SYNOPSES

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Acicular hornblende schists and associated metabasic rocks from North-West Pakistan

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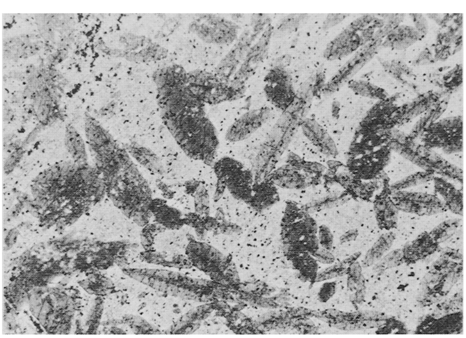
A SUITE of unusual acicular hornblende schists is found at Warsak (34° 10′ N. 71° 23′ E.), some 30 km WNW. of Peshawar, North-West Pakistan. The schists occur in association with sill-like masses of amphibolite facies meta-igneous rocks, possibly a metamorphosed gabbroic and doleritic, dioritic, and granitic calc-alkaline series, and intrusions of alkaline granite and microgranite. These rocks lie within Palaeozoic metasediments and all are folded synclinally. The area was first described by Ahmad *et al.* (1969).

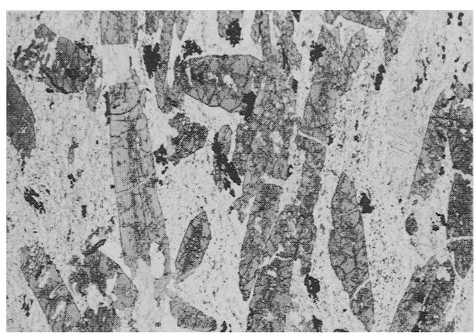
The rocks of the acicular hornblende schist suite (fig. 1) consist essentially of large, idioblastic hornblende crystals—comprising some 30–60% of the rock—in a fine-grained granoblastic matrix of oligoclase feldspar with minor quartz, iron oxide, biotite, and rutile. The boat-shaped, blue-green hornblendes, twinned on {100}, reach 5 mm in length and are often grouped in sprays or clusters; they are sieved with quartz, ilmenite, and patchy calcite. The groundmass also contains patches and veins of calcite, associated with ragged patchy areas of reddish brown, amorphous iron oxide or hydroxide, perhaps introduced hydrothermally. The schists coarsen in grain size outwards through the sill-form, the hornblendes reaching 4 cm, become rich in chlorite and biotite, and grade into the apparently metagabbroic amphibolitic rocks.

The acicular hornblende schists have a generally basaltic composition, while the hornblendes are tschermakitic. An analysed amphibole has 16·5% Al_2O_3, is slightly zoned with alumina increasing from core to rim, and has the formula:

$$K_{0\cdot06}Na_{0\cdot50}Ca_{1\cdot90}Mg_{2\cdot13}Fe^{2+}{}_{1\cdot49}Mn_{0\cdot02}Fe^{3+}{}_{0\cdot14}Ti_{0\cdot04}Al^{vi}{}_{1\cdot16}Si_{6\cdot31}Al^{iv}{}_{1\cdot69}O_{21\cdot97}(OH,F)_{2\cdot03}$$

Three hypotheses of the origin of the rocks were considered; metamorphism of a suite of basic tuffs is the most favoured. Origins involving metamorphism of a lamprophyre-appinite suite or of a gabbroic marginal facies are therefore rejected. Texturally the rocks strongly resemble metatuffs (fig. 2) that occur associated with metagreywackes





FIGS. 1 and 2: FIG. 1 (*left*). Photomicrograph of fine-grained acicular hornblende schist (BM 1970, P 40(92)), showing idioblastic hornblendes, sieved with quartz and ilmenite, in a groundmass of mainly granoblastic plagioclase, with iron oxide and calcite patches. Plane polarized light, × 5. FIG. 2 (*right*). Photomicrograph of actinolite-quartz-plagioclase-calcite-chlorite-epidote schist (BM 1938, 86(21)), lower Waikukupa stream, South Westland, South Island, New Zealand, showing idioblastic hornblendes in a groundmass mainly of plagioclase, quartz, and calcite, with some chlorite, epidote, and iron ore. Plane polarized light, × 6·5.

