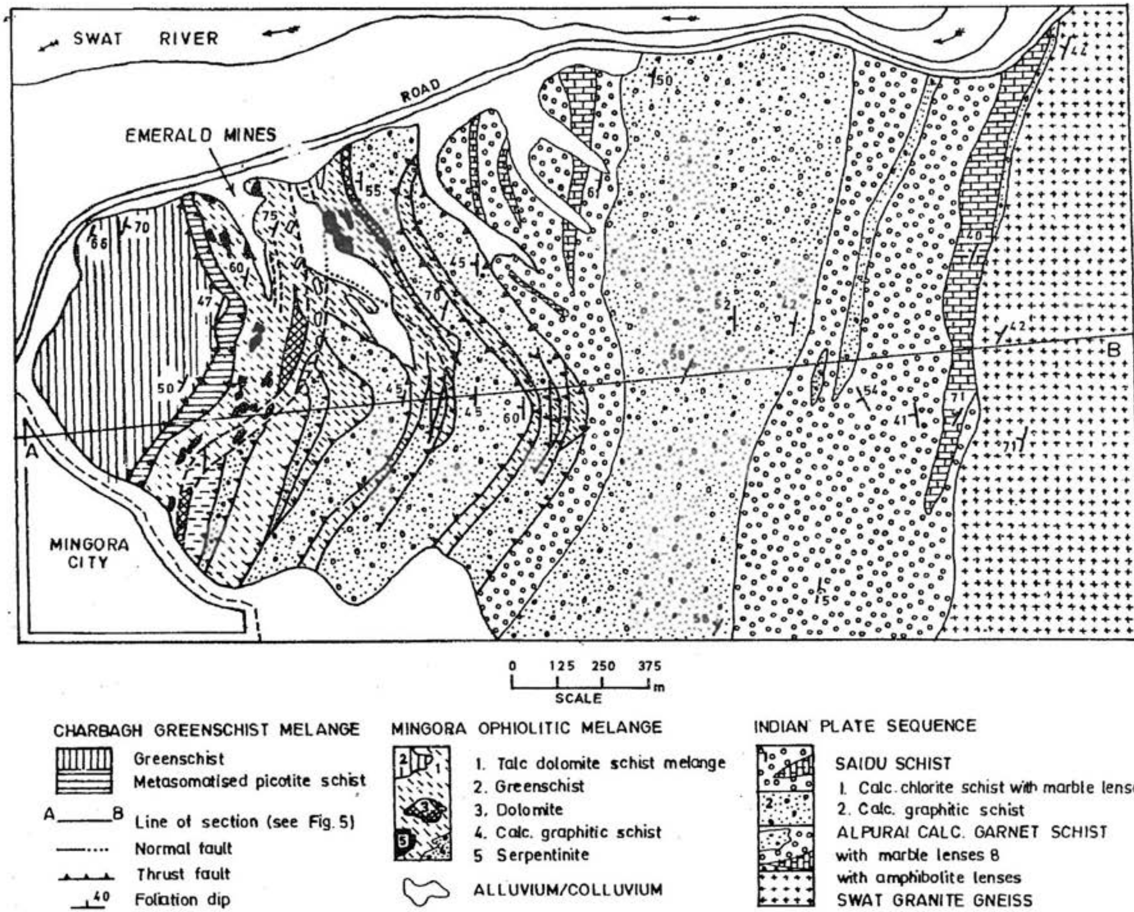

Fig. 4. Geological map of the Mingora area.

at the western end of the cross section (Fig. 5) are younger than those at the eastern end.

The age of the Saidu and Alpurai schists is uncertain to say the least. Previously the supposed intrusive contact with the Swat gneiss was taken to indicate a Precambrian age of formation, and these units were equated to the Salkhala Formation of Kashmir (Tahirkheli, 1979). The recognition of an unconformity between the Alpurai schist and the Swat gneiss means that these two schist units are bracketed by the Swat gneiss below and the time of emplacement of the Mingora ophiolite melange above (discussed below). Their deposition could have occurred anytime during most of the Paleozoic or Mesozoic. The Alpurai schist appears to be composed of typical shelf sediments with potential Himalayan correlatives of many ages, but we would like to raise the possobility that the Saidu schist is metamorphosed flysch, the local equivalent of the Indus flysch of Ladakh (Thakur & Bagati, 1983). Clearly metamorphic stratigraphy and radiometric age dates are essential to unravel the important details of the tectonics of this region.

