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Crystalline rocks of the Spinatizha area, Pakistan

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Abstract—During the Cretaceous an andesitic arc developed across south Asia facing the Tethys Ocean. Remnants of this arc are preserved in Iran, Afghanistan, and the Chagai Hills and Kohistan, Pakistan. West of the Chaman fault near Spinatizha, Pakistan (33° 33'N, 66° 23'E) a terrain of crystalline rocks is exposed that links the Chagai Hills portion of this arc with the Kandahar portion of it in Afghanistan. Four units are present. (1) The Spinatizha Metamorphic Complex includes orthogneiss, greenschist, amphibolite, metavolcanics, marble and foliated muscovite granite. Extreme variation in rock type and degree of metamorphism characterises the entire complex. It is the oldest unit west of the Chaman fault in Pakistan. (2) The Bazai Ghar Volcanics consist of weakly deformed tuffs, flow breccias, and other coarse-grained pyroclastics of andesitic-arc type. Andesite flows and at least one silicic welded tuff are also present. The Bazai Ghar Volcanics are everywhere separated from the Spinatizha Metamorphic unit by granitic intrusions and a major fault. (3) Both the above units are intruded by a series of calc-alkaline granitic plutons ranging from diorite to granite. The silicic plutons generally intrude the more mafic ones. The Bazai Ghar Volcanics and related intrusions are probably equivalent to the Cretaceous (?) Sinjrani volcanics and the Cretaceous and younger intrusions of the Chagai Hills. (4) Along the fault zone between the volcanic and metamorphic rocks is a small area of previously unknown clastic sedimentary rocks: conglomerates and slates. The unit is of Palaeogene age but cannot yet be correlated with known units. The Spinatizha crystalline terrain extends south along the Chaman fault into Afghanistan and is covered by the Helmund desert to the west. It is the eastern continuation of the calc-alkaline arc terrain of the Chagai Hills dragged by oroclinal flexing into the Chaman transform zone. To the north it connects with the Kandahar volcanic arc. The metamorphic complex may represent the basement on which the arc terrain rests, only exposed due to strong vertical uplift near the Chaman fault.

INTRODUCTION

THE CLOSURE of the Mesozoic Tethyan Ocean across southern Asia is now widely considered to have been a multistage process (Aubouin *et al.* 1980). Closure of several different oceanic basins and migration of microcontinental blocks derived from either the Gondwanaland or the Asian plates are involved (Bassoulet *et al.* 1980, Adamia *et al.* 1980). Crucial data needed to interpret this history in detail are still lacking, but a brief and highly speculative account is outlined below to provide the framework needed to understand the setting of the data given herein. In general it seems probable that the early Mesozoic Tethyan Ocean between the Indo-Pakistani portion of Gondwanaland and south-central Asia may have resembled the island-choked seas between Australia and southeastern Asia of today.

Two, and in places three, suture zones are recognized across southern Asia from Iran to the Himalayas. Between these sutures are a series of microplates most of which were originally part of Gondwanaland (Fig. 1). These microplates include the central Iran, Lut, and Afghan blocks to the west (Klootwijk 1979, Stöcklin 1977, Andrieux & Brunel 1977) and probably portions of southern Tibet (Thakur 1980, Sinha-Roy 1981, Bassoult *et al.* 1980). These microplates separated from Gondwanaland prior to the main breakup of this supercontinent and migrated north during the early Mesozoic to close the Palaeotethys Ocean by subduction that occurred along the southern margin of Asia (Boulin & Bouyx 1978, Sengor 1979, Bernoulli & Lemoine 1980). By Late Jurassic time most of these microplates had arrived in the vicinity of southern Asia leaving the Tethys Ocean between themselves and the bulk of Gondwanaland. The northern suture zones closed and subduction began along the southern margin of the assembled microplates. Andesitic-arc volcanism and plutonism developed along this margin from the late Early Cretaceous onwards (Tapponnier *et al.* 1981). Along most of this margin andesitic arc development terminated in the Palaeocene nearly simultaneously with obduction of the Waziristan, Zhob, and Las Bela ophiolites in Pakistan (Tapponnier *et al.* 1981, Asrarullah *et al.* 1979). Arc development continued along the Makran Coast of Pakistan and Iran where continental collision has not occurred.

The existence of a Cretaceous andesitic arc along much of the southern margin of the microplates accumulated against Asia has only been pieced together recently (Fig. 1). North of the Zagros Mountains of Iran is a belt of Late Cretaceous to Eocene volcanic–plutonic rocks (Falcon 1969, Alavi 1980) that are interpreted as the roots of this Cretaceous arc (Crawford 1972, Pamic *et al.* 1979). This belt extends eastwards to the Oman Line. Exposure is concealed across the Lut Block (Stöcklin & Nabavi 1973), but continues as the Chagai Hills intrusions and related Sinjrani volcanics north of the Makran Coast of Pakistan (Bakr & Jackson 1964). The Sinjrani volcanics are Maestrichtian in age and are intruded by granitic rocks of Late Cretaceous age (Jones 1961). The easternmost outcrop of these rocks occurs adjacent to the Chaman