in the Otago schists of New Zealand (Turner, 1933); like many similar Alpine schists they also contain tschermakitic hornblendes. The Warsak tuffs could have formed originally, together with the meta-igneous rocks, possibly as lavas, in an inter-plate tectonic environment; the high Al content of the hornblende, which is typical of many amphiboles from the surrounding alpine environment in North-West Pakistan, and other mineralogical evidence in the region support a high-pressure environment for the metamorphism of the rocks to just within the amphibolite facies, at moderate temperatures of approximately 465 °C.

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Full text in the Miniprint section, pp. M33–6.

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Magnetic chromites from Kondapalli, Andhra Pradesh, India

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THE Kondapalli region (16° 37′ N. 80° 32′ E.) in the Eastern Ghats, Andhra Pradesh, consists of high-grade granulite facies rocks: charnockites, hypersthene granites, and enderbites are plutonic intrusives into khondalites—garnetiferous sillimanite granites, garnetiferous granites, sillimanite-garnet quartzites, and quartzites. Pyroxene granulites of gabbroic and noritic compositions are distinct basic intrusive bodies, occurring as sills and dykes.

Chromite orthopyroxene nodules are enclosed in serpentinite and carbonate rock, formed from altered peridotite; they are younger than the charnockites and pyroxene granulites and are confined to the cores of south-eastern-plunging overturned isoclinal anticlines. The chromites are massive in coarse-layered pyroxenites and granular in fine-layered rocks; those found at Gangineni are magnetic and are associated with bronzite (En_{77-85}), those from the Binny and Loya mines are non-magnetic and associated with enstatite (En_{88-95}).

Chemical analyses and X-ray powder data are given for five specimens, including both types. The magnetic susceptibility appears to increase with increasing Fe^{3+}. The unit-cell size is negatively correlated with Cr^{3+}, Al^{3+}, and Mg^{2+} and positively with Fe^{2+} and Fe^{3+}.

Full text in the Miniprint section, pp. M38–9.

ACICULAR HORNBLENDE SCHISTS AND ASSOCIATED METABASIC ROCKS FROM NW PAKISTAN

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The geology of the Warsak area (34° 10' N, 71° 23' E), some 30 km WNW of Peshawar, NW Pakistan, was first described in detail by Ahmad et al. (1969), although the region had been visited briefly by geologists of the Geological Survey of India, notably Griesbach (1892) and Hayden (1898). The area is transected E-W by the Kabul River, across which is built the Warsak dam on a foundation of alkali granite. The granite forms the sill-like core of the 12 km long, northwards-plunging syncline, probably faulted on the NE, which is the central structure of the area (see map in Ahmad et al. or fig. 2 in Kempe, 1973b). No aerial photographs of the area are available but an ERTS (Earth Resources Technology Satellite) enlargement has been examined; unfortunately it does not add to the structural interpretation outlined above.

The rocks of the syncline consist mainly of Siluro-Devonian to Upper Palaeozoic high greenschist to low amphibolite facies metasediments (slates, quartzites, phyllites, marbles, and schists) which extend westwards into the Khyber Hills and Afghanistan but disappear to the east under the Peshawar alluvial plain. The level of this plain probably approximates closely to the Siluro-Devonian sea-floor, consisting of a largely ?Precambrian basement, which includes the Attock Slate Series (cf. Tahirkheli, 1970), on which rest several Siluro-Devonian reef complexes (cf. Stauffer, 1968; for an extended bibliography of the area, see Jan and Kempe, 1970). [A K/Ar date of 554 ± 14 m.y. has been obtained on one whole rock sample of the Attock Slates, by C. C. Rundle and N. J. Snelling (personal communication, 1972).] The local marbles were described by Coulson (1937), some tilloids by Kempe (1973a), and the 41 m.y. old (K/Ar on riebeckite) alkali granite by Coulson (1936), Kempe and Jan (1970), and Kempe (1973b). Other crystalline rocks with sill-like forms in the syncline are porphyritic microgranite, metagabbro and metadolerite, and the Acicular hornblende schist of the Middle (Hornblende Schist) Series of the mainly metasedimentary series (Ahmad et al., 1969).

