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TECTONIC CONTROL OVER EMERALD MINERALIZATION IN SWAT

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ABSTRACT

Emerald and chromian tourmaline occur in carbonate-talc/serpentine/chlorite rocks, carbonate-bearing talc schists, and associated quartz veins near Mingora, Charbagh, and Shangla. The rocks are altered ultramafics found in a discontinuous belt of volcanic, volcano-sedimentary, and sedimentary rocks that have undergone high P– low T metamorphism. The belt is a thrust slice overlying Gondwanic sialic metasediments and underlying the Kohistan (? oceanic) amphibolites both of which display Barrovian metamorphism in the almandine amphibolite facies. It appears that the emerald-bearing belt represents a marginal basin or trench rocks of (?) Mesozoic age with tectonically incorporated lenses of ultramafic rocks from the upper mantle.

INTRODUCTION

Emerald has been mined near Mingora, Swat, for over two decades. Although many of its crystals are fractured and imperfect, some highly precious stones have also been recovered from the area. It is claimed that the good quality crystals are second to none. In recent years, more emerald-occurrences have been discovered from Charbagh area, and Gujar Kili in Shangla Par (A.H. Kazmi, pers. comm.). Jan *et al.*, (1972) have described a green chromian tourmaline from Alpurai. Although this mineral is in tiny grains and only of academic interest, its petrographic set-up is the same as those of the emerald occurrences.

This paper gives a petrographic account of the tourmaline- and emerald-bearing and associated rocks of Swat in the light of tectonic data which has a direct bearing on the occurrence of the gem minerals. The work is based on field studies and thin section examination of over 180 rocks. We are glad to report that the recently formed Gemstone Corporation of Pakistan is currently carrying out a detailed exploration of the region for locating more gem deposits.

PETROGRAPHY

Mingora Area

Preliminary accounts of the petrography of the emerald-bearing rocks from this area have been presented. The mineral occurs in carbonate-talc rocks (Jan, 1968), carbonate-bearing talc schist (Kazmi, pers. comm.), and in quartz veins found along shear zones that lie along the contact of greenschists and phyllitic schists (Davies, 1962). Associated with the shear zones, according to Davies, are tectonically broken lenses of ultramafic rocks. The greenschists and phyllitic schists were considered by Martin *et al.* (1962) to be the upper members of the Palaeozoic Lower Swat-Buner schistose group.

The emerald-bearing rocks consist of carbonate (calcite/dolomite but some is stained brown and may be siderite), talc, serpentine, and minor opaque oxide. Bright green chromian mica (fuchsite) and chlorite, and quartz occur in some rocks and clinozoisite in a few. Veins of carbonate and quartz are found in the rocks. Associated with these rocks are chromite-rich concentrations (chromitites) veined by kammererite or green chlorite, epidote, and calcite. The entire association thus appears to be the alteration product of ultramafic rocks at low temperatures rather than being of sedimentary origin. Among the carbonate minerals, aragonite has been identified by Davies (1962).

Some calcareous rocks of the Mingora area are different from the above-described rocks in that they contain white mica instead of green Cr-mica, have more quartz and carbonate with albite in a few, and generally lack talc and serpentine. These, probably, are calcareous metasediments associated with rocks of sedimentary, volcano-sedimentary, and volcanic origin. The common mineral assemblages in this group of rocks are albite + quartz + chlorite ± carbonate ± white mica ± rutile ± sphene ± biotite ± epidote + opaque oxides, and chlorite schists containing variable amounts of albite ± white mica ± epidote ± quartz ± rutile ± opaque minerals.

The rocks to the W of Swat river and S of Kabal are an extension of those near Mingora. They include greenschists, phyllitic– and graphitic schists, calcareous rocks, deformed dolerites and serpentinized ultramafic lenses. Blueschists have not been found *in situ* but their presence is suggested in rare boulders containing blue amphibole (F. Proust, personal communication).