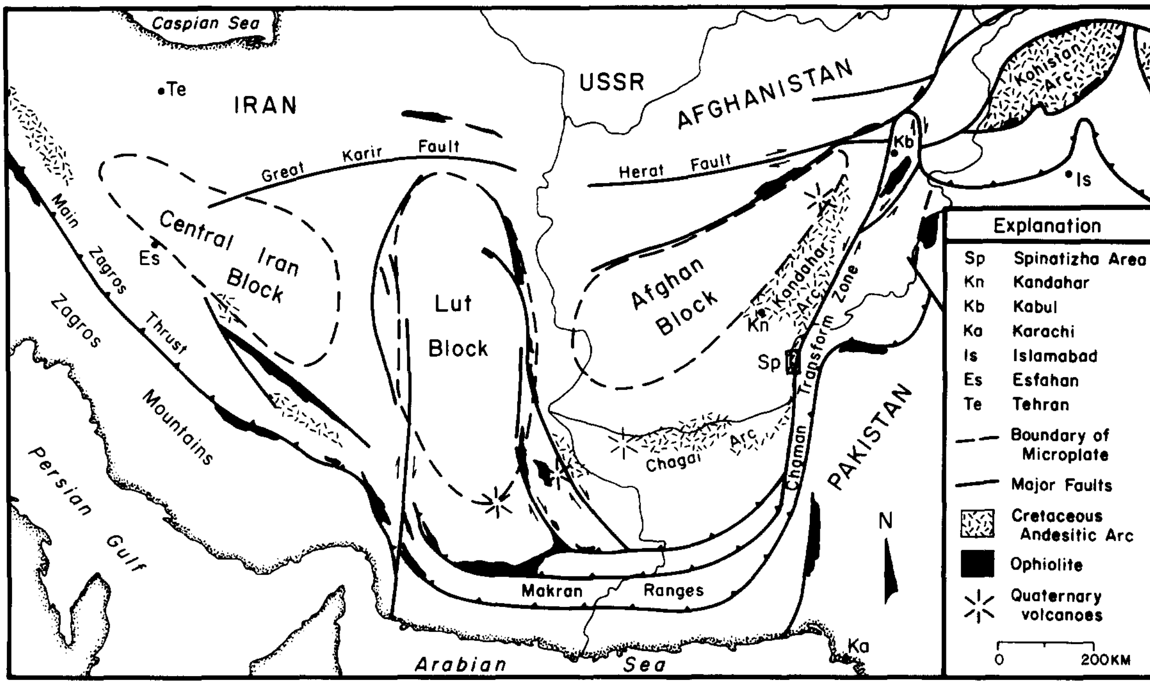

Fig. 1. Principal tectonic elements of South Asia related to the Spinatizha area.

fault in the Siah Koh. Andesitic-arc rocks again appear in eastern Afghanistan just west of the Chaman fault as the Arghandab batholith and Kandahar volcanics. Most of this part of the belt is of Cretaceous age (Wittekindt & Weippert 1973, Bellon *et al.* 1979, Weippert *et al.* 1970, Afzali *et al.* 1979), but late Jurassic ages are reported in the north toward Kabul (Tapponnier *et al.* in press). East of the Chaman transform zone andesitic arc materials appear in the Kohistan sequence which is considered to be a Cretaceous island arc built on oceanic crust (Tahirkheli *et al.* 1979, Bard *et al.* 1980). Thus new data suggest that during the Cretaceous and perhaps Late Jurassic an andesitic arc was built across southern Asia. This arc was built on the southern edge of the central Iran, Lut, and Afghan microcontinents and then extended east to Ladakh as an oceanic arc.

THE SPINATIZHA AREA

The Spinatizha area (Figs. 1 and 2) exposes crystalline basement rocks west of the Chaman fault in the gap between the Kandahar and Chagai Hills portions of this andesitic arc. The area exposes rocks seen nowhere else in Pakistan. Similar rocks are not clearly reported from either of the adjacent portions of this arc terrain. We have studied and mapped this area in reconnaissance to provide the first 15′ quadrangle maps of these rocks and their interrelationships (to be published by the Geological Survey of Pakistan). We present here a generalized map of the area, and a preliminary petrographic study of the units involved. (All unit names used are informal designations used for convenience in discussion.) The map comprising Fig. 2 is necessarily generalized since small outcrops of post-metamorphic intrusive rocks of the Khwaja Amran Series are widespread throughout the unit. They are so abundant near the western margin of the outcrop area that a mixed unit has been defined for much of this region.

Four major units of rocks are recognized in the area (Fig. 2). These are; (1) the Spinatizha Metamorphic Complex, (2) the Bazai Ghar Volcanics, (3) the Khwaja Amran Intrusive Series ranging from diorite to granite in composition and (4) a sedimentary rock sequence of unknown relation with the other units. These units are found only west of the Chaman fault. East of the fault, a series of Tertiary slates is unrelated to rocks west of the fault at this latitude; these will be discussed in a separate paper (Lawrence *et al.* in preparation). Within the fault zone is an assemblage of exotic rocks (Lawrence & Yeats 1979).