The acicular hornblende schists are a group of most unusual rocks, especially texturally, which it is the purpose of this paper to describe, proposing a tentative origin for the suite.

Petrography. The rocks of the acicular hornblende schist suite consist essentially of large, idioblastic hornblende crystals - comprising some 30-60% of the rock - in a fine-grained granoblastic matrix of plagioclase with a few percent of minor and accessory minerals. The fine-grained variety is illustrated in the synopsis. The boat-shaped blue-green hornblendes, up to 5 mm in length, are often grouped in radiating, plumose sprays or clusters, set in a matrix of small granular, untwinned oligoclase grains (An_{21} ± 1, determined by J. C. Bevan by electron microprobe). Staining has indicated that K-feldspar is absent; the small amount present in the CIPW norm of the rock (Table II) is probably a consequence of the calculation. The hornblende is twinned (longitudinally) on (100) and is sieved with quartz and ilmenite, and patches of calcite. The iron oxide is present also in the groundmass, with possibly a little quartz, biotite, and rutile; otherwise, the only other minerals are patches and veins of calcite associated with ragged areas, more or less evenly dispersed throughout the rocks, of reddish brown iron oxide or hydroxide. The latter is amorphous to X-rays (powder films showed only calcite) and both the iron and carbonate phases are thought to result from post-metamorphic hydrothermal activity; some of the iron-rich patches are rhomb-shaped and could be altered Fe-carbonate (siderite).

The grain size of the rocks increases outwards through the sill-form until in the coarsest member of the group, a particularly schistose rock, the hornblendes reach 3 or 4 cm in length; they have multiple (100) twinning and are richly sieved with rods of ilmenite. Locally, there is the suggestion that the hornblendes might have been derived from pre-existing crystals of pyroxene. Chlorite and biotite are present increasingly in the coarser rocks, as well as quartz. The coarsest variety grades into the surrounding amphibolitic metagabbros or metadolerites, forming the next bed or sill, and locally into garnet-hornblende schist.

These associated amphibolitic metabasic rocks consist mainly of blue-green hornblende, intermediate plagioclase, often saussuritised, and lesser amounts of quartz, epidote, biotite, euhedral acicular apatite,

TABLE I. Chemical analyses and structural formulae of hornblendes

	1 a	1 b	2	A	B	C	D
SiO_2	43.10	43.25	37.7	44.77	41.06	40.95	43.3
TiO_2	0.93	0.32	2.03	0.39	1.59	1.03	0.85
Al_2O_3	15.30	16.51	16.5	17.16	16.56	17.54	15.8
Fe_2O_3	1.37	1.27	1.70	1.23	2.80	2.23	[2.22]
FeO	14.60	12.19	15.9	5.26	14.76	15.85	[15.50]
MnO	0.15	0.15	0.30	0.13	0.13	0.07	0.16
MgO	8.95	9.77	6.26	16.10	7.08	6.76	8.74
CaO	11.25	12.14	12.2	10.38	11.58	10.81	10.4
Na_2O	1.60	1.78	1.50	1.50	1.45	2.25	1.40
K_2O	0.31	0.34	0.48	0.37	0.68	0.47	0.48
H_2O^+	2.00	2.00	2.74	2.80	2.14	2.47	[2.00]
H_2O^-	nil	nil	n.d.	nil	0.25	nil	-
P_2O_5	0.13	0.13	0.87	0.06	-	-	-
F	0.17	0.17	n.d.	n.d.	0.14	0.12	-
less O ≡ F	0.07	0.07	-	-	0.06	0.05	-
Total	99.79	99.95	98.18	100.15	100.19	100.50	[100.85]

