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TECTONIC SIGNIFICANCE OF MYLONITES FROM MINGORA, SWAT

MUNIR HUMAYUN
Department of Geology, University of Peshawar.

ABSTRACT

Rocks below the Swat gneisses, formerly thought to be a single unit, are a varied assortment of thrust slices consisting of rapakivi granites, sillimanite gneisses, marbles, and schists, in a mylonite zone. This zone is interpreted as the base of a large thrust. Thus, the overlying Swat gneisses and associated schists constitute a crystalline thrust sheet or nappe (?), that probably formed in response to the obduction of the Kohistan island arc.

INTRODUCTION

The geology of Mingora is dominated by the Main Mantle Thrust (MMT) which is the western extension of the Indus-Tsangpo suture zone (Jan *et al.*, 1981a). The MMT marks the collision of the northern margin of the Indian plate with the Kohistan island arc (Tahirkheli *et al.*, 1979). The suture zone has been depicted as a region of multiple thrusts, imbricate faults, and nappe formation (Dargai klippe), however, no direct evidence of thrusting has been recorded in the basement in support of this concept (Tahirkheli *et al.*, 1979; Bard *et al.*, 1980; Kazmi *et al.*, 1984). Geophysical data, although, suggest the presence of sialic material upto a depth of 100 kms (Malinconico, 1982).

Present studies identify a large mylonite zone in the basement of the Indian plate and extensive shearing, deformation and subsequent metamorphic recrystallization, probably related to the obduction of the Kohistan island arc. These findings will require major revision of the stratigraphic setup and the chronology of metamorphic and structural events.

PREVIOUS WORK

The initial work on the geology of Swat by Martin *et al.* (1962), has been subsequently revised by the application of plate-tectonic concepts (Jan *et al.*, 1981a; Tahirkheli *et al.*, 1979; Kazmi *et al.*, 1984). Martin *et al.* (1962) classified the granitic rocks of Swat and Buner into two groups: the Ambela Granite intruding the Swabi-Chamla sedimentary group in the south, and the Swat granitic gneisses intruding the Lower Swat-Buner schistose group in the north. They suggested that the Swat granitic gneisses intrude the lowest unit of their schistose group, the siliceous schist, in the form of a thick concordant sheet. It is this unit, and its relationships with the gneisses and other schistose units that has undergone major revision by Kazmi et al. (1984) and the present studies.

Kazmi *et al.* (1984) considered the gneisses to be intruded into the siliceous schists (renamed as Manglaur crystalline schist) and proposed a major unconformity between this Precambrian-Cambrian basement and the overlying Alpurai schists and Saidu schists. The Swat granitic gneisses are considered to be part of the S–type granite-gneiss belt that extends along the northern margin of the Indian plate (Jan *et al.*, 1981b) from Malakand to Nanga Parbat and possibly along the entire length of the Lasser Himalayas (Le Fort *et al.*, 1983). These gneisses are, therefore, correlatable with the Mansehra Granite having a Rb/Sr whole-rock isochron of 516±16 m.y. (Le Fort *et al.*, 1980) and the Simchar pluton of Nepal with a similar age (Le Fort *et al.*, 1983).

PARENT ROCK LITHOLOGY

The rocks of the Indian plate beneath the MMT (Fig. 1) may broadly be grouped into three units. Structurally, from top to bottom these are an upper unit of schists, amphibolites and marbles (the Alpurai schist and Saidu schist of Kazmi *et al.*, 1984), an intermediate unit of granitic rocks generally lumped together as the Swat granitic gneises (for more data see Humayun, 1985), and an underlying assortment of gneisses, schists, mafic rocks, marbles and mylonites (the Manglaur schists of Kazmi *et al.*, 1984). A schematic cross-section is shown in Fig. 2. The rocks studied here belong to the lower two units.

The Swat granitic gneisses:

The main lithology is porphyritic granodiorite, estimated to be of batholithic dimensions. Underlying this (see Fig. 2) is a small sheet of biotite granite locally developing rapakivi textures and associated with mafic intrusives. Both lithologies have been intruded by thin dykes and sills of tourmaline granite that rarely exceed 2 m in thickness.

The porphyritic granodiorite consists of white potash feldspar megacrysts with rectangular shapes and 7x4 cm sizes, in a matrix of quartz, mica and plagioclase. The megacrysts are euhedral perthitic orthoclase, or microcline with faint grid-iron twinning. The rocks have been gneissified to varying extents, from coarse augen gneiss to mylonite. It is this lithology that has been correlated with the Mansehra granite and other augen gneisses (Jan *et al.*, 1981b; Le Fort *et al.*, 1983).