A crucial problem in the consideration of these units is the significance of the Spinatizha Metamorphic Complex. It has been described as similar to Precambrian basement exposed near Kabul, Afghanistan (Gansser 1979 and personal communication 1978). Metamorphic rocks have been mapped (Wittekindt & Weippert 1973) adjacent to the Chaman fault in Afghanistan near Kalat, a town about 140 km northeast of Kandahar where they are currently considered Precambrian (Fig. 1). Bordet (1980) relates these rocks to the Beshud schist that outcrops on the northwest border of the Central Ranges of Afghanistan. However, as we will show here the Spinatizha rocks are of andesitic-arc type having the same range of rock compositions as widespread Cretaceous to Tertiary arc material found in the Chagai Hills, Ras Koh, and Siah Koh of Pakistan (Jones 1961) and in the Hada Hills and surrounding country east and northeast of Kandahar, Afghanistan (Fig. 1). The Spinatizha Metamorphic complex may be an older Mesozoic arc complex underlying this terrain that is exposed because of strong vertical uplift

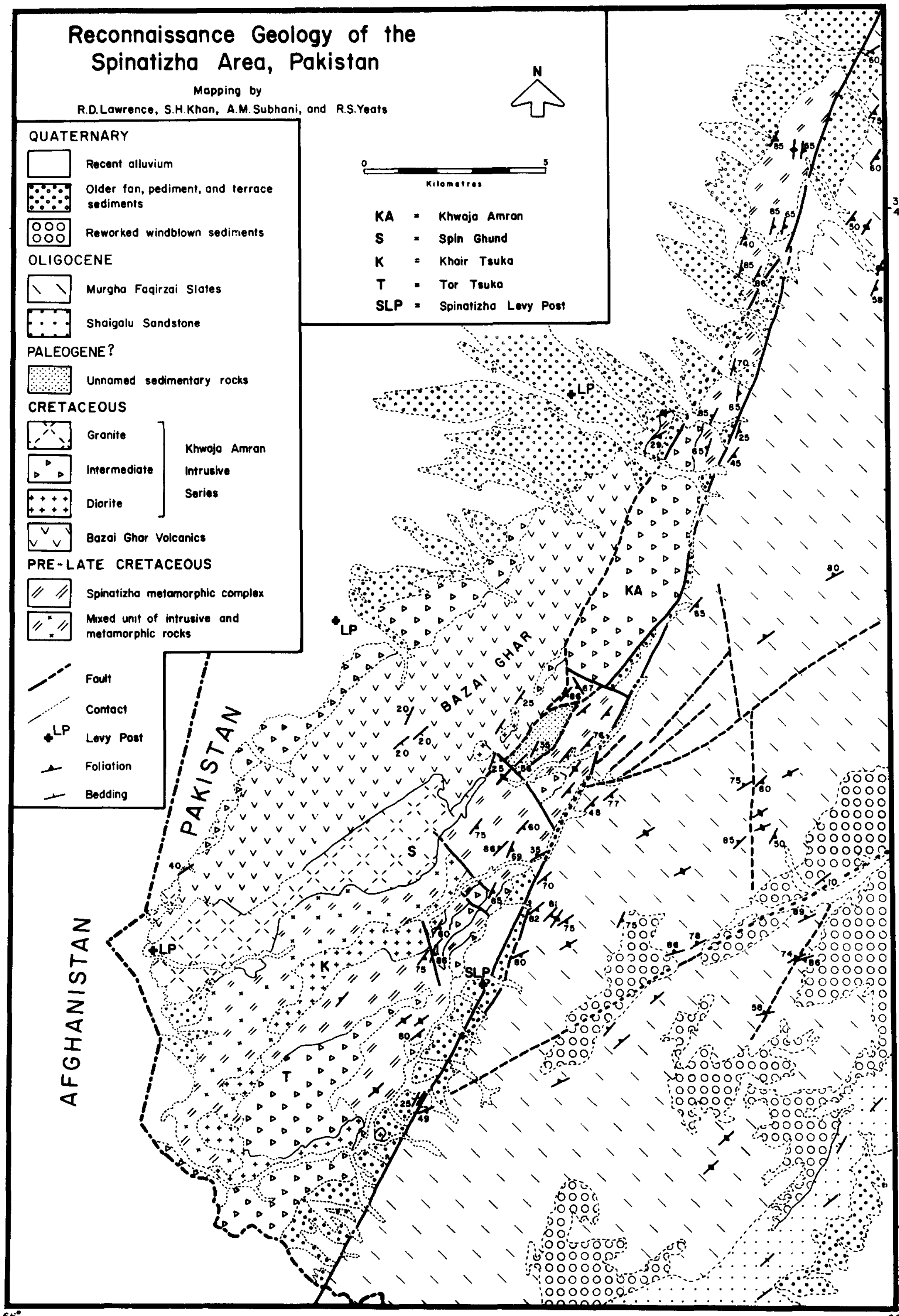

Fig. 2. Reconnaissance geological map of the Spinatizha area.

adjacent to this portion of the Chaman fault. Alternatively, more intense deformation adjacent to the Chaman fault may have altered and deformed the late Cretaceous andesitic arc material until it has the appearance of a distinct unit. Resolution of this uncertainty has important implications for the tectonic history of the Chaman fault and development of the adjacent portion of the Afghan block. Evidence related to this problem is a central concern of the present discussion.

THE SPINATIZHA METAMORPHIC COMPLEX

The Spinatizha Metamorphic Complex is found between the Chaman fault and the outcrop area of the Bazai Ghar volcanics (Fig. 2). This well-exposed unit is composed of meta-igneous rocks.