	1 b'	A'	B'	C'	D'
Si	6.314	6.23	6.10	6.03	6.34
Al	1.686	1.77	1.90	1.97	1.66
Al	1.157	1.05	1.00	1.08	1.07
Ti	0.035	0.04	0.18	0.11	0.09
Fe^{3+}	0.140	0.13	0.31	0.25	0.25
Fe^{2+}	1.489	0.61	1.83	1.95	1.90
Mn	0.018	0.02	0.02	0.01	0.02
Mg	2.126	3.34	1.57	1.49	1.91
Ca	1.899	1.55	1.84	1.71	1.63
Na	0.504	0.40	0.42	0.64	0.40
K	0.063	0.07	0.13	0.09	0.09
OH	1.947	2.60	2.12	2.43	1.95
F	0.078	-	0.07	0.06	-
$100Mg/(Mg+Fe^{2+}+Fe^{3+}+Mn)$	56.3	81.4	42.0	40.2	46.9

1a. Tschermakitic hornblende (with inclusions), Acicular hornblende schist, Warsak, NW Pakistan, BM 1970, P 40 (94). Anal. C. J. Elliott.

1b. Tschermakitic hornblende, as 1a. Recalculated, to allow for inclusions, from an electron microprobe analysis by J. C. Bevan.

2. Tschermakitic hornblende (with inclusions), Acicular hornblende schist, Warsak, NW Pakistan, BM 1970, P 40 (96). Anal. V. K. Din (by XRF and AAS).

A. Alumino-tschermakite, corundum amphibolite/hornblendite, Timurgara, Dir, Pakistan (Kemp & Leake, 1975). Anal. A. J. Kemp.

B. Hornblende, quartz-oligoclase-biotite-hornblende-garnet schist, no. 10759b, Alfred River, SE Nelson, South Island, New Zealand. (Reed, 1958, Table 4). (Total includes Cr_2O_3 0.03). Anal. F. J. Seelye.

C. Hornblende, quartz-oligoclase-biotite-almandine-hornblende schist, Callery River, Southern Alps, South Island, New Zealand (Mason, 1961, Table 4). Anal. H. B. Wiik.

D. Tschermakitic hornblende, Z/Sch 09D, no. 2, Hornblendegarbenschiefer, eastern Alps (Koller, 1976). (Total Fe is given as FeO, 17.50; Fe_2O_3/FeO ratio and H_2O^+ have been estimated for calculation purposes).

1 b' to D'. Numbers of ions on the basis of 24 (O, OH, F).

orthite, calcite, and ilmenite, which is partially skeletal and altered to sphene and hematite. Some of the rocks are dioritic, with fine-grained symplectic intergrowths of quartz and feldspar in one. Finally, a metagranitic rock occurs in association with the basic rocks, consisting of quartz, sodic plagioclase, green biotite, and muscovite, with some K-feldspar, epidote and orthite, sphene, apatite, and a graphic intergrowth of quartz and feldspar.