The biotite granite (Humayun, 1985), is equigranular to porphyritic in texture and consists of alkali feldspar, plagioclase, quartz, biotite, and sphene. It appears undeformed megascopically but shows mortar texture in thin-section. The alkali feldspar is flesh pink in colour, ovoid to euhedral in shape and 0.5 to 2 cm in diameter. Both the undeformed appearance of the groundmass and the rapakivi feldspars distinguish the biotite granite from the granodioritic gneiss. The tourmaline granites are typical subsolvus granites consisting of equal amounts of quartz,

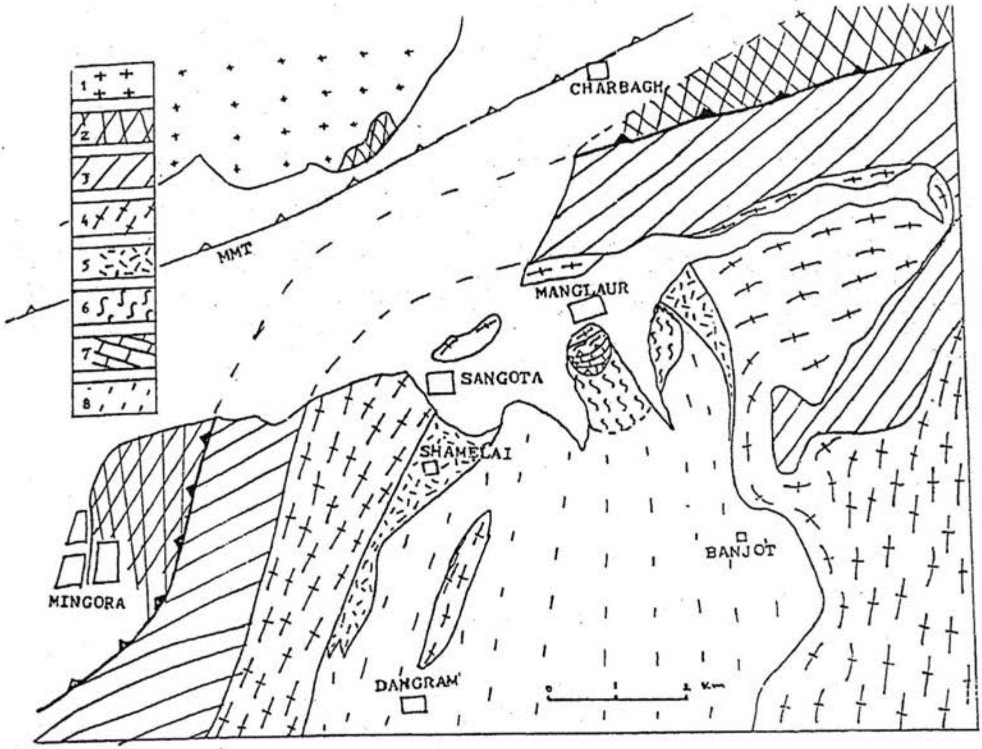

Fig. 1. Geological map of the Mingora area. Explanation : 1 — Kohistan amphibolites, 2 — Ophiolitic melange, 3 — Swat schists, marbles, and amphibolites (part of the Swat-Buner schistose group), 4 — Swat gneisses, 5 — Biotite granite (Rapakivi), 6 — Sillimanite gneisses, 7 — Marbles, 8 — Mylonites.

albitic plagioclase and well-twinned microcline with lesser amounts of muscovite and tourmaline. They are leucocratic in appearance and equigranular in texture, but have been mylonitised, folded or boundinaged in various places.

The mafic rocks are common as small intrusions throughout the underlying schists and gneisses. Those occurring in the biotite granites consist of titanaugite, biotite, plagioclase, and sphene, indicating an alkaline mineralogy. Most of the mafic rocks associated with the granodioritic gneisses occur as concordant amphibolite layers consisting of hornblende, and plagioclase, with garnet or epidote. These rocks are usually associated with schists, consisting of garnet, biotite, and plagioclase.