The Indus Suture Melange Group.

In the Mingora area the Indus suture zone is characterized by a thick pile of melanges that reach maximum extent near Shangla Pass. There is considerable controversy concerning the definition and genesis of malange. For example, it is considered to originate due only to intense tectonic deformation (Dewey & Bird, 1971; Hsu, 1968, 1974); or due to deformation associated with spreading ridges and transform faults (Barret & Spooner, 1977); or it comprises a suite of deformed rocks representing accretionary prisms (Tekeli, 1981); or it is a descriptive term for a chaotic assemblage of limestone, radiolarite, turbidite, basalt, peridotite, gabbro, and blueschist including olistrostromes occurring along active continental margins or mountain belts (Cowan, 1975, 1978; Ozkaya, 1982). In this paper the term Indus suture melange group has been used in conformity with Gansser's (1974) definition of ophiolitic melange as an olistrostromal and tectonic mixture of ophiolitic material and sediments of oceanic origin with exotic blocks which are intimately related to ophiolitic belts and that indicate suture lines connected to plate boundaries.

Near Mingora, the Indus suture melanges are a chaotic assemblage of rocks derived from oceanic crust, volcanic arcs, trenches, and continental margins, ranging from Precambrian (?) to late Cretaceous in age. They are tectonically milled and strung together as fragmented blocks, sheets, and lenses, from a few meters to a few kilometers in extent, and set in a ductile matrix of volcanoclastic to pelitic schist, serpentinite, or talc-dolomite schist. The role of gravity processes in their creation is difficult to discern through the overprint of continental collision. They were created in processes at the margins of the Tethys ocean and combined during collision. Major thrust faults, the Kohistan, Shangla, Makhad, and Charbagh-Kishora thrusts, slice this melange complex into three melange units (Fig. 2). From south to north these are (a) the Mingora ophiolitic melange, (b) the Charbagh greenschist melange, and (c) the Shangla blueschist melange.