Rocks of surficial origin include both flows and volcaniclastic materials of probable andesite and basalt original composition, pyroclastic material being most abundant. One greatly sheared ignimbrite was observed. Minor beds and lenses of marble are present mingled with the metavolcanic material. Relict textures of flow porphyries, breccias, tuffs, and similar rocks are preserved locally. Abrupt changes from well-preserved relict textures to highly foliated rocks are common, occurring over distances of a few 10's of metres. In thin section the foliation is seen to be cataclastic with much evidence of shearing. Fractured and augened feldspars, mostly plagioclase, are surrounded by sheared matrix, newly crystallized and aligned actinolite, and/or ribbon quartz depending on the original rock composition. Together these features suggest that much of the deformation during metamorphism occurred along discrete zones, probably deep crustal shear zones. Similar deformation in the Maydan shear zone west of the Chaman fault in the Kabul area of central Afghanistan has been described by Nicolas *et al.* (1977). In the Spinatizha area the foliation strikes subparallel to the Chaman fault and is vertical or steeply inclined. Where inclined it most commonly dips towards the Chaman fault.

Meta-intrusive rocks are present in the Spinatizha Metamorphic Complex as small, elongated, pre-tectonic plutons. The most common of these are intermediate orthogneisses with granodiorite and granite the most abundant rock types. Available modal data is shown in Fig. 3. These rocks normally have sheared contacts with the adjacent metavolcanic rocks but locally non-sheared areas clearly reveal intrusion of the orthogneiss into the metavolcanics. In addition to the rocks just described a distinctive muscovite–granite orthogneiss is locally present as greatly elongated bodies subparallel to the foliation, the most notable of these being very close to the Chaman fault. All of the orthogneiss bodies have clear cataclastic textures in the field and in thin section. Plagioclase is broken and augened and surrounded by ribbon quartz. Indeed, this textural character is one basis for separating plutonic material of the Spinatizha Metamorphic Complex from that of the Khwaja Amram Intrusive Series.

Petrographically the mineral assemblage of the Spinatizha Metamorphic Complex is consistently of upper greenschist facies. A typical mineralogy is quartz, albite, actinolite, epidote, opaque, ± chlorite, ± biotite, ± muscovite, ± prehnite, ± sphene, ± calcite.

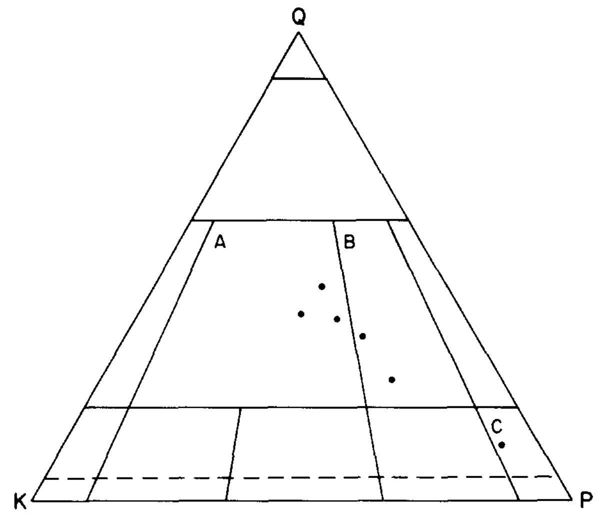

Fig. 3. Modal compositions of intrusive rocks of the Spinatizha Metamorphic Complex. A, granite; B, granodiorite; C, quartz diorite; following IUGS classification, 1973.

Three chemical analyses of samples from the Spinatizha Metamorphic Complex have been performed (Table 1). Sample 78100 is an example of the muscovite granite the composition of which is quite similar to that of the granites of the Khwaja Amran intrusive complex (Tables 2 and 3). Sample 78127 is a mylonite with augen of metavolcanic and plutonic fragments. It has a surprisingly silicic composition and may be derived from a welded tuff. Sample 7845 is a meta-andesite breccia that is typical of the better preserved parts of this unit.

Table 1. Chemical analyses* from the Spinatizha Metamorphic Complex and Bazai Ghar Volcanics

Sample No.	78100	78127	7845†	78108	78109
$SiO_2 \pm 0.5$	73.5	74.0	51.3	53.5	71.3
$Al_2O_3 \pm 0.5$	13.8	14.1	16.8	17.33	13.9
$FeO \pm 0.1$	2.6	1.9	9.7	8.5	3.3
$CaO \pm 0.1$	0.7	1.5	10.0	7.1	1.9
$MgO \pm 0.1$	0.1	0.5	6.4	2.2	0.1
$K_2O \pm 0.05$	4.21	3.47	0.62	1.78	2.33
$Na_2O \pm 0.1$	4.3	3.5	3.1	4.1	5.5
$TiO_2 \pm 0.05$	0.30	0.25	1.34	1.34	0.64
Total	99.4	99.2	98.9	97.6	98.80
UTM Location‡	343734	332749	288647	325742	286742

* Analyses by R. L. Lightfoot and E. M. Taylor, November 1980 and January 1981.

Si, Al, Fe, Ca, K and Ti by XRF; Na and Mg by AAS; total iron as FeO; and anhydrous.