Shangla Area

Apart from a greater variety of rocks, the geology of the Alpurai– Shangla-Malam Jaba area is similar to that of Mingora. Martin *et al.* reached a similar conclusion in 1962 and grouped the rocks of the two areas into greenschists and phyllitic schists. As in Mingora, rocks of the Shangla area are also sedimentary, volcano-sedimentary (tuffs and agglomerates), volcanic, and intrusive in nature. Low grade metamorphites (tuffs, pelites, psammites, graphitic schists, greenschists, calcareous rocks) and ultramafic rocks make the bulk of the Shangla area. The graphitic schists contain quartz, plagioclase, carbonate, graphite and white mica as their principal components. The greenschists, produced generally from volcanic and volcanoclastic rocks, contain chlorite, plagioclase, ore and quartz, with variable proportions of epidote and actinolite. Biotite, muscovite/phengite, rutile, and sphene occur in a few rocks, and garnet in rare cases. We consider that most of the pelitic-psammitic-looking rocks in the western part of Shangla pass are tuffaceous in origin.

Interesting is the occurrence of piemontite schists and, especially, blueschists at Shangla and to the W and NW. The piemontite schists consist of quartz, albite, white mica, piemontite, Mn–rich chlorite, magnetite, tourmaline and, locally, spessartine garnet (Jan and Symes, 1977). Considered to be metamorphosed shales, the high MnO content (2.1%) of these rocks has been attributed to volcanic or hydrothermal activity at the time of deposition of the shale horizon.

The blueschists contain blue amphibole with variable amounts of epidote, albite, phengite, quartz, chlorite, garnet, tourmaline, rutile and pyrite (for further details, see Shams, 1972; Desio, 1977). Shams (1980) and Shams *et al.* (1980) found the blue amphibole to be crossite, however, our optical examination (including refractive indices) suggests that at least in some rocks the amphibole is zoned and ranges from crossite to glaucophane in composition. In a few cases, a green (?)sodic pyroxene occurs in the rocks whilst calcite pseudomorphs after lawsonite have been found in chlorite-phengite schists near Bania China, NW of Malam (Bard *et al.,* 1979). Other minerals found in these rocks are actinolite, sphene, calcite, and apatite. A most peculiar rock of Shangla area consists of pure calcite with some blue amphibole. Like many others, the Shangla blueschists are found in the form of lenses and patches in low to very low grade metamorphic rocks.

Shams (1972, 1980) recognized two paragenetic types of blueschists in Shangla: one being allochemically metamorphosed igneous rocks whilst the other metasomatised sediments. A meta-doleritic origin has been suggested for a blueschist from this area by Shams *et al.* (1980). We think that many of the blueschists are derived from volcanic flows and breccias (agglomerates). A few of the rocks, however, may owe their brecciated nature to tectonization.

Ultramafic rocks are closely associated with the blueschists, greenschists and other rocks of the Shangla-Malam Jaba area. Such an association has already been documented in Franciscan and other well-known examples of high pressure-low temperature metamorphic zones. In addition to the > 5 x 2 Km lensoid outcrop at Alpurai, a number of small ultramafic lenses occur in the area. (Careful mapping and distinction of altered ultramafics from calcareous sediments should delineate more occurrences). They are commonly sheared, altered, and display tectonic fabric. Serpentinization, steatization, and carbonate alteration are common but the presence of olivine, orthopyroxene, and clinopyroxene in the less altered rocks points towards their alpine peridotitic nature of the harzburgite sub-type (Jackson and Thayer, 1972).

It is interesting that the ultramafic rocks of the Jijal area, 30 km to the NE, are also harzburgite subtype and considered to be derived from the upper mantle (Jan and Howie, 1981). As with Jijal, chromite streaks and bands have also been reported from these ultramafics (Khan and Humayoun, 1980).

Of particular interest are carbonate + talc ± serpentine ± quartz rocks generally found on the eastern margin of the main ultramafic body at Alpurai. These rocks locally contain bright green chromian mica (fuchsite) and/or chlorite, and green chromiferous incrustations. The rocks also contain local quartz and calcite veins and it was in one of such rocks that a green tourmaline with 8.5% Cr_2O_3 was reported in the W of old Alpurai village (Jan *et al.*, 1972). The newly discovered emerald is also found in these rocks near Gujar Kili, about 2 Km S of Katkai (Kazmi, pers. comm.). A third emerald occurrence, known for some years, is near Charbagh. The rocks here are an extension of the Shangla area and the gem mineral occurs, again, in carbonate + talc ± fuchsite host rocks (Kazmi, pers. comm.).