Hornblende compositions. Analyses of the blue-green hornblendes are given in Table I, together with one structural formula. The two analyses, from the finest- and coarsest-grained acicular schists in the suite, are similar. The wet chemical analysis of the former has been recalculated to allow for the inclusions of quartz and ilmenite, using a second, electron probe analysis. This hornblende is shown by the probe analysis to be slightly zoned, with Al increasing from core to rim and corresponding decreases in (total) Fe, Mg, and Si, each of the order of one half percent (of the oxide). Probably the replacement from core → rim is: Mg → Fe^{2+} and Fe^{3+} + Si → Al; thus the replacement of (Fe^{3+} + Si) by Al is probably the most important factor in the zoning as well as in the bulk composition of the amphibole: both hornblendes are notably rich in Al_2O_3, with 15.30 (16.51) and 16.5%, respectively. The hornblendes are thus tschermakitic, similar to the colourless amphibole from the corundum-bearing amphibolite/hornblendite of Timurgara, Dir, some 110 km NNE of Warsak (Jan et al., 1969, 1971; Kemp and Leake, 1975). Unlike the Dir alumino-tschermakite, however, the Warsak amphibole plots quite close to the theoretical maximum line on the Si (or Al^{IV})– Al^{VI} in the half unit cell plot (Leake, 1965b, 1971). The Warsak and Dir amphiboles differ significantly only in their CaO content and 100 Mg/(Mg+Fe^{2+}+Fe^{3+}+Mn) ratios, which are 56.3 and 81.4, respectively. Similar tschermakitic (Al_2O_3 up to 18.4%) hornblendes also occur in the 'noritic' and 'dioritic' granulites of upper Swat, about 150 km to the NE (Jan and Kempe, 1973; Jan, 1977), and a very unusual aluminous hornblende, containing 22.6% Al_2O_3, has been reported from Hunza, Pakistan zone of Kashmir, some 380 km to the northeast, by Bunch and Okrusch (1973). The high octahedral Al content (and, indeed, total Al) and low Ti of such hornblendes suggest formation under high-pressure but moderate-temperature conditions (Leake, 1965 a, b), supported by the presence in the region of other high-pressure minerals, discussed in a later section.

TABLE II. Chemical analyses, some trace elements, and CIPW norms of the acicular hornblende schist and associated meta-igneous rocks

	1	2	3	4	5	6
SiO_2	48.20	48.70	46.90	56.50	53.20	67.90
TiO_2	1.66	1.60	4.78	2.32	3.14	1.06
Al_2O_3	15.20	15.00	12.30	13.20	13.30	13.50
Fe_2O_3	1.25	2.20	5.07	4.27	4.56	1.50
FeO	7.90	8.95	9.95	7.74	8.89	3.80
MnO	0.17	0.18	0.23	0.23	0.28	0.16
MgO	4.65	6.86	5.09	2.39	2.58	0.90
CaO	11.60	10.38	9.02	5.61	5.72	2.27
Na_2O	3.24	2.93	2.94	4.23	4.31	4.65
K_2O	0.25	0.59	0.94	1.59	1.71	3.04
H_2O^+	1.60	1.80	1.56	1.23	1.46	0.66
H_2O^-	0.12	0.10	0.15	0.08	0.14	0.06
P_2O_5	0.21	0.13	0.27	0.56	0.69	0.15
CO_2	3.84	0.01	0.07	0.20	0.22	0.50
F	0.10	0.03	0.06	0.12	0.13	0.09
less O ≡ F	0.04	0.01	0.03	0.05	0.05	0.04
Total	99.95	99.45	99.30	100.22	100.28	100.20
			Trace elements (p.p.m.)			
Cr		235	<5	<5	<5	<5
Li		13	15	16	17	15
Ni		150	65	60	55	40
Cu		100	30	20	30	25
Sr		293	310	280	240	200
Rb		4	20	40	50	80
			CIPW norms (calculated cc-free)			
Q	-	-	2.61	11.32	6.72	22.88
or	1.48	3.49	5.56	9.40	10.11	17.97
ab	27.41	24.79	24.87	35.79	36.47	39.34
an	26.20	26.04	17.59	12.34	11.90	6.99
di	24.72	20.23	21.15	10.08	10.20	2.78
hy	5.76	8.48	9.48	8.84	9.92	6.47
ol	2.98	8.09	-	-	-	-
mt	2.17	3.19	7.35	6.19	6.61	2.17
il	3.15	3.04	9.08	4.41	5.96	2.01
ap	0.50	0.31	0.64	1.32	1.63	0.35

1. Acicular hornblende schist (?meta-tuff), BM 1970, P 40 (94), road south of Kabul River leading to dam, Warsak, NW Pakistan. Anal. C. J. Elliott.
2. Metagabbro, BM 1970, P 40 (59), locality as above. Anal. C. J. Elliott.
3. Metagabbro, BM 1970, P 40 (62), locality as above. Anal. C. J. Elliott.
4. 'Metadiorite', BM 1970, P 40 (68), locality as above. Anal. C. J. Elliott.
5. 'Metadiorite', BM 1970, P 40 (61), locality as above. Anal. C. J. Elliott.
6. Metagranite, BM 1970, P 40 (58), locality as above. Anal. C. J. Elliott.