†Average of two analyses.

‡Locations by UTM grid reference on Pakistan 1:50,000 sheet 34 J/6.

Sample description

78100, Muscovite granite orthogneiss from the Spinatizha metamorphic complex.

78127, Mylonite with metavolcanic and orthogneiss augen from the Spinatizha metamorphic complex.

7845, Meta-andesite breccia from the Spinatizha Metamorphic Complex.

78108, Andesite breccia from the Bazai Ghar volcanics.

78109, Rhyolite welded tuff from the Bazai Ghar volcanics.

Table 2. Chemical analyses* from named plutons of Khwaja Amran Intrusive Series

Sample No.	78179	796	78132	78113	78130	78128	7923	7915†	7926	7846
$SiO_2 \pm 0.5$	75.6	74.4	75.4	76.9	72.0	55.6	63.4	55.4	55.0	47.7
$Al_2O_3 \pm 0.5$	13.0	12.4	12.9	12.9	14.3	16.7	15.8	17.3	16.4	16.2
$FeO \pm 0.1$	0.9	1.4	1.2	1.6	2.7	6.8	4.1	7.8	7.2	7.7
$CaO \pm 0.1$	1.0	0.7	0.9	0.4	1.9	4.9	3.8	7.3	10.0	12.4
$MgO \pm 0.1$	—	—	—	—	0.2	2.4	2.2	3.8	6.0	10.7
$K_2O \pm 0.05$	4.60	5.00	4.06	4.60	4.11	2.97	3.76	2.75	1.49	0.7
$Na_2O \pm 0.1$	3.8	4.4	4.4	4.0	4.5	5.2	3.7	3.3	2.7	1.8
$TiO_2 \pm 0.05$	0.15	0.05	0.15	0.10	0.45	0.94	0.50	1.09	0.69	0.45
Total	99.0	97.7	99.0	100.4	100.0	95.6	97.1	98.7	99.5	97.7
UTM Location Map sheet 34 J/6	225669	245644	305722	292717	334768	334761	236624	277682	230633	272618

*Analysts as on Table 1.
†Average of 2 analyses.

Sample descriptions
78179, Spin Ghund granite (Modes: Q39, P23, K38); 796, Spin Ghund granite (Modes: Q43, P19, K38); 78132, Spin Ghund granite (Modes: Q41, P29, K30); 78113, Spin Ghund granite (Modes; Q43, P27, K30); 78130, Khwaja Amran granodiorite (Modes: Q30, P31, K39); 78128, Khwaja Amran granodiorite (Modes: Q29, P51, K20); 7923, Centre of Tor Tsuka pluton (Modes: Q33, P47, K20); 7915, Border zone of Tor Tsuka pluton (Modes: Q12, P81, K7); 7926, Border zone of Tor Tsuka pluton (Modes: Q14, P80, K6) and 7846, Border zone of Tor Tsuka pluton.

Table 3. Chemical analyses* from unnamed plutons of the Khwaja Amran Intrusive Series

Sample No.	78169	7839	784	78170	7916†	7914	7936†	78176†	78114
$SiO_2 \pm 0.5$	75.3	73.5	71.6	70.1	63.3	62.4	51.8	51.1	45.8
$Al_2O_3 \pm 0.5$	12.1	14.6	14.5	14.7	15.6	15.9	17.9	16.7	15.6
$FeO \pm 0.1$	1.6	2.1	2.9	3.2	5.0	4.6	9.3	9.5	8.7
$CaO \pm 0.1$	2.1	1.8	2.0	2.1	3.8	4.4	9.2	9.7	12.6
$MgO \pm 0.1$	—	0.2	0.4	0.2	2.2	2.2	5.2	6.5	11.6
$K_2O \pm 0.05$	0.35	4.21	4.01	3.96	3.71	3.47	1.76	0.69	0.40
$Na_2O \pm 0.1$	5.2	3.5	4.0	4.3	3.7	3.6	2.9	3.0	1.2
$TiO_2 \pm 0.05$	0.10	0.15	0.40	0.45	0.57	0.59	0.84	0.92	0.15
UTM Location Map Sheet 34 J/6	233689	319721	351821	295684	238667	223648	321798	358828	314737

*Analysts as on Table 1.
†Average of 2 analyses.

Sample descriptions
78169, Tonalite (Modes: Q43, P55, K2); 7839, Granodiorite (Modes: Q35, P44, K21); 784, Granite (Modes: Q27, P37, K36); 78170, Tonalite (Modes: Q22, P73, K5); 7916, Granodiorite (Modes: Q36, P45, K18); 7914, Granodiorite (Modes: Q26, P49, K24); 7936, Quartz diorite (Modes: Q10, P86, K4); 78176, Diorite (Modes: Q5, P93, K2) and 78114, Diorite.