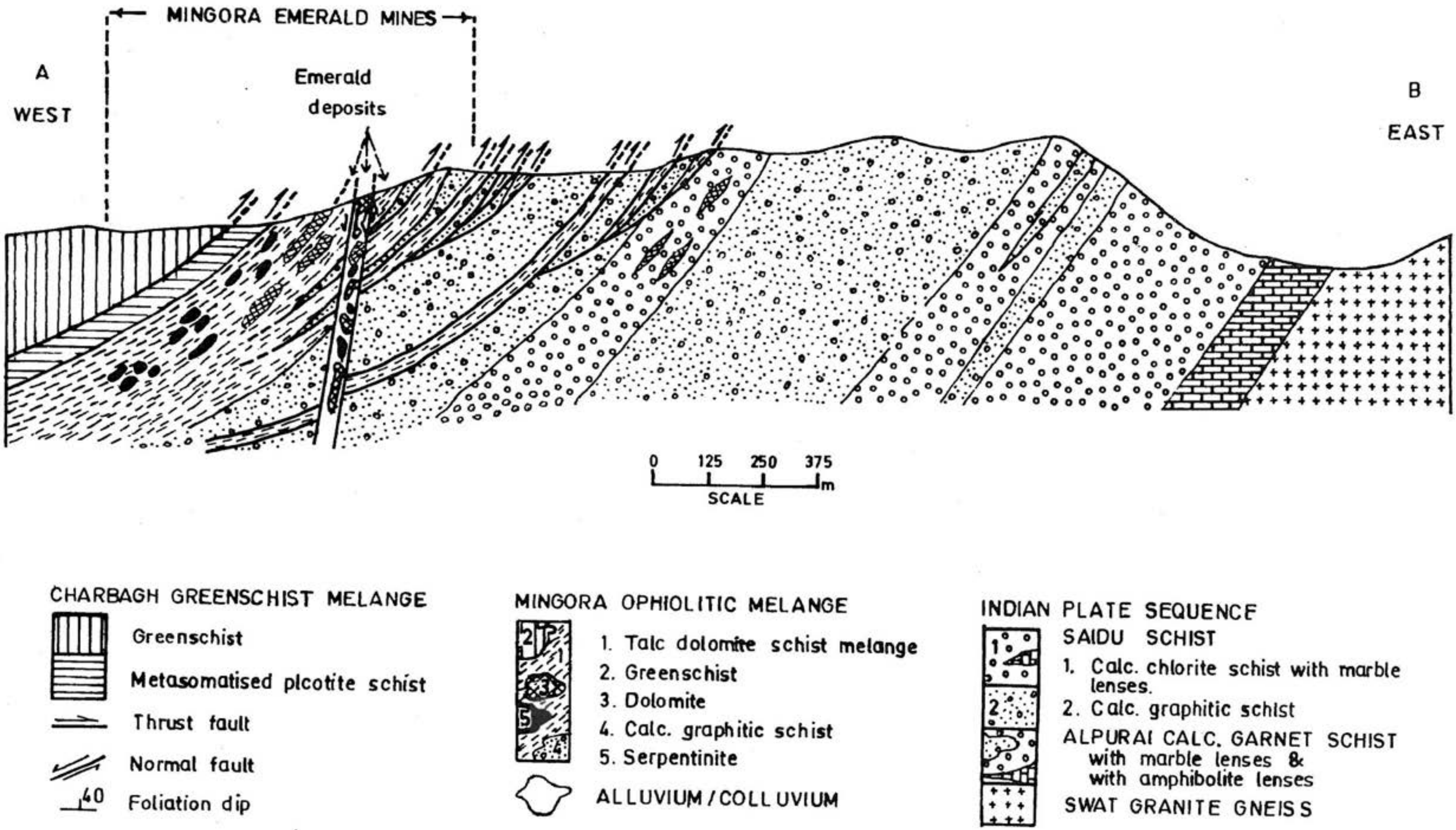

Fig. 5. Geological cross section of the Mingora area.

(1) *The Mingora ophiolitic melange.* At Mingora this unit occurs as a narrow north-south trending wedge and contains the Mingora emerald deposits. North-eastward it may be traced beyond Alpurai (Fig. 2). Westward it intermittently crops out from Kabal (Kazmer *et al.,* 1983) and continues into Dir district. Its thickness varies from a few hundred meters between Mingora and Makhad to (?) several hundred meters between Kishora and Alpurai. In decreasing order of abundance, it is composed of tectonized blocks and clasts of serpentinite, talc-dolomite schist, greenstone metabasalt, greenschist metapyroclastic, metagabbro, metasediments, and a metachert. All of this is set in a matrix of talc-chlorite-dolomite schist (abundant near Mingora) and scanty calcareous quartz-mica-chlorite schist. The latter occurs as slivers and thrust sheets squeezed in between the other tectonized blocks. Three main features distinguish this melange from the others: (a) abundance of the ophiolite suite of rocks, (b) presence of talc-dolomite schist, and (c) emerald mineralization.

(2) *Charbagh greenschist melange.* This melange crops out between Charbagh and Shangla Pass (Fig. 2) and forms a thick tectonic wedge between the overlying Shangla blueschist melange to the north and the Mingora ophiolitic melange to the south. It is characterized by greenstone metabasalts and greenschist metapyroclastics with minor tectonized layers and wedges of metasediments. The latter have been extensively sheared and mylonitized, particularly along its lower thrust contact with the ophiolitic melange, where ±100 meter long en echelon lenses of talc-dolomite schist have been strung out parallel to the Makhad thrust.

(3) *Shangla blueschist melange.* This melange crops out in a relatively small triangular area (6–9 km) between Chamtali village (east of Khawaza Khela), Shangla Pass, and Lilauni village (north of Alpurai). It forms a tectonic wedge between the Kohistan arc sequence to the north and the underlying Charbagh greenschist melange to the south. It is characterized by blocks of crossite-bearing blueschists (Shams, 1972, 1980; Shams *et al.,* 1980; Guiraud *et al.,* in press). It is composed of large dismembered masses (3 to 6 km in extent) of metavolcanics and phyllite schists with smaller lensoidal masses of serpentinite, metadolerite, metagraywacke, metachert, and marble.