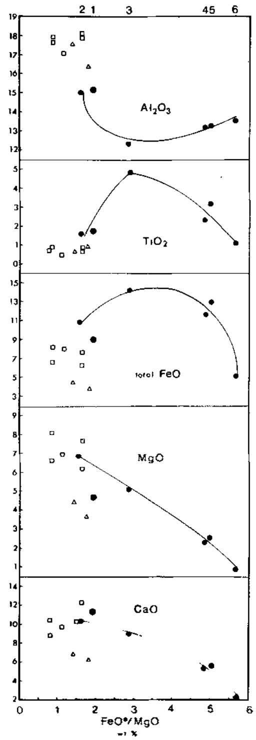

Fig. 1. Rock analyses: oxide variations plotted against (total) FeO*/MgO ratio. Solid circles, Warsak rocks; large circle is the acicular hornblende schist. Numbers correspond with those in Table II. Open squares, Swat series metabasic rocks and (open triangles) metadiorites (Jan and Kempe, 1973).

Rock compositions. The fine-grained acicular hornblende schist has been analysed (Table II). Also reported are analyses, with some trace elements, and CIPW norms (calculated on a calcite-free basis) of five of the associated meta-igneous rocks: two meta-gabbros, two 'metadiorites', and a metagranite; it is recognised, however, that the norms will not reflect changes in, for example, alkali contents and oxidation ratios induced by metamorphism.

The acicular rock has a generally basaltic composition, similar to that of one of the metagabbros (1970, P 40 (59)). If the six rocks are plotted on an oxide vs SiO_2 (wt. %) variation diagram, smooth curves result for Na_2O, K_2O, Sr, and Rb; fairly smooth curves for MgO, CaO, MnO, and Ni; and smooth curves for four only of the rocks for TiO_2, Al_2O_3, (total) FeO*, and Cu, the aberrant rocks being the acicular schist and, to a lesser extent, the metagabbro of similar composition; in the other plots they again tend to depart from the general trend. If oxides are plotted against FeO*/MgO ratio, the very low ratios of the aberrant metagabbro and the acicular rock result in parabola-like curves for Al_2O_3, TiO_2, and FeO* (fig. 1); the curves for Na_2O and K_2O show a more or less steady increase. Although the data are limited, these plots are consistent with the suggestion that they represent a group of rocks - metagabbros, (? secondary) diorites, and metagranite - which could be related by differentiation, and shown in the AFM and alkalis-lime diagrams (fig. 2) to have possibly a calc-alkaline trend. In each plot the acicular schist falls to one side. This is hardly surprising; if the rock was a basic tuff, as suggested in the next section, its composition, although similar to that of basalt and even if related to the meta-igneous rocks, would be governed also by non-igneous (sedimentary) components and alteration products derived from glass and similar unstable primary igneous material.

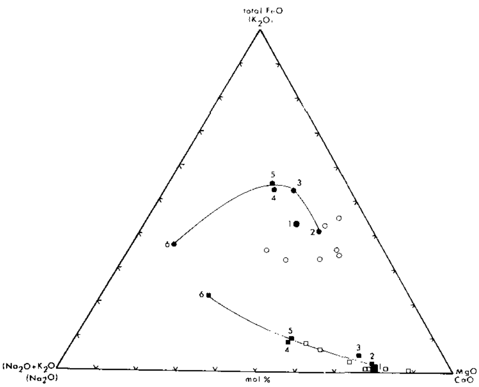

Fig. 2. Triangular diagrams (molecular percentages). AFM diagram, circles; alkalis-lime diagram, squares. Solid symbols, Warsak rocks, the large symbol representing the acicular hornblende schist; numbers correspond with those in Table II. Open symbols, Swat meta-igneous series (Jan and Kempe, 1973).