The contacts of the Spinatizha Metamorphic Complex with neighbouring units are tectonic or intrusive. The base of the unit is not exposed anywhere. The unit is intruded by plutons of the Khwaja Amran Series with clear, undeformed intrusive contacts. The relation between the metavolcanics of the Spinatizha Metamorphic Complex and the compositionally similar Bazai Ghar Volcanics is of great interest. In most of the area these two units are separated by the Spin Ghund granite of the Khwaja Amran Series. North of this pluton the contact is a fault which is continuous with and probably equivalent to the Traqqi fault that is clearly defined in the northern part of the area. In the north, the Traqqi fault is active, includes exotic materials, and broke during the 1928 Chaman earthquake (Lawrence & Yeats 1979, Griesbach 1893). That this recent activity is the reaction of an old fault is shown by the intrusion of the Spin Ghund granite into the fault in the south. No evidence for recent activity could be found in the time at our disposal in the vicinity of this pluton. In the northern portion of the map-area a block of the metamorphic complex is present west of the Traqqi fault, but does not come into exposed contact with the volcanics. Thus field evidence does not define the contact relations between the Bazai Ghar Volcanics and the Spinatizha Metamorphic Complex.

BAZAI GHAR VOLCANICS

The Bazai Ghar Volcanics are exposed as a single block along the western edge of the map area (Fig. 2). This unit is not easily accessible to reconnaissance study, but is well exposed and relatively easily mapped from aerial photographs. We have made three traverses through it, but have less detailed familiarity with it than with the unit discussed above.

The rock types involved are volcanic flows, tuffs, breccias, and ignimbrites. Most of the material is andesitic in composition. It is probable that future work will be able to subdivide the unit into three broad subunits. The top subunit is mainly volcaniclastic rocks. Only a few andesite flows are present. At one location a limestone bed is interbedded with the flows. At another there is an ignimbrite for which we have a chemical analysis (Table 1). The middle subunit is mostly andesite flows and flow breccias, one of which was analysed (Table 1), with minor volcaniclastic material. The bottom subunit is again volcaniclastic. The entire unit is at least 760 m thick. It is little deformed (dips less than 20°) except adjacent to the Traqqi fault where dips up to 45° towards the fault were encountered.

We have only a little petrographic data on this unit. In the few thin sections at which we have looked the rock is recrystallized, but textures are well preserved. Plagioclase is partially replaced by albite. Chlorite and actinolite pseudomorphically replace mafic minerals. Epidote is widespread in the groundmass. The chemical data (Table 1) are very restricted, but appear to reflect typical andesitic arc materials.

The Bazai Ghar Volcanics are similar to and probably correlate with the Sinjrani Volcanics of Late Cretaceous (pre-Maestrichtian) age (Jones 1961) which crop out in the Chagai Hills and Siah Koh (Fig. 1). The single sample of Sinjrani Volcanics from the Siah Koh that we have examined in thin section is recrystallized with new albite, chlorite, and fine-grained epidote, but does not show actinolite. Similar Cretaceous volcanics are mapped in Afghanistan immediately south of the map area and to the north and northwest in the Hada Hills where late Early Cretaceous (Barremian) to early Late Cretaceous (Cenomanian) ages are given (Wittekindt & Wieppert 1973). These are the southern end of the Kandahar volcanic arc (Fig. 1) of Bellon *et al.* (1979). These authors report early Late Cretaceous K/Ar dates, 4 from near Kabul and 1 from near Moqur, in this belt. Bordet (1980) reports the main Kandhar volcanics are overlain by Middle Cretaceous (Albian) limestones near Kandahar, but that volcanism continued longer to the north.

THE KHWAJA AMRAN INTRUSIVE SERIES

The Khwaja Amran Intrusive Series includes four large plutons and a large number of smaller bodies (Fig. 2). The four large intrusions can be informally designated by a major peak that is present within each of them. Compositionally the bodies range from diorite to granite (Fig. 4). The Khair Tsuka diorite is a mafic body of diorite and quartz diorite. The Khwaja Amran granodiorite is a large pluton of granodiorite to quartz diorite with sheared margins on all sides. The Tor Tsuka zoned pluton is in the southern part of the map-area and has a granodiorite to quartz diorite core with a hornblende diorite border zone along its southern margin. The Spin Ghund is the youngest and most silicic body in the area. In outcrop it is the most uniform pluton in the series. An unnamed intrusion of intermediate composition is present in the low hills west of the Brazil Ghar Volcanics. Between the Spin Ghund granite and the Khair Tsuka diorite is an area in which granite and granodiorite mutually intrude each other and contain abundant autoliths and xenoliths of nearly assimilated country rocks of the Spinatizha Metamorphic Complex and perhaps the Bazai Ghar Volcanics.

The large plutons have sharp intrusive contacts with each other and with the rocks of the Bazai Ghar Volcanics and the Spinatizha Metamorphic Complex. The order of intrusion is clearly defined in the southern part of the area with the mafic bodies being the oldest, the intermediate bodies next, and the granite the youngest body. Modal compositions have been determined for about 50 samples by point counting either thin sections or stained slabs (Fig. 4). The collection procedure was not systematic and we cannot hope to do more than illustrate the broad range of compositions present. Most of the material was collected from the southern part of the map area. The vast majority of the samples are granite or granodiorite. A considerable number of samples range from diorite through quartz diorite to tonalite. Between these there is a gap of modal compositions, plagioclase-rich granodiorites, that was not sampled. We are not certain whether this gap is real or an artifact of the irregular reconnaissance sampling. The spread of compositions along the quartz-plagioclase boundary may reflect the effects of assimilation on the mafic component of the unit.