The lower schist unit:

Biotite-Sillimanite gneisses with orthoclase, and locally garnet, are a common lithology in the lower schists. Typical outcrops are located just south of

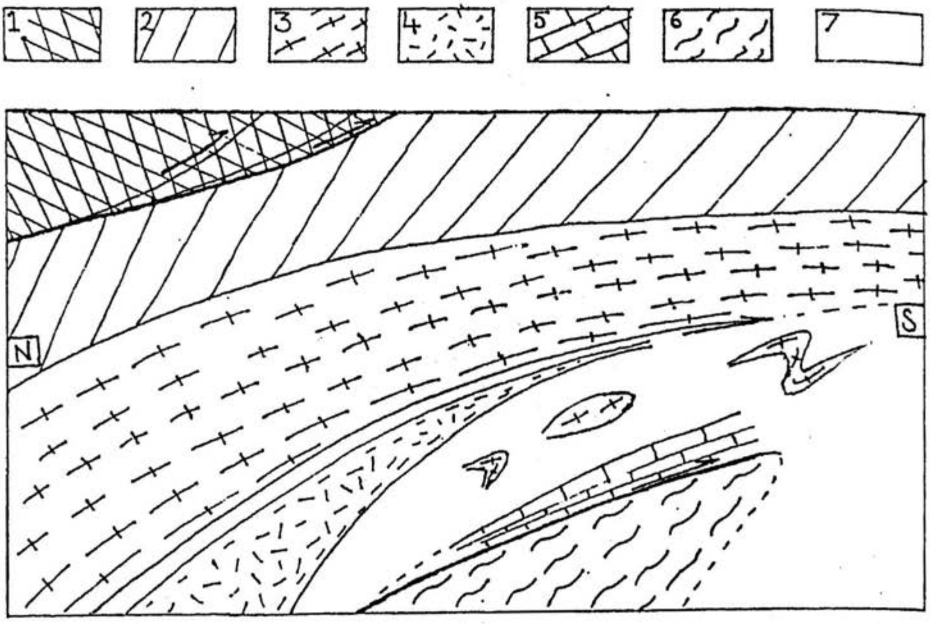

Fig. 2. Schematic cross-section of the area. Explanation : 1 — Ophiolitic melange, 2 — Swat schists, marbles and amphibolites, 3 — Swat gneisses, 4 — Biotite granites, 5 — Marbles, 6 — Sillimanite gneisses, 7 — Mylonites.

Manglaur (Fig. 1), and are overthrust by a marble layer (Fig. 2) that is quarried for building stone. Smaller layers of marble with minor quartzite are intercalated with schists and gneisses. The marbles are yellow to grey, coarse grained calcite + dolomite + tremolite (actinolite) marbles. Other rocks include graphite schists, and garnet-quartz micaschists with intercalated gneisses.

METAMORPHIC AND DEFORMATIONAL EPISODES

At least two phases of metamorphism have affected the entire Indian plate sequence (cf. Kazmi *et al.,* 1984). The rocks of the Indian plate have undergone almandine-amphibolite facies metamorphism, indicated by the presence of almandine-amphibolite and sillimanite-orthoclase assemblages. This has been followed by the main period of cataclasis. Then, the entire Indian plate-suture zone-island arc sequence has undergone a greenschist facies metamorphism that recrystallized the products of cataclasis, and formed retrograde assemblages in the island arc (Jan, 1980; Jan *et al.,* 1981a) and the Indian plate. Post-metamorphic folding produced the Mingora anticline (which folded the MMT) and many smaller folds.

MYLONITES

The rocks below the MMT retain a strong evidence of tectonism despite the subsequent recrystallization. Overall, the gneiss has a cataclastic foliation

S_1, parallel to the regional schistosity. The grainsize varies from euhedral megacryst-bearing granodiorite with a deformed matrix to medium-grained gneisses with large matrix fractions and small porphyroclasts of feldspar. The progressive cataclasis can be traced by the increasing fracturing and decreasing grain-size of the megacrysts. Mylonitization, accompanied the gneissification and shear zones up to 50 m wide are common in the gneisses. Similar mylonite zones from the Blue Ridge Basement, Virginia (U.S.A.) have been termed ductile deformation zones (DDZs) (Mitra, 1978). They form in rocks with initially high quartz+mica to feldspar ratios, and take up large amounts of strain without catastrophic failure. The DDZs in the Mingora gneisses are felsic, medium- to fine-grained recrystallized mylonites. They have been mistaken for dykes, but when weathered, for "feldspathized quartzites". Depending upon the degree of recrystallization, the contacts of the DDZs with the gneisses are either sharp, or diffuse. The diffuse contacts show signs of severe deformation. Large differences in strain are evident near the contacts, where single megacrysts are 7 to 10 times longer than their widths.