It appears that the carbonate – talc – rocks, like their equivalents in Mingora, are also an alteration product of the ultramafic rocks due to an influx of H_2O, CO_2 and possibly, Si, Ca, and Al. They margin the ultramafics, lack sedimentary features, contain ghost–like relics, and their mode and mineralogy lend sufficient support to this view. It is absurd to think that these rocks are metamorphosed impure dolomites because of their rather high Cr content expressed in Cr-bearing minerals and incrustations that are locally abundant. In the N of Lilaunai, the following sequence of progressive alteration is noted:

Ultramafic rocks ➔ Grey green altered ultramafics, veined by talc and having abundant relics ⟶ brown rocks with reddish brown relics and some quartz veins ⟶ Brown or green carbonate + talc ± Cr– mica rocks, relics absent or rare, much green colouration and many quartz veins. Elsewhere, as seen on the road to the W of Shangla, the ultramafic patches may be converted to talc-tremolite and talc-actinolite schists.

Other igneous rocks of the Shangla–Malam area include dolerites and greenish to pinkish altered feldspathic rocks that may range from hornblende gabbro to dioritic and (?) trondhjemitic in composition. These have yet not been studied carefully but may be of significant petro-tectonic importance.

Summary

The petrography of the Shangla and Mingora areas leads to the following conclusions :

(1) The geologic and petrographic set-up of the two areas is quite similar. In both areas the country rocks are volcanic, volcanoclastic, and sedimentary in origin.

(2) Ultramafic rocks, some strongly altered, are intimately associated with them. The ultramafics are sheared (especially on their margins), broken, and they display tectonic fabric; their deformation may have facilitated their alteration (metasomatism).

(3) Severely altered ultramafics, containing carbonate-talc/serpentine/ chlorite, host emerald and chromian tourmaline but quartz and, rarely, calcite veins

in or near such rocks may also contain the gem. Consequently, soft rocks with a higher proportion of talc (and chlorite) should be better sites for extracting highly precious and perfect stones.

TECTONIC SET-UP

The rocks of Shangla-Malam Jaba, Mingora, and across the river to the S of Kabal were considered by Martin *et al.* (1962) to constitute the phyllitic schists and greenschist members of the Palaeozoic Lower Swat-Buner schistose group. Martin *et al.* also noted that the metabasic rocks of the Hornblendic Group (since renamed the Kohistan complex or sequence), occurring to the N, are thrust faulted over them. Jan and Symes (1977) pointed out the regional extent of this fault and Jan (1977) suggested that the thrust is an extension of the Indus suture which marks the subduction of the Indo-Pakistan plate under the Asiatic mass. A number of other workers have more recently come to this conclusion and Tahirkheli *et al.* (1979) have named it the Main Mantle Thrust. Bard *et al.* (1980) and Jan (1980) have shown that the Shangla-Mingora type rocks are not only thrust against the amphibolites of the Kohistan complex but also against the rest of the rocks of the schistose group of Martin *et al.* Thus these rocks should no longer be regarded as a part of the Palaeozoic schistose group.

The mineral assemblages, especially the occurrence of glaucophane and crossite, lawsonite (pseudomorphed by calcite), aragonite, and phengite, indicate that the Shangla-Mingora rocks have undergone a high P–low T metamorphism. Glaucophane schist terrains are typical in subduction/obduction zones (Coleman, 1972). We assume that temperatures in the Shangla-Mingora zone were generally less than 400°C, although a later overprinting (as indicated by the occurrence of garnet-bearing veins in the blueschists, and possible conversion of the latter to greenschists) of slightly higher temperatures might have taken place. Shams *et al.* (1980) have presented two analyses of crossites from Shangla. One of these comes from a rock containing, among other minerals, albite and garnet, the An content of the plagioclase being 0.14 (Kempe, pers. comm.). The Ca/alkalis distribution in the plagioclase-amphibole pair in their rock 14348 yields a temperature of < 400°C (~ 380°) by the method of Perchuk (1966). The crossite contents of the two amphibole analyses yield approximate pressures of about 7 Kbar according to the method of Brown (1977). The presence of albite instead of jadeite + quartz, of albite + lawsonite (later pseudomorphed), and of calcite instead of aragonite (except in one place) also suggest that operating pressures were approximately 7 Kbar (cf. Brown, 1977).