Petrographically the rocks are typical granitic material, most having hypideomorphic–granular textures. Late deuteric alteration is seen in some samples, but all are free of the metamorphic overprint seen in the Spinatizha Metamorphic Complex and, to a lesser degree, the Bazai

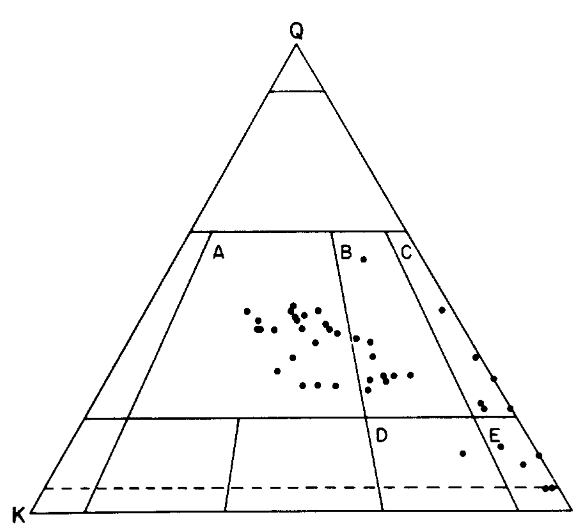

Fig. 4. Modal compositions of intrusive rocks of the Khwaja Amran Intrusive Series. A, granite; B, granodiorite; C, tonalite; D, quartz monzodiorite; E, quartz diorite; following IUGS classification, 1973.

Ghar Volcanics. Cataclastic deformation and mylonitic textures are locally present in some rocks and reflect shear zones related to the Chaman fault. The sheared borders of the Khwaja Amran quartz diorite result from the position of the intrusion. It is caught between several splays of the Chaman fault which merge south of it.

Chemical analyses of nineteen samples from these plutons are given in Tables 2 and 3. All four samples, taken from widely separated locations in the Spin Ghund granite, are very similar and have typical granite compositions. Two samples from the Khwaja Amran granodiorite are very different. 78128 is thought to be typical of the main granodiorite mass, which is everywhere near the margins of the body. 78130 is a granite. Rocks this rich in potash feldspar were rarely observed in the field. Four samples were analysed from the Tor Tsuka zoned pluton. This pluton has a well defined mafic border phase with distinct contacts. One sample (7923) of the interior is a granodiorite. Three samples from widely separated locations of the border zone (7915, 7926 and 7846) are much more mafic. 7915 and 7926 are quartz diorites on the west and northwest borders of the body. 7846 is a horneblende diorite on its southeast margin. Table 3 gives data from numerous small plutons and shows something of the variation in rock types present.

The chemical data are plotted on an AFM diagram in Fig. 5. This shows a typical calc-alkaline trend for the Khwaja Amran Intrusive Series. Although data are not adequate for a firm conclusion on the basis of such limited reconnaissance study, we tentatively interpret these as a single family of rocks of related origin. They appear to be I-type granites with an igneous source typical of magmatic arcs (Pitcher 1979, Chappell & White 1974). The few samples of Spinatizha Metamorphic Complex are very similar to the Khwaja Amran Intrusives, but the Bazai Ghar samples are slightly more enriched in iron. This enrichment supports our conclusion that the Spinatizha Metamorphic Complex is a distinctly separate older unit, and not simply more deformed material of the Khwaja Amran and Bazai Ghar units.

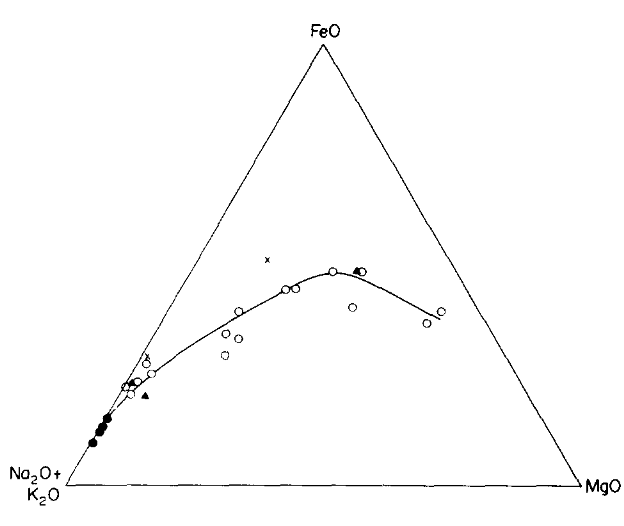

Fig. 5. AFM diagram of chemical analyses from the Spinatizha area. Solid circles, Spin Ghun granite; open circles, other rocks of the Khwaja Amran Intrusive Series; solid triangles, rocks of the Spinatizha Metamorphic Complex; crosses, Bazai Ghar Volcanics. Total iron as FeO.