Typically, the strain rates are very variable. In a vertical profile through the gneisses, generally, the central portions are much less deformed compared with the margins. The upper contact of the gneiss is mildly deformed when compared with the gross mylonitization into which the lower contact grades. Even within the basal mylonite there are local zones of very low strain, in which porphyritic rocks are preserved. These local zones are fewer and narrower than the converse zones of high strain (DDZs) in the porphyritic parts.

BASAL MYLONITES

1. Petrography

The basal mylonites show well developed fluxion textures. In the early stages of the development of fluxion texture, quartz and mica are the first minerals to be affected. Quartz grains develop undulose extinction, grain border mismatch and seriate textures (for the definition of terms used see Moore, 1970; Higgins, 1971; Bell and Etheridge, 1973). Biotite is kinked and shredded. The quartz-mica matrix forms a reticulate enclosure of the feldspars. Rocks richer in quartz and mica develop macroscopic foliation later than those rich in feldspars. Consequently, the granodiorites are everywhere well-foliated. Accessory minerals, such as garnet, sphene and opaques are granulated, too.

Plagioclase deforms more readily than alkali feldspar. It becomes saussuritized during the early stages of deformation. Subsequent recrystallization to albite, white mica, and epidote further contributes to the increased proportion of matrix. Alkali feldspar is progressively granulated in the more advanced stages of mylonitization. Porphyroclasts become smaller but more abundant; and the foliation wraps around these.

2. Recrystallization

Three factors determine the wide variety of observed rock-textures: parent lithology, degree of deformation and the nature of subsequnt rcrystallization. In the study area, the various types of recrystallization and corresponding products observed are described below. The assemblages produced are typically those described from greenschist facies terrains.

a). Recrystallization resulting in an increase in matrix fraction with the development of abundant muscovite. This may accompany mylonitization if sufficient fluid is present. The reaction is

3 Orthoclase + 2 water ⟶ Muscovite + 6 Quartz + 2 KOH

Similarly, albite forms paragonite and quartz. All the white mica in the gneisses appears secondary. The replacement of feldspar by micas and quartz produces a wide variety of recrystallized mylonites that include quartz-feldspar phyllonites, two-mica gneisses, quartz two-mica schists and garnet-quartz micaschists. These grade into less recrystallized mylonites, some having relict porphyroclasts of alkali feldspar, the "feldspathized quartzites" and "siliceous schists" of previous workers (Martin *et al.,* 1962; Kazmi *et al.,* 1984). The recrystallized mylonites contain small fragments of unstrained crystals of biotite, quartz and feldspar with coarse crenulated layers of white mica and, commonly, porphyroblasts of garnet. Trails of garnet result when new phases are nucleated over the crushed and drawn out fragments of an older one. Occasionally, biotite shows significant increase in grain size with recrystallization.

b). Recrystallization resulting in an increase in grain size without substantial increase in matrix fraction. In outcrops these rocks are clearly mylonites, but in thin section these are medium- to fine-grained microcline-albite-quartz rocks with thin flakes of biotite and muscovite and grains of epidote in a roughly equigranular texture. The recrystallization is patchy and fractured grains (of alkali feldspar, garnet, and sphene), interlobate grain edges and seriate textures are found. In some of these mylonites, garnet porphyroblasts appear to grow over the mylonite foliation.

c). Recrystallization with the development of large matrix fractions but no prominent muscovite. These mylonites probably recrysta lized in the absence of excess fluid, preventing the growth of large micas. The mylonites consist of porphyroclasts of alkali feldspar in a phyllonitic matrix of fine grained (less than 0.05 mm) aggregates of biotite, quartz, epidote, muscovite, and fragments of garnet, and feldspar. In some rocks, the coarse alkali feldspars completely disappear. Narrow zones bearing feldspar porphyroclasts in such rocks have been mistaken for intrusions in the "Manglaur schist". An interesting feature within the non-porphyroclastic mylonites is the development of pods of mantled rapakivi feldspars about 15–20 cm in diameter. These pods are flasers of resistant minerals aggregated by mechanical differentiation (Higgins, 1971, pp. 62–64), probably involving thinning of the matrix between the feldspar grains.

d). Recrystallization without increase in grain size or matrix fractions. Such rocks are typical of mylonites developed on fault planes, and are fine grained, flinty, banded rocks with small porphyroclasts visible in thin section. These frequently have two mylonitic foliations: an older layering of quartzofeldspathic material and at about 45 degrees to this, a cross-cutting mylonitic foliation of both felsic and micaceous minerals. On the weathered surface it resembles cross-bedding and, indeed, the rocks have been described as "a fairly pure hornfelsed quartzite, still retaining its cross-bedding" (Martin *et al.*, 1962, p. 3).