These temperature estimates are significantly lower and pressure estimates higher than those prevailing during the metamorphism of the amphibolites and schists immediately N and S, respectively, of the Shangla-Mingora belt. The occurrence of garnet and staurolite in the schistose group to the E of Alpurai, along with kyanite in Manglaur area (Talegram), indicate moderate to high-grade Barrovian metamorphism in the schistose group. The amphibolites of Kohistan in the north, similarly, are generally metamorphosed up to at least the middle of Barrovian almandine amphibolite facies (Jan, 1977). Garnet is abundant in some rocks of Lilaunai area, at places accompanied by clinopyroxene.

The rocks of the schistose group are sialic in nature with only a small quantity of amphibolites that represent basic intrusions and tuffs. Thus the lithology, metamorphic conditions, as well as structure (data to be presented at a later date) of the Shangla-Mingora-Kabal zone are distinctly different from those of the basic rocks (amphibolites and gneisses) of Kohistan to the N and the sialic metasediments of the schistose group to the S.

The occurrence of a confused mixture of volcanic, volcanoclastic and sedimentary rocks along with ultramafic and gabbroic to (?) trondhjemitic rocks indicates that the Shangla-Mingora-Kabal zone represents either a marginal basin or trench type environment. The presence of still-preserved pillow structure in volcanic rocks near Asharko village on the Malam-Jaba road and of manganiferous metasediments add to this idea. During the subduction/obduction of this zone, ultramafic material from the upper mantle was tectonically incorporated in the overlying crustal rocks and the entire association was thrust on to the sialic rocks (schistose group) of the Indo-Pakistan plate. This event was coeval with the obduction of the basic rocks of the Kohistan complex on to the Indian plate as well as the Shangla-Mingora-Kabal zone. So, in our opinion, the latter zone is a thrust slice of a trench or marginal basin rocks.

If so, a Palaeozoic age is highly improbable for these rocks. They must have formed in response to the northwards drift of Indo-Pakistan plate and may be Late Jurassic to Middle Cretaceous. The blueschist metamorphism is dated at 67 and 84 M.A. by Bard *et al.* (1980) and Shams (1980), respectively. These ages are similar to those found for basic to intermediate rocks of Swat Kohistan (Jan, 1977, 1980) and possibly mark the obduction of the Kohistan complex.

Bard et al. (1979) have suggested the occurrence of a 200 Km long but discontinuous belt of high P–low T rocks extending from Babusar in the E to Kabal in the W. The presence of blueschists in Dir, again between the Kohistan amphibolites and sialic rocks of the Indian plate (Butt *et al.*, 1980), and of piemontite schists and greenschists in Bajaur area indicates that the belt is much longer in extension. The entire zone is worth looking at carefully for Cr-bearing gem minerals especially where carbonate + talc ± green mica-bearing ultramafics are present.

In the past the emerald and Cr-tourmaline mineralization has been connected with granitic plutons in the area (c.f. Davies, 1962; Jan *et al.*, 1972). Our model, however, cannot substantiate this view for two reasons: (1) the granitic plutons are confined to the Lower Swat-Buner schistose group which is over-thrust by the emerald-bearing Shangla-Mingora zone, and (2) the granitic plutons of Swat are very similar to the Mansehra granites which have a Rb/Sr isochron age of 516 m.y. (Le Fort *et al.*, 1980). The complex tectonic history of the Swat granitic gneisses