It is interesting to compare the compositions of the Warsak rocks with those of the basic and intermediate meta-igneous rocks (granulites) of upper Swat (Jan and Kempe, 1973; Jan, 1977). The most notable differences are the depletion in Al_2O_3, MgO, and CaO of the Warsak relative to the Swat rocks, and enrichment in FeO* and TiO_2; thus they have, of course, a much higher FeO*/MgO ratio and this, coupled with high TiO_2, suggests a more highly differentiated original magma (figs. 1 and 2; see also fig. 2 in Jan and Kempe, 1973). Fig. 1 also shows that only the Swat 'diorites' separate from the remaining, basic rocks which, unlike the Warsak suite, all have very similar FeO*/MgO ratios. This feature shows again in their very flat differentiation curve (fig. 2).

Petrogenesis of the acicular hornblende schists. The main group of meta-igneous rocks - metagabbros, meta-diorites, metagranite - are in no way unusual in an alpine environment such as the sub-Himalayan area of Warsak. The acicular hornblende schists, however, with their rather unusual texture are clearly not normal metagabbros. The shapes of the porphyroblastic hornblendes are suggestive of an igneous porphyritic texture, but the granoblastic feldspar matrix with its triple-point texture points strongly to a metamorphic origin.

Three hypothetical parageneses were considered after considerable discussion with colleagues (see Acknowledgements). The first two are rejected and the third is proposed tentatively as the most probable origin of the rocks:

A metamorphosed lamprophyre - appinite suite. The assemblage hornblende-plagioclase, and the outline of the hornblende crystals, are similar to those of the dioritic lamprophyre spessartite and the coarse-grained rock of similar composition known as appinite. Chemically (Table III), the fine-grained acicular rock from Warsak resembles the average composition of 45 spessartites given by Métais and Chayes (1963), apart from K_2O and perhaps CaO contents. However, as these authors point out, chemical composition is not the easiest way positively to identify a lamprophyre. The hornblendes, although superficially resembling the panidiomorphic hornblendes of the spessartitic lamprophyres, are blue-green metamorphic amphiboles rather than the usual brown or deep green primary hornblendes and contain inclusions suggesting metamorphic growth within a granular matrix of small feldspar crystals in triple-point contact with each other. Further, no lamprophyres or appinites are known to recrystallize on metamorphism into rocks of this nature: the usual products of their metamorphism are greenschists and amphibolites.

A metamorphosed gabbroic marginal facies. Although some basic magmas crystallize with margins, veins and apophyses of unusual habit and texture, it is hard to envisage how such a segregation, even under shear stress, could develop into rocks as markedly different from the other metabasic rocks as the fine- and coarse-grained acicular schists.

Metamorphosed basic tuffs. Pyroclastic basic rocks may well have formed layers within the Palaeozoic metasediments at Warsak, especially if the so-called metagabbros and metadolerites are in fact metamorphosed basalts or other basic volcanic rocks, recrystallized to relatively coarse-grained rocks during metamorphism. Most of the Otago schists of New Zealand are metamorphosed greywackes but metamorphosed basic tuffs, such as occur at South Westland, South Island (Turner, 1933, 1938, p. 170), bear a striking textural resemblance to the Warsak rocks. The rock illustrated in the synopsis contains idioblastic blue-green hornblende crystals in a matrix of plagioclase and quartz, locally calcite-rich, with minor chlorite, epidote, and occasional irregular grains of iron ore.

Tschermakitic hornblendes occur in the Otago greenschists (Tables I and III) and also widely in metamorphic rocks from the Alps (Table I). Examples of metamorphosed tuffitic layers, together with dolomitic marls, giving rise to Hornblendegarbenschiefer, from the eastern Alps are described by Koller (1976). These high greenschist to low amphibolite facies rocks are rich in Na_2O and TiO_2, and low in K_2O.