OTHER MYLONITES

These mylonites are formed from pegmatites, mafic rocks, marbles and sillimanite gneisses. Pegmatites are fairly common, contrary to some opinion (Martin *et al.*, 1962), and occur as strongly deformed quartz veins with feldspar cores, and occasionally epidote pods. The mylonitized mafic rocks are commonly altered to biotite or chlorite schists. The potash required may be supplied by the muscovitization of the adjacent gneisses. At Manglaur, a marble unit is thrust over sillimanite gneisses (Fig. 2) with a purplish-brown mylonite in between, which is derived from sillimanite gneisses. Similar mylonites have been found at several other places.

POST-MYLONITIC DEFORMATION

The mylonites, intercalated schists and gneisses of the lower schist unit have been subsequently folded by tight to isoclinal folds with southward vergent axial planes. These may have been formed by deformation during the later stages of obduction. At least some of the folds are parasitic folds formed by the regional Mingora anticline, in the core of which these are exposed. Some of the folds are large enough to produce significant lithologic repetitions of layers of gneiss, recrystallized mylonite, and marble. The gneiss layers are thickened in the fold noses and thinned along the flanks. These thickened fold noses are occupied by coarse grained augen gneisses that weather out as distinct bodies.

DISCUSSION

Mylonites are widely distribution in orogenic belts. These occur as narrow zones of intense shearing, either localized on fault planes, or dispersed in crystalline basements. At temperatures of the greenschist facies or beyond, deformation of crystalline rocks may proceed largely by the formation of narrow planar shear zones (Mitra, 1978). Such mylonites are common in the Mingora gneisses. The mylonites at the base of the gneisses, however, could not have been formed in this manner. The thickness (over a hundred metres) and the unrelated rocks below indicate their formation at the base of a large thrust sheet. This thrust may have been formed in response to the obduction of the Kohistan island arc (Fig. 3). The presence of a northward plunging lineation in the rocks below the suture and the regional northward dip of the major structures (Malinconico, 1982) suggests southward thrusting of the Swat gneisses, possibly over the Ambela granite.

It is further proposed that the term "Manglaur schist" be formally abandoned and the various lithologies referred to individually, until more data becomes available for proper nomenclature. The general recrystallization of mylonites observed in the study area suggests that other major shears in the region may be similarly obscured.

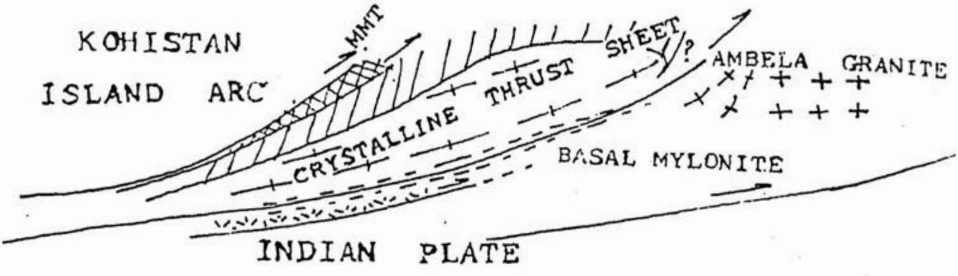

Fig. 3. Tectonic model for the interpretation of the gneisses and overlying schists as a crystalline thrust sheet.

CONCLUSIONS

Schists, marbles, amphibolites, and underlying gneisses of lower Swat and Buner constitute a crystalline thrust sheet of the Indian plate. This unit moved southwards in response to the obduction of the Kohistan island arc, on a thrust plane now exposed at the base of the Swat gneisses as a zone of recrystallized mylonites. These mylonites have smaller thrust slices of rapakivi granites, sillimanite gneisses, marbles, and schists. The entire unit is tightly folded, and has been considered to be a metasedimentary sequence into which the Swat gneisses have been intruded. Infolding and thrusting account for the intercalation of the gneisses and schists which have been previously mistaken for intrusions or xenoliths. The recrystalliation of the mylonites explains their late recognition.

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