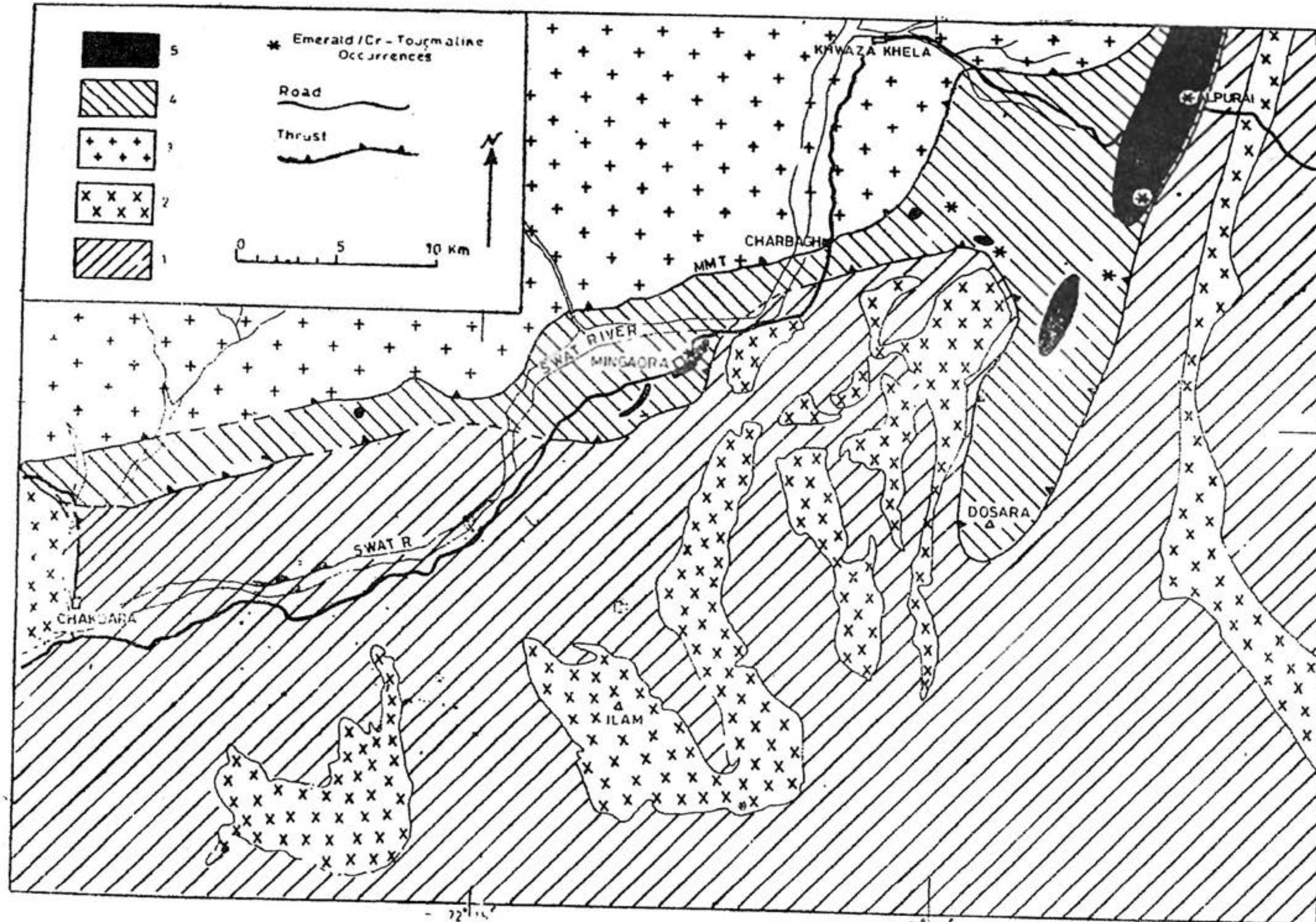

Fig 1. Simplified geological map of Upper Swat (After Martin *et al.*, 1962).
1. Precambrian metasediments, 2. Cambrian granites,
3. (?)Mesozoic amphibolites of the Kohistan sequence,
4. (?)Mesozoic Shangla-Mingora high P–low T metamorphic zone, and
5. Ultramafic rocks.

leads us to postulate that they may be Pan-African in age and much older than the emerald-bearing belt. It is likely that hydrothermal/pneumatolytic solutions were responsible for introducing Be and B, and their source may be the same that caused the alteration of the ultramafics which in turn provided the necessary chromium for the gems. The solutions may have been connected with the widespread extrusive and intrusive igneous activity in the trench/marginal basin but contribution from the sediments during metamorphic recrystallization should not be totally ruled out.

This paper is ended with repeating the suggestion that a careful search of altered (metasomatised) ultramafics and their contact rocks in Shangla and other areas of the high P–low T tectonic slice may reveal additional occurrences of Cr-bearing gem minerals. Such rocks, as pointed out by Tahirkheli (1980), occur in the vicinity of the Main Mantle Thrust which marks the subduction of the Indo-Pak plate.

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REFERENCES

Bard, J.P., Jan, M.Q., Maluski, H., Matte, Ph. & Proust, F. 1979. Position et extension de la "ceinture" metamorphique A facies schistes blues dans 1'Himalaya du Pakistan nord. 7e R. Ann. Sc. Terre, Lyon, 29.