If the third, meta-tuff, hypothesis is correct, the Warsak syncline probably represents a series of metamorphosed sediments and basic, intermediate, and acid volcanic rocks, including tuffs: the only sills are likely to be the granites, and the porphyritic microgranites (Kempe, 1973b) could in fact be metamorphosed, highly porphyritic, alkaline rhyolitic lavas, strongly sheared and locally garnet-bearing. Kempe (1973b) interpreted the foliation in the main astrophyllite-bearing alkali granite to be due partly to igneous flow resulting from intrusion as a sill and partly to subsequent folding and metamorphism.

TABLE III. Chemical analyses for comparison with the acicular hornblende schist

	1	A	B
SiO_2	48.20	52.37	43.39
TiO_2	1.66	1.31	1.39
Al_2O_3	15.20	15.44	15.05
Fe_2O_3	1.25	3.27	4.53
FeO	7.90	5.35	5.43
MnO	0.17	-	0.22
MgO	4.65	6.27	4.02
CaO	11.60	7.36	14.23
Na_2O	3.24	3.30	3.13
K_2O	0.25	2.54	0.23
H_2O^+	1.60	2.36	2.26
H_2O^-	0.12		nil
P_2O_5	0.21	-	0.17
CO_2	3.84	0.41	5.78
F	0.10	-	-
Total	99.95	99.98	100.07
CIPW norms			
Q	3.89	0.24	3.84
or	1.48	15.01	1.11
ab	27.41	27.92	26.20
an	26.20	19.82	26.41
di	4.71	11.29	5.37
hy	20.30	15.17	11.76
ol	-	-	-
mt	1.81	4.74	6.50
il	3.15	2.49	2.58
ap	0.50	-	0.34
cc	8.73	0.93	13.10

1. Acicular hornblende schist (?meta-tuff), BM 1970, P 40 (94), (Table 2).

A Average of 45 spessartites (Métais and Chayes, 1963).

B Albite-epidote-actinolite-chlorite schist, no. 2718, summit of Coronet Peak, Wakatipu, Western Otago, South Island, New Zealand (Hutton, 1940, Table 18, analysis A). (Total includes FeS_2 0.22, Cr_2O_3 0.02). Anal. C. O. Hutton.

Metamorphism to just within the amphibolite facies is suggested (Turner, 1968, p. 366) by the mineralogy and by the geothermometric method of Perchuk (1966): the Ca/(Ca+Na+K) partition ratios in coexisting hornblende (0.77) and plagioclase (0.21) give a temperature in the region of 465°C.

Subsequent hydrothermal activity probably resulted in the introduction of the limited amounts of calcite and patchy iron oxide that are present. The evidence from the hornblende composition for a high-pressure environment has already been discussed, and is in accord with the presence in the region of other high-pressure minerals. For example, kyanite occurs in the Lower Swat-Buner Schistose Group (Martin et al., 1962), some 130 km to the NE, with glaucophane locally at Topsin (Shams, 1972). Slightly further N, rutile is abundant in the amphibolites and epidote amphibolites of Swat (Jan and Kempe, 1973) and the hornblende gneisses of Dir (Jan et al., 1969, 1971); this mineral also occurs sparsely in the fine-grained acicular hornblende schist. East of the amphibolites high-pressure garnet granulites occur at Jijal (Jan, 1977), whilst the kyanite (and sillimanite) belt occurs again at Nanga Parbat, 320 km to the NE (Misch, 1949).

Comparison with rocks from New Zealand and the Alps, where greenschist-blueschist parageneses are relatively common, suggests that a similar environment might have obtained at Warsak. A basic calc-alkaline magma derived from the melting of ocean crust material generated in a Himalayan ocean-continent plate collision would satisfactorily explain the rocks, low in K_2O but rich in CaO and Na_2O, encountered at Warsak. High pressures, together with a suitable composition, would have encouraged the metamorphic growth of CaAl-rich tschermakitic hornblende, whilst the low K_2O content would explain the absence of K-feldspar.

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