The metavolcanics are composed of metatuffs and metabasalts. The tuffs retain relict bedding at places, commonly contain lapillae and volcanic bombs and largely occur as soft schistose rocks of variegated colour. Near Shangla Pass the tuffs are gray or grayish-pink and contain piedmontite, albite, quartz and mica (Jan & Symes, 1977). The metabasalts are brown to brownish-green and contain relict pillow structure. They are resistant to erosion and commonly occur as large blocks or lensoidal phacoids in the softer, sheared metatuffs. The mineral assemblage has been shown on Table 2. Jan *et al.* (1981) reported the pressure-temperature conditions during the blueschist metamorphism of approximately 7 kbar and <400°C on the basis of its mineralogy; they also indicate the possibility of a later higher temperature overprinting. Age dates on the metamorphism of 70 m.y. (K/Ar, Shams *et al.*, 1980) and 75–80 m.y. ($^{39}Ar/^{40}Ar$, Maluski & Matte, 1984) have been reported. Kazmer *et al.* (1983) report fossils of Jurassic to middle Cretaceous age from a limestone block in the Shangla blueschist melange near Kabal.

Based on the presence of three types of zoned amphiboles, actinolite, Na-amphibole, and hornblende, Guiraud *et al.* (in press) have inferred three metamorphic facies in the Shangla blueschist melange. According to these workers an oscillatory transition occurs between the blueschist and the epidote amphibolite facies. Combining experimental data and thermodynamic calculations, they interpret it as a reflection of 'a negative thermal gradient of –70 to –65 °C/km' and of 'a low gradient characteristic of the convergence zones' which is calculated from the highest pressure assemblages to be ±17.0 °C/km and ±13.5 °C/km for Afghanistan and Pakistan. They consider these physical conditions to reflect a subduction zone.

DISCUSSION

Previous workers have treated the Indus suture melange unit as one unit with the MMT as a bounding fault sometimes north of the unit and sometimes south of it. Desio & Shams (1980), Frank *et al.* (1977), and Guiraud *et al.* (in press) relate the melange unit to intra-oceanic subduction, whereas Tahirkheli *et al.* (1979), Bard *et al.* (1979, 1980), and Tapponier *et al.* (1981) link it to the obduction of oceanic and/or island arc crust over the Indo-Pakistan subcontinent. We first recognized the complex nature of this suture zone (Lawrence *et al.*, 1983) here mapped as three different units of different tectonic origins and separated by four major faults (Fig. 2). We interpret the Shangla blueschist melange to have developed above a subduction zone, north of the Neotethys ocean and oceanward of the Kohistan arc, that operated during Jurassic-Cretaceous ocean closure. The presence of blueschist knockers, materials of diverse metamorphic grades, Mesozoic fossils, sedimentary melange matrix, pillow basalts, and serpentinite fragments are all consistent with this interpretation. The Mingora ophiolite melange, on the other hand, most clearly resembles a block obducted onto the Indo-Pakistan subcontinent similar to the Las Bela, Muslimbagh, Waziristan, Logar, Dargai, Spongtang, and Jungbawa blocks (Asrarullah *et al.*, 1979; Abbas & Ahmad, 1979; DeJong & Subhani, 1979; Gansser, 1980; Tahirkheli, 1980; Thakur, 1981). This material is best interpreted as generated at a midocean ridge in the Neotethys and emplaced on the northern margin of the Indian subcontinent sometime between latest Cretaceous and early Eocene. The Charbagh greenschist melange is of more obscure origin. It is probably part of the obduction complex, perhaps a midocean island on which a large amount of tuffaceous sediment was generated. On the other hand, it could be island arc related and included in the suture zone by strike-slip slivering as a result of oblique subduction or collision. The three melange blocks were not juxtaposed until collision occurred, probably in the middle Eocene (Powell, 1979), but perhaps even later.

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