———, Maluski, H., Matte, Ph. & Proust, F. 1980. The Kohistan sequence: Crust and mantle of an obducted island arc. Proc. Int. Commit. Geodynamics, Grp. 6, Mtg. Peshawar, Nov. 23-29, 1979, 87–94.

Brown, E.H. 1977. The crossite content of Ca-amphibole as a guide to pressure of metamorphism. J. Petrol. 18, 53–72.

Coleman, R.G. 1972. Blueschist metamorphism and plate tectonics. 24th Int. Geol. Cong., Montreal, 2, 19–26.

Davies, R.G. 1962. A green beryl (emerald) near Mingora, Swat State. Geol. Bull. Punjab Univ. 2, 51–52.

Desio, A. 1977. The occurrence of blueschists between the middle Indus and the Swat valleys as an evidence of subduction (North Pakistan). Rend. Accad. Naz. Lincei, Ser. viii, 62, 1–9.

Jackson, E.D. & Thayer, T.P. 1972. Some criteria for distinguishing stratiform, concentric and alpine peridotite-gabbro complexes. Proc. Int. Geol. Cong., Montreal, 2, 289–296.

Jan, M.Q. 1968. Petrography of the emerald-bearing rocks of Mingora (Swat State) and Prang Ghar (Mohmand Agency), West Pakistan. Geol. Bull. Univ. Peshawar, 3, 10–11.

——— 1977. The mineralogy, geochemistry, and petrology of Swat Kohistan, NW Pakistan. Ph.D. Thesis, Univ. London.

——— 1980. Petrology of the obducted mafic and ultramafic metamorphites from the southern part of the Kohistan island arc sequence. Proc. Int. Commit. Geodynamics, Grp. 6, Mtg. Peshawar, Nov. 23-29, 1979, 95–107.

——— & Howie, R.A. 1981. The mineralogy and geochemistry of the metamorphosed basic and ultrabasic rocks of the Jijal Complex, Kohistan, NW Pakistan. J. Petrol. 22, 85–126.

———, Kempe, D.R.C. & Symes, R.F. 1972. A chromian-tourmaline from Swat, West Pakistan. Min. Mag. 38, 356–359.

——— & Symes, R.F. 1977. Piemontite schist from Upper Swat, NW Pakistan. Min. Mag. 41, 537–540.

Khan, T.U. & Humayoun, M. 1980. Geology of the Shangla-Alpurai area, Swat district, N.W.F.P. M.Sc. Thesis, Univ. Peshawar.

Le Fort, P., Debon, F. & Sonet, J. 1980. The "Lesser Himalayan" cordierite granite belt typology and age of the pluton of Mansehra (Pakistan). Proc. Int. Commit. Geodynamics, Grp. 6, Mtg. Peshawar, Nov. 23-29, 1979, 51–61.

Martin, N.R., Siddiqui, S.F.A. and King, B.H. 1962. A geological reconnaissance of the region between the Lower Swat and Indus Rivers of Pakistan. Geol. Bull. Punjab. Univ. 2, 1–13.

Perchuk, L.L. 1966. Temperature dependence of the coefficient of distribution of calcium between coexisting amphibole and plagioclase. Dokl. Acad. Sci. USSR, Earth Sci. Sect. 169, 203–205.

Shams, F.A. 1972. Glaucophane-bearing rocks from near Topsin, Swat. First record from Pakistan. Pak. Jour. Sci. Res. 24, 343–345.

——— 1980. Origin of the Shangla blueschist, Swat Himalaya Pakistan. Proc. Int. Commit. Geodynamics, Grp. 6, Mtg. Peshawar, Nov. 23-29, 1979, 67–70.

———, Jones, G.C. & Kempe, D.R.C. 1980. Blueschists from Topsin, Swat district, NW Pakistan. Min. Mag. 43, 941–942.

Tahirkheli, R.A.K. 1980. The Main Mantle Thrust: Its score in metallogeny of northern Pakistan. Proc. Int. Commit. Geodynamics, Grp. 6. Mtg. Peshawar, Nov. 23-29, 1979, 193–198.

———, Mattauer, M., Proust, F. & Tapponnier, P. 1979. The India-Eurasia suture zone in northern Pakistan: synthesis and interpretation of data at plate scale. In Geodynamics of Pakistan. (A. Farah and K. DeJong eds.). Geol. Surv. Pak., 125–130.