Similar intrusive rocks are present in the Chagai Hills (Fig. 1) where they have been considered Late Cretaceous because they intrude the Sinjrani volcanics, and granitic clasts are found in Palaeocene conglomerates (Jones 1961). However, at least some of the intrusions could easily be younger in age. Fission track ages from zircon and apatite give concordant uplift ages of 35 and 20 Ma for samples from the Chagai Hills (G. Johnson, personal communication 1980). Thus while some plutons are Late Cretaceous, some could be as young as early Oligocene. Younger intrusions are present in the Ras Koh. Similar intrusions are also present in Afghanistan as the Arghandab batholith which extends northeast from Kandahar. This body intruded and contact metamorphosed rocks as young as late Early Cretaceous (Aptian) and has Late Cretaceous K–Ar ages of 110–100 Ma (Weippert *et al.* 1970, Tapponnier *et al.* 1981). A Rb/Sr age of 106 $\pm$ 8 Ma has been determined for the Zarkachan intrusion, a small body east of the Arghandab batholith (Afzali *et al.* 1979). Their initial Sr ratio of 0.7056 suggests a mantle origin at the time of emplacement of the body. The Khwaja Amran Intrusive Series is probably an eastern outlier of the Arghandab batholith which is itself part of the Kandahar volcanic arc described by Bellon *et al.* (1979). We think it is also the easternmost expression of the Chagai Hills intrusions and thus forms a link between these Cretaceous igneous areas.

SEDIMENTARY ROCK UNIT

South of Khwaja Amran and east of Bazai Ghar is a newly discovered area of sedimentary rocks, composed of coarse and fine clastics. Future work may be able to map these as separate units, but we did not have sufficient time to distinguish between them. The coarse-grained rocks include coarse-grained sandstones and conglomerates. They crop out on the west of the sedimentary unit and probably underlie the slates. Conglomerate clasts are up to 25 cm in diameter and are composed of volcanic and volcaniclastic rocks, sandstones, granitic rocks, and chert. The conglomerates are mostly dark coloured. Beds are up to 2 m thick. No other sedimentary structures were seen. The fine-grained rocks are in the eastern area of the unit. They are composed of interbedded grey–green to white fine-grained sandstones. Beds are 0.5–7.0 cm thick. Neither graded bedding nor any other sedimentary structures were observed. Slaty cleavage and several sets of crenulation cleavages with associated kink folds are present. No fossils were found in the sedimentary rock unit.

As a single unit these rocks do not resemble any others described or seen by us either east of the Chaman fault or to the south in the Ras Koh or Siah Koh. If two units are present the coarse-grained material is similar to the Palaeocene Rahkshani Formation (Jones 1961) which we have mapped in the northeastern end of the Ras Koh. The fine-grained material resembles the Murgha Faqirzai slates exposed east of the Chaman fault. However, there is no apparent mechanism for bringing fragments of either of these units into this area and tectonic setting. The best suggestion that we can offer for the origin of this unit is that it is a small fragment of forearc basin material related to the volcanic arc recorded by the Bazai Ghar Volcanics and Khwaja Amran Intrusive Series. The clast assemblage in the conglomerates is compatible with this interpretation. It could also represent the base of the Murgha Faqirzai sequence exposed east of the Chaman fault. If this last possibility is correct it is important because the base of the sequence is not exposed anywhere in Pakistan. It may be exposed just south of Kabul in Afghanistan, but there the geologic setting is not comparable.

STRUCTURE

Structural features in the study area evolved during three major tectonic events. The earliest of these was the development of NNE trending shear zones and associated foliation in the Spinatizha Metamorphic Complex. The shear zones were later intruded by the younger plutons of the Khwaja Amran Intrusive Series. In places, as at the north end of the Spin Ghund granite, these younger intrusions clearly follow the early shear zones. Subsequently minor cross faults of NW trend offset all of these features. Northwest trending valleys that transect the structure of the area are probably eroded along the faults indicating that they are more abundant than our mapping has disclosed. The faults cut all rock units except Quaternary gravels and record a structural stage younger than the arc volcanism and intrusion, but probably older than the initiation of the Chaman transform fault zone. The Chaman fault zone and related splay faults are the youngest structures in the area. They developed during Oligocene or later times (Lawrence *et al.* 1981). In summary: the area records three major tectonic events; (1) structures related to arc volcanism and intrusion, (2) structures developed in the interval between arc tectonics and transform tectonics and (3) structures related to transform tectonics.

DISCUSSION

The paucity of palaeontologic or radiometric age data from the study area and from the region as a whole limits the interpretation of the tectonic significance of the data presented. It seems clear that a volcanic–plutonic arc wrapped around the southern and eastern margin of the Afghan microplate in Cretaceous time. Initiation of activity in this arc corresponds in time with collision of the Afghan microplate with Asia in the Panjaw region of Afghanistan. Thus collision in the north activated subduction in the south (Tapponnier *et al.* 1981). Activity of this arc should have ended sooner along the eastern edge of the Afghan block by the arrival of the Indo-Pakistani continental block, but may have lasted longer along the south margin of the block that continued to face a subducting oceanic plate. The area studied here is important in exposing the Spinatizha Metamorphic Complex, a deformed portion of the base of the Kandahar volcanic arc. It is not clear whether the Spinatizha Complex is the age equivalent of the Bazai Ghar Volcanics and Khwaja Amran Intrusive Series which has been more intensely deformed or is an older portion of the volcanic arc. Our field interpretation that the Spinatizha Complex includes deformed intrusives and has been subsequently intruded by Khwaja Amran intrusions supports the latter interpretation. Thus we suggest that we are here looking at part of the roots of the Kandahar volcanic arc brought to the surface by vertical motion adjacent to this segment of the Chaman fault.

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