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On the Geology of the Tirich Mir Area, Central Hindu Kush (Pakistan)*)

By MANFRED F. BUCHROITHNER & HERFRIED GAMERITH**)

With 9 Figures and 1 Geological Map 1 : 50.000 (Enclosure)

Pakistan
Hindu Kush
Tirich Mir
Geological Map
Satellite Imagery
Sedimentary Series
Intrusives
Tectonics
Upper Palaeozoic to Tertiary

Dedicated to the tribes of the Hindu Kush, who had a heroic past, who live in a very hard present, and who hopefully will enjoy a better future!

Content

Zusammenfassung

Mit Schwerpunkt auf dem Tirich Mir-Gebiet wird eine Übersichtsdarstellung der Geologie von Zentral-Chitral (Hindukusch, Pakistan) gegeben. Die Beschreibung der lithologischen Einheiten und der Tektonik sollen als Erläuterungen zu einer neuen geologischen Karte des Tirich Mir-Massivs im Maßstab 1 : 50.000 (Beilage) dienen.

Summary

An outline of the geology of Central Chitral (Hindu Kush, Pakistan) with emphasis on the Tirich Mir Area is given. Descriptions of rock units and structure shall serve as explanatory notes on a new geological map 1 : 50.000 of the Tirich Mir Massif (enclosure).

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**) Authors' addresses: Univ.-Doz. Dr. MANFRED F. BUCHROITHNER, Graz Research Center, Institute for Image Processing and Computer Graphics, Wastiangasse 6, A-8010 Graz, Austria; Dr. HERFRIED GAMERITH, Rebhahnweg 16, A-4060 Leonding, Austria.

Resumé

Un exposé de la géologie de Chitral Central (Hindou Kouch, Pakistan) avec point capital sur la région du Tirich Mir est présenté. Les descriptions des unités lithologiques et de la tectonique doivent servir à une note explicative d'une nouvelle carte géologique du Massif du Tirich Mir à l'echelle 1 : 50.000 (supplément).

Preface

Between 1965 and 1975 the authors had several opportunities to visit the valleys of the northern and southern slopes of the Central Hindu Kush and also parts of the areas depicted on the geological map of the Tirich Mir Massif which is presented in this paper. It was mainly the knowledge of the surrounding terrain and the availability of a set of aerial stereo-photographs that led to the plan to produce a large-scale geological map of the highest part of the Hindu Kush range.

Accompanying studies of multispectral Landsat MSS data (cf. fig. 3) and high resolution Metric Camera and Large Format Camera photographs taken from the Space Shuttle supplied additional sources of geological information (cf. BUCHROITHNER, 1984). The richness in topographic detail also makes this map a useful tool for mountain hikers and climbers (KOSTKA & BUCHROITHNER, in prep.). Thus, it represents a comparatively new type of a geological high mountain map based on locally proved geological information compiled with the aid of air- and spaceborne data for wide-range coverage.

1. Geographical Setting

The 1200 km long Hindu Kush, which culminates in the over 7700 m high Tirich Mir, is the continuation of the Karakorum and represents the western portion of the Himalayan System. In its higher central and eastern parts massive, snow-covered mountains with long, scree-covered glaciers and deeply eroded, dry valleys with meandering seasonal rivers determine the landscape (GRUBER, 1977).

The Hindu Kush lies almost beyond the influence of the Monsoon. Its Central Asian alpine climate is characterized by dry, hot summers and cold winters with little snow. In the region of the Tirich Mir melted snow and ice supply enough water for modest cultivation of cereals, willows, poplars, walnut and other fruit trees as well as various types of vegetables, mainly grown on terraces between or at the foot of talus fans. Forests only occur in Nurestan, an Afghan province, some 100 km southwest of the Tirich Mir.

The major settlement of the region is Chitral with

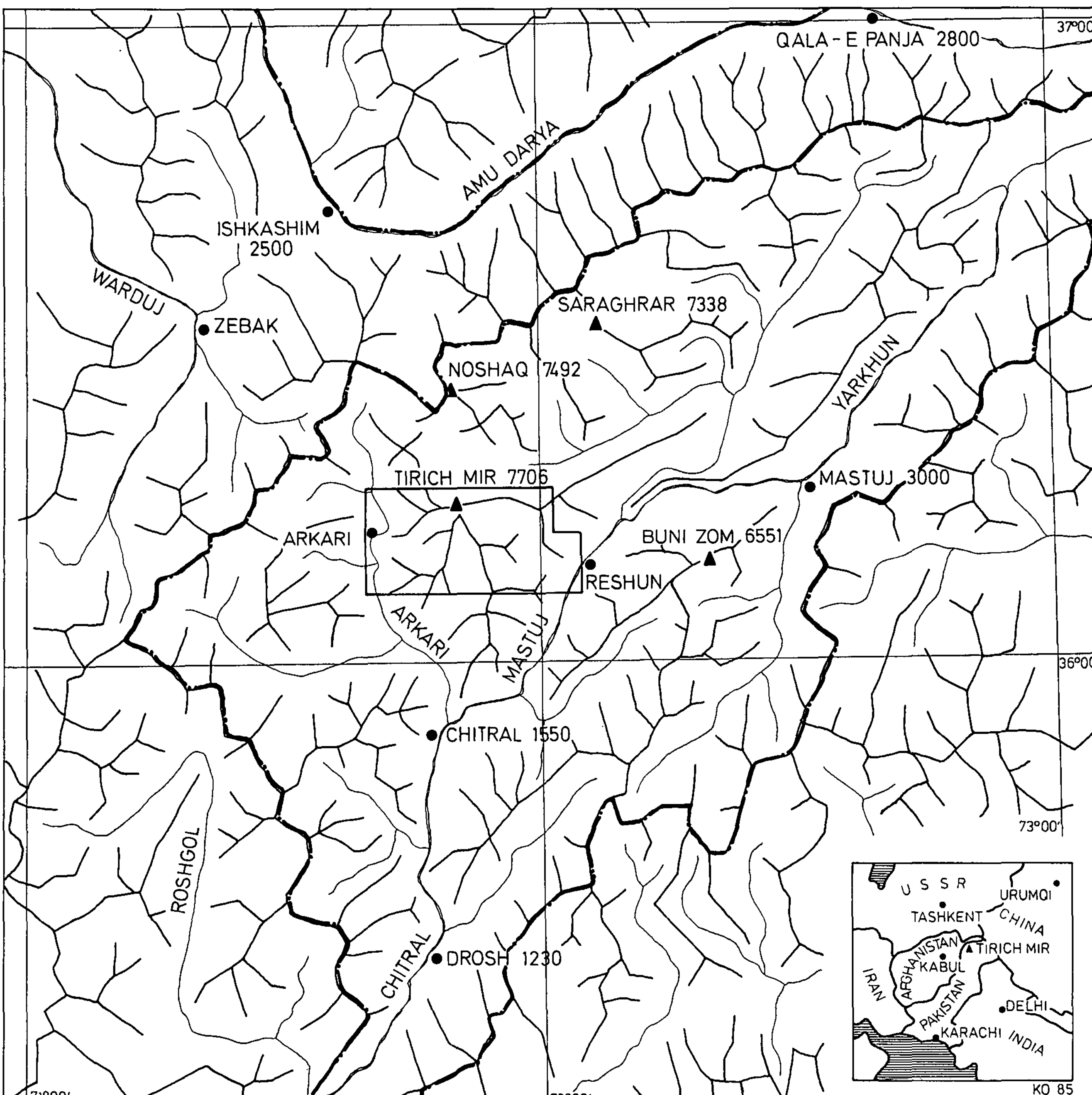

Fig. 1: Sketch map of Chitral and surroundings indicating the area of the 1 : 50.000 geological map of the Tirich Mir Massif. Compiled by R. KOSTKA, Graz (Austria), on the basis of USAF Pilotage Chart and various topographic sketch maps.

Fig. 2: Views of Tirich Mir main peak from southeast.

some ten thousand inhabitants, located at the river with the same name, about 45 km due south of the Tirich Mir. It is the capital of the District of Chitral, which was an independent principality until 1969. The District of Chitral covers approx. 14800 km² and houses some 115000 people (in 1965), mainly of Dardic origin (Khos). Apart from a flight connection from Chitral to Peshawar, traffic is restricted to track-like gravel-roads over the Lowari Pass (3118 m) and caravan trails. (Sound recent information on population and road conditions is difficult to obtain.) Figure 1 represents a sketch map of Chitral and surroundings.

The Tirich Mir Massif itself rises some 5000 m above the surrounding valleys (fig. 2). The main summit attains a height of 7708 m. There are other individual peaks of over 7000 m, including the 7692 m high East Summit. The main summit was first climbed on July 22 1950 by the Norwegian Per Kvernberg in a solo attempt.

2. History of Geological Research

It seems justified to give a brief account of the geological exploration of Chitral and the Tirich Mir region in particular. Detailed descriptions of fossil faunas or floras can be found in publications referred to in the literature mentioned.

Early information concerning the geology of the mountains in question comes from general geographic descriptions of travellers in diplomatic, military or surveying missions. The presumably first report dedicated to the geology of the area was by Ferdinand STOLICZKA in a monography by W. T. BLANFORD (1878). MC MAHON & HUDLESTON (1902) described, among others, Devonian fossils collected by GURDON and GRANT from the limestones of the Series of Owir. In 1911 and 1922 F. R. COWPER-REED determined some additional Devonian fossils from various locations in Chitral. In 1916, the director of the Geological Survey of India, H. H. HAYDEN, provided a comprehensive description of his geological observations in the Pamir, Gilgit and Chitral. In two publications (FERMOR, 1924; PASCOE, 1924) TIPPER describes fossils from the Upper Palaeozoic of the Chitral Slates (see chapter 4.1.5.). In a 25 page paper by CIZANCOURT & VAUTRIN (1937) the structure of the western and Central Hindu Kush is outlined.

IVANAC, TRAVES & KING (1956) discussed the northwestern part of the Gilgit Agency, adjacent to the Chitral District. SCHNEIDER (1957) described tectonics and magmatism of that area. In 1964 a first geological map of Pakistan at the scale of 1 : 2,000000 by ABU BAKR & JACKSON gives a very crude presentation of the Eastern Hindu Kush. The results of the Kyoto University Scientific Expedition 1955 to Hindu Kush and Karakorum contain one volume dedicated to geology (MATSUSHITA & HUZITA, 1965). At the International Geological Congress in Copenhagen the geotectonics of the granites of the Karakorum and the Hindu Kush were made known to the worldwide geological community by Ardito DESIO and Antonio MARUSSI (1960). In 1963 DESIO provided a first review and attempt to correlate the various geological "formations" of these regions. One year later, first radiometric datings of intrusive rocks in Badakshan, the Eastern Hindu Kush and the Western Karakorum were published (DESIO, TONGIORGIO & FERRARA, 1964). The first detailed examination of a Palaeozoic sedimentary

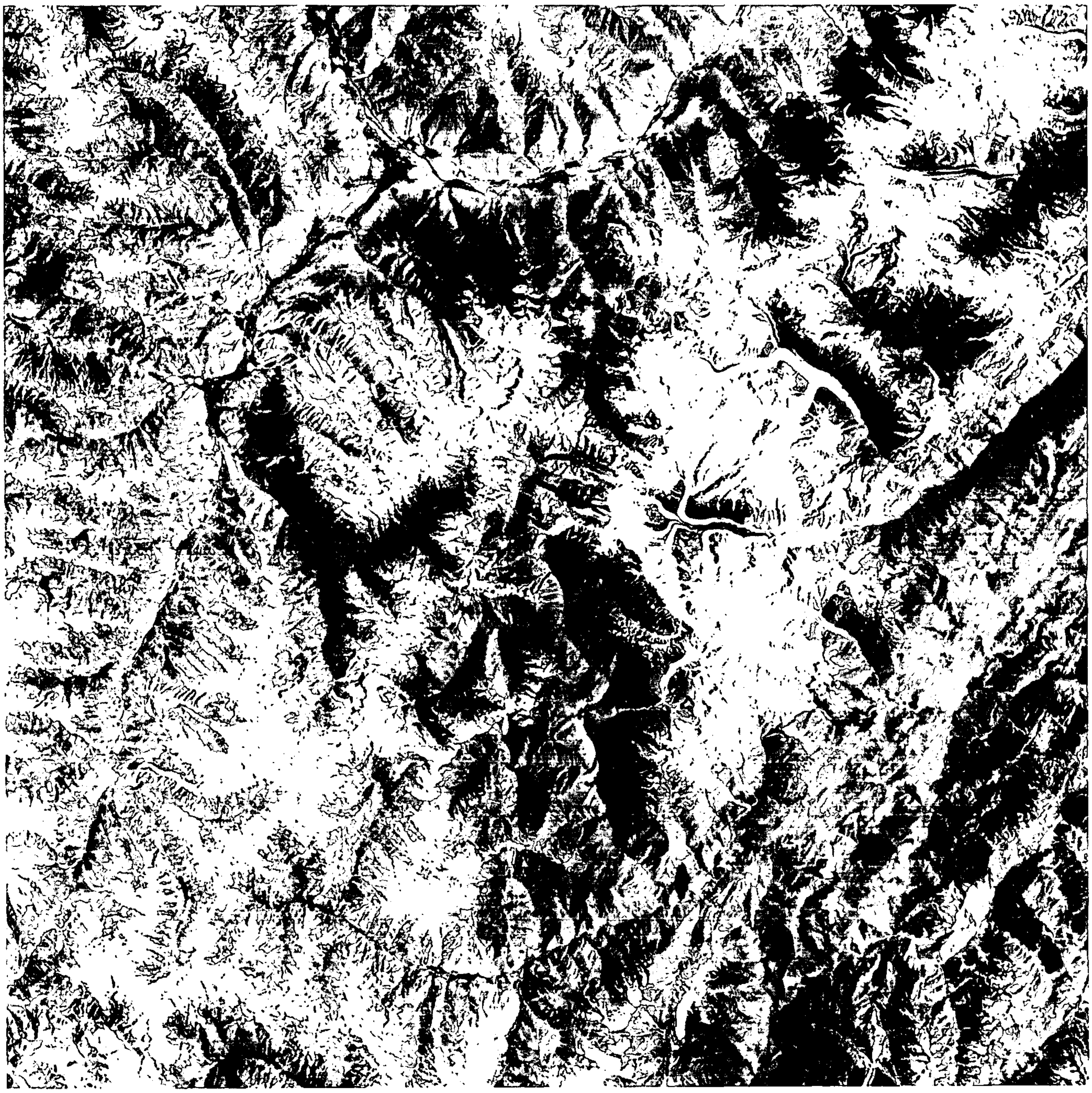

Fig. 3: Landsat-1 MSS satellite image, Scene E–1354-50233, from July 12, 1973, showing the Tirich Mir area and surroundings. Compare with figures 1, 4 and 8.

sequence (type locality of the Devonian Shogran Formation close to Mastuj in Chitral) is presented by DESIO (1966). The second find of Receptaculites in Asia from the limestones at the Owir Pass south of the Tirich Mir is described by VOGELTANZ (1968, 1969) and VOGELTANZ & SIRONI-DIEMBERGER (1970). In the same year (1968), Kurt DIEMBERGER published the first geological sketch map of the Tirich Mir Massif proper at the scale of approximately 1 : 300000. Also in 1968, DESIO, GUY & PASQUARÈ cited the first mica age from the Tirich Mir Granite with Lower Cretaceous in a paper on the geology of the Afghan Wakhan.

MÜLLER (1970) briefly touched the geology of the Noshaq Massif north of the Tirich Mir. With emphasis on the Koh-e Keshnikhan area north of the Noshaq, H. GAMERITH (1972) gave an outline of the geology of the Eastern Hindu Kush. Together with H. KOLMER he investigates the intrusives of the Eastern Hindu Kush and trace element contents of carbonatic rocks from the Buni Zom Group east of the Tirich Mir (GAMERITH & KOLMER, 1973, 1975). In the same year (1975) DESIO published some integrative notes on the geology of the Chitral Valley.

In a review paper AUDEN (1974) depicted the structure of the eastern part of Afghanistan and West Pakistan, putting the main geological features of this area into context with the whole Indo-Himalayan region. STÖCKLIN (1977) gave a structural correlation of the alpine ranges between Iran and Central Asia. A geological map at a scale of 1 : 250000 compiled by BUCHROITHNER & GAMERITH (1978) covers the area of the Pamir-e Wakhan and the easternmost Hindu Kush and reaches to some 50 km northeast of the Tirich Mir. An outline of the geological evolution of the Karakorum by DESIO (1979) also covers the Eastern Hindu Kush. The last comprehensive presentation of the regional and economic geology of the Eastern Hindu Kush, Hinduraj and northwestern Karakorum, which includes a 1 : 250.000 geological map, is not yet published (GAMERITH, 1979, 1980).

Further literature on the studied area can be found in bibliographic review articles by DESIO (1977) and BUCHROITHNER (1979).

3. Geological Setting

The geology of the whole Chitral District and the Tirich Mir Area in particular is characterized by the occurrence of thick sedimentary series of the Tethys Zone of the northern Karakorum and of the volcano-sedimentary sequences of the southern Karakorum (DESIO, 1979). Both sequences were intruded by Upper Jurassic/Cretaceous to Tertiary igneous rocks (DESIO, TONGIORGI & FERRARA, 1964; BUCHROITHNER & SCHARBERT, 1979).

The Palaeozoic to Mesozoic geosynclinal sequences were strongly compressed, tectonically folded and faulted during the Upper Cretaceous to Tertiary orogenic activities.

Following the strike direction of the young orogene, extensive igneous rock masses of quartzdioritic and granitic composition were intruded. The occurrences of some narrow and elongated bodies of basic to ultrabasic rocks are controlled by important tectonic lineaments and fault zones (AUDEN, 1974, cf. fig. 8, 9).

In the western and eastern portions of the Chitral District the geosynclinal sequences have undergone heavy metamorphism during the Cretaceous/Tertiary orogenesis, combined with the intrusions of igneous rocks. Locally, granitization can also be observed. In the central and northeastern portion, and hence in the Tirich Mir area, metamorphism was not so intense. Due to the syntaxial tectonics, the northwestern Karakorum and the Hindu Kush show a very characteristic bending of the mountain ridges from an E–W trend in the eastern portion to a NE–SW trend in the western portion (BILLINGTON et al., 1977; EBBLIN, 1978). In general, the rock series display intensive isoclinal folding (WADIA, 1931, 1957; DESIO, 1976).

A simplified presentation of the geology of the Tirich Mir area is given in figure 4.

4. Rock Units

In the following summarizing descriptions of the lithological/lithostratigraphic units occurring in the Tirich Mir Massif and in adjacent areas are given. For more details the reader is kindly referred to the literature cited.

4.1. Geosynclinal and Meta-Volcanic Series

In the Chitral District a number of sedimentary and volcano-sedimentary series can be observed, which have a general trend parallel to the strike of the orogen. They are divided by important tectonic lineaments of distinct fault zones. Some are also bordered by intrusive bodies or series of high metamorphics.

At present an accurate determination of the age of these series is not possible because fossils were only found at and determined from a few places. Due to the high metamorphism no fossils can be expected. Concerning the sequence and the true thickness of the sedimentary series sufficient details are not yet known. Nevertheless, for the geosynclinal sequences of Chitral a total thickness of several thousand meters can be calculated (GAMERITH, 1980).

A comparison of different series of the Tirich Mir and other regions with respect to age, macro- and microfacies ist very difficult and in part not relevant, because there are often significant changes in facies in the strike direction of one particular series of the same age. Additionally, the difficult tectonic structure of this mountain range complicates the classification of the geosynclinal series and their separation into individual geological units (cf. DESIO, 1963, 1979).

4.1.1. Account of the Series in Chitral

From North to South the following seven stratigraphic-tectonic units can be distinguished in Chitral (cf. also fig. 4):

a) A Mesozoic sequence of dark-grey slates to siltstones and fine-grained quartzites with intercalations of limestones and calcareous schists (Arkari Series/Atak Series).

b) An Upper Palaeozoic sequence of middle- to dark-grey slates to siltstones and fine-grained quartzites respectively, light greenish or brownish-greyish, argillaceous-arenaceous-calcareous schists with large lenses of varying thickness, consisting of light- to middle-greyish limestones or white to light yellowish-brownish dolomite; to a smaller extent intercalations of green meta-volcanics and volcano-sedimentary rocks, which in some places show considerable thickness (Awireth Series/Series of Owir).

c) A thick Upper Palaeozoic to Lower Triassic sequence of dark-grey slates and some siltstones with marker beds of light quartzites; rare, thin lenses of ferrogenous limestones or calcareous schists; distribution from the Afghan Pamir (Wakhan) to west of the Tirich Mir (Wakhan Formation).

d) A Cretaceous to Tertiary sequence with frequently changing facies in strike direction, consisting of white to light-grey, partly reddish limestones and, to a lesser extent, also dolomites. In the Southwest of Chitral transitions to sandstones, conglomerates and red calcareous schists occur (Shoghor Limestone/Reshun Formation/Reshun Conglomerate).

e) A Cretaceous to Tertiary sequence of dark-grey slates to siltstones and fine-grained quartzites. To a lesser extent greywacke and conglomerates with light-grey to whitish calcareous schists or limestones and partly thick intercalations of green-schists and (meta-) volcanics (Chitral Slates) occur

f) An Upper Palaeozoic sequence of middle- to dark-grey slates and light- to middle-grey argillaceous-arenaceous-calcareous schists, partly with lenses and beds of white to light-grey limestones and dolomites, probably also (meta-) volcanics and green-schists (Golen Gol Series).

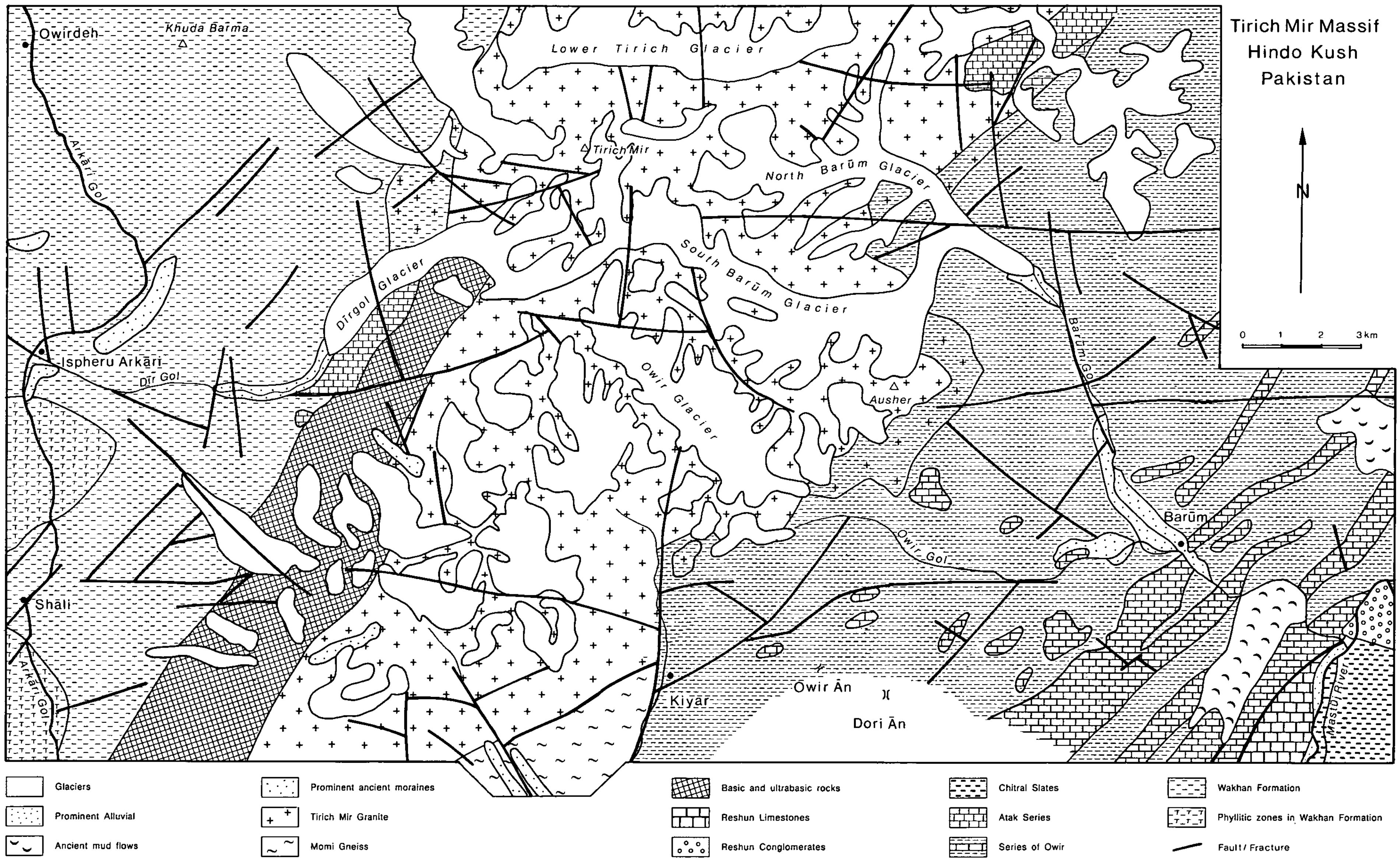

Fig. 4: Geological sketch map of the Tirich Mir area. Straight lines indicate the location of the cross sections given in figure 9.

g) An Upper Palaeozoic (?) sequence of dark-grey slates, to siltstones and fine-grained quartzites as well as carbonatic intercalations of variable thickness (Series of Mastuj = ? Darkot Series).
h) A Cretaceous to Tertiary sequence of middle-grey slates and reddish to violet calcareous slates to calc-schists with intercalations of mostly thin lenses or beds of light limestones, red sandstones to quartzites, partly thick greenish (meta-)volcanics, tuffs and tuffites in the southwestern portion (Shishi Series).

The upper Palaeozoic series c) and f) are similar in terms of their facies. Series g) is different from a) and f), due to the absence of light quartzites as well as carbonatic and volcanic rocks in this series.

Series a), d), e) and h) are most probably of Mesozoic age. While series a) probably also contains Jurassic (the limestone of the upper Arkari Valley) and even Triassic members (the limestones of the Atak Series are comparable with the "Pamir Limestones" in the USSR; DESIO, 1963), series d), e) and h) seem to be mostly of Cretaceous to Lower Tertiary age. Regarding their facies, there are some differences between the series which allow the assumption of three different sedimentation areas for series a), for series d) and e) and for series h).

A normal stratigraphic sequence from the Upper Palaeozoic members to the above mentioned series has not been observed; also no disconformities of erosion or other types are reported. At present, within the geosynclinal sequence of the Chitral District, there are no sediments older than Devonian known.

The basement of the geosynclinal structure is nowhere exposed. The crystalline schists of Chitral are probably integral parts of the higher-metamorphic geosynclinal series.

4.1.2. Wakhan Formation

A continuous zone of very dark, homogeneous slates, siltstones and quartzites with some minor intercalations of calcareous schists and limestones extends from the Baroghil Pass in the East to south of Qazi Deh at the western end of the Wakhan. The width of this zone varies considerably. This is due to the irregular shape of the intrusive body of the Koh-e Baba Tangi/Lunkho Granodiorite, which borders these sediments in the South. Moreover, this strip is intersected and dislocated by transcurrent faults which in most cases follow the short side valleys draining to the Northnorthwest into the Ab-e Panj. In the North the Wakhan Formation is bordered by gneisses which, in part, can be considered as metamorphic products of this very sequence.

HAYDEN (1916) first mentioned and named this sequence "Wakhan Slates". Short descriptions of the Wakhan Slates were given by MIRWALD & RÖMER (1967), DESIO et al. (1868; "Khandut Slates") and GAMERITH (1972). BUCHROITHNER (1978) studied this series in more detail. According to its lithostratigraphy, he introduced the name "Wakhan Formation", as this unit comprises different rock types and not only slates.

Between the Shakhawr Valley in the North (Afghanistan) and the Udren Valley in the South (Chitral) the axial batholith of the Hindu Kush plunges below dark slates (cf. also GAMERITH, 1972). Hence, the question rises, whether the "Atak Formation" south of the main ridge of the Hindu Kush as a whole or in part represents an equivalent of the Wakhan Formation. Moreover, the Wakhan Formation might have its continuation west of the extensive Tirich Mir, Istor-o Nal and Koh-e Keshnikhan Batholith, which, as described by GAMERITH (1972: 106), discordantly intruded into the sedimentary series. With respect to their low metamorphism the dark slates and siltstones with some thin intercalations of limestones in the middle and upper Arkari Valley show a very similar habitus.

Based on lithological comparisons, DESIO, GUY & PASQUARÈ (1968) tried to correlate the "Khandut Slates" with formations further to the East such as the "Misgar Slates", the "Kilik Formation" and the "Sarikol Shales" as well as with various Palaeozoic and Mesozoic black slates in Badakhshan and in the Soviet Pamir.

The range of age of the Wakhan Formation can be restricted to pre-Cretaceous, based on radiometric age determinations of a granodioritic rock sample of the Tirich Mir Massif sampled by K. Diemberger, which yielded an age of 115 ± 4 million years (DESIO, GUY & PASQUARÈ, 1968).

Beside detailed lithostratigraphic studies, BUCHROITHNER (1978, 1979) was able to describe some microfossils in limestone intercalations in a part of the Wakhan Formation northeast of the Ab-e Wakhan in the Afghan Pamir. A conodont fauna indicating two conodont zones of Scythian (Lower Triassic) age was reported. It originates from a lense-shaped limestone intercalation in the western slopes of the Ptukh Valley northwest of the village of Sarhard. This limestone did not yield any macrofossils due to the close contact about 1 km off the Issik Granodiorite, the intensive tectonics as well as the recrystallization of these limestones.

BUCHROITHNER & KOLMER (1979) give a comprehensive fauna list of the conodont population and also describe the depositional conditions and geochemical parameters of the Wakhan Formation as well as of some of its equivalent metamorphic rocks, including hornfelses and slates. Based on these studies, the authors come to the conclusion that at least part of the Wakhan Formation belongs to the Skythian and has been deposited under the conditions of a warm shallow sea.

4.1.3. Series of Owir

HAYDEN (1916) mentioned fossiliferous limestones from the vicinity of the Owir Pass, south of the Tirich Mir, which he assigned to the Devonian. A find of *Receptaculites neptuni* (DEFRANCE) from the Owir An (Owir Pass), described by VOGELTANZ (1968, 1969) and VOGELTANZ & SIRONI-DIEMBERGER (1970), corroborates the Devonian age. This finding of Receptaculites was only the second in Asia. The fossiliferous limestones are embedded into thick dark slates (fig. 5, 6). HAYDEN (1916) called this limestone-bearing sequence "Sedimentary Series of Owir". A description of the fine-clastic rocks is given in chapter 4.1.1.

The frequent limestone intercalations which are the characteristic features of the Series of Owir consist of medium to dark grey, locally greenish- to brownish-grey, anchimetamorphic, coarse-grained biosparite with oolithic portions. These light-weathered, frequently dolomitized limestones locally show encrinites and iron inclusions. The iron-bearing crinoid stems and hematite ooids (with a sorting coefficient of 1.52 after TRASK) lie

Fig. 5: Valley west of Owir An (in the background), deeply incised into the dark Slates of the series of Owir.

Fig. 6: Brachiopod specimen in encrinitic ferrogenous limestone intercalations in the Series of Owir. Owir An (4336 m). Length of matchbox 5 cm.

in a fine-grained debris of shells with quartz grains (clasticity index 0,24 mm) and authigenous chamosite. The found specimens of Receptaculites also display dolomitization, especially in the lumina region.

4.1.4. Atak Series

This mesozoic sequence has an extension from west of the Baroghil Pass at the northeastern boundary between Chitral and Afghanistan through to the Shah Jinali area and the upper Rich Valley (Turkho) towards the Upper Tirich Valley, where the sequence is cut off by the intrusion of the Tirich Mir Granite. West of the Tirich Mir Massif the sequence becomes more metamorphic. In places granitization has been observed. Between the upper Yarkhun Valley and the Tirich Valley partly crystalline limestones of locally more than thousand meters are developed along the southern slopes of the range.

In the eastern part of the thick limestone belt of Gazikistan, in the upper portion of the Arkari Valley, outcrops of reddish and violet calcareous slates with fifty meters maximum thickness have been mapped, which are similar to the reddish calcareous slates of the Reshun Formation and in the Shishi Valley. The age determination of the Atak Series is doubtful since it has only yielded a few heavily re-crystallized crinoidea. From the limestones of Gazikistan one single find of a probably Jurassic belemnite is reported (BRIEGLEB, 1978). The maximum thickness of the whole sequence amounts to some 500–600 meters.

4.1.5. Chitral Formation

The "Slate Series of Chitral" was first mentioned by HAYDEN (1916: 282). Under this name the author includes a sequence of grey slates to phyllites and quartzites which occur between the town of Chitral and the village of Gahiret. TIPPER in FERMOR (1924: 55) took over this name and described badly preserved fossils from limestone intercalations, unfortunately without cit ing the exact locations. Based on a fauna of *Spirifer* sp., *Dielasma* sp. and unidentifiable corals, the author comes to an age assignment to the Upper Palaeozoic. In another paper, TIPPER in PASCOE (1924: 44) changes the name of this series to "Chitral Slates". DESIO (1963: 491) calls it "Chitral Formation" and mentions a thickness of some 5000 meters. He also points out a distinct anticlinal structure of this sequence.

The assumption of DESIO that the Chitral Slates form an "anticlinal fold" is incompatible with the conception of CHALKINS (1968), who describes the Chitral Slates as a Cretaceous syncline to the West and to the East bordered by limestones. As, on the other hand, it is not known from which limestones the Upper Palaeozoic fauna described by TIPPER in FERMOR (1924) originates, and as on the other hand, the limestones of Shogor yielded a Cretaceous fauna (DESIO, 1959), the solution of the stratigraphic as well as of the tectonic position of the Chitral Slates and the limestone series to the West and East of it is not yet possible.

The Chitral Formation represents a rather uniform sequence of grey, partially black and frequently shiny slates to phyllites. Locally, more sandy to quartzitic intercalations and sporadic intercalations of limestones and calcareous schists occur. In the southeastern and eastern portion of this distribution green schists and meta-volcanics respectively of considerable thickness are also intercalated. Well-exposed outcrops of these rock types can be observed at the entrance of the Birri Valley. Also in the striking continuation to the Northeast and East into the Mastuj Valley the fine-clastic sediments are more and more replaced by „greenstones" and meta-volcanics respectively.

As already indicated, the present state of information does not allow a clear age assignment.

4.1.6. Reshun Formation

According to CHALKINS (1968: 9), the "Reshun Formation", beside the "Reshun Conglomerate" (HAYDEN, 1916), occurs in the form of three spatially separated stripes in the southern part of the Chitral District.

CHALKINS considers the two thick marble/limestone occurrences which follow the general strike direction (Gahired-Roghili Valley and Shogor-Kafiristan) as well as the Shishi Series Cretaceous in age. Fossiliferous Cretaceous rocks, however, have only been proved in the surrounding of Shogor/Krinj (DESIO, 1959: 225), and Orbitolita-bearing, thin limestone intercalations occur only in the Shishi Valley. According to CHALKINS the two limestone stripes should be considered of same age and combined to one large syncline, in the center of which the Chitral Slates were deposited as a thick filling of the central trough. This conception, however, is incompatible to that of DESIO (1963: 491) who considers this structure to be an anticline.

The yellow-reddish, limestone-bearing "Reshun Conglomerate" is exposed between Chitral and the village of Mastuj, south of Reshun. It was first mapped and described by HAYDEN (1916). The first Palaeozoic age assignment by HAYDEN was soon changed to the Cretaceous based on Orbitolina findings (DESIO, 1959).

Further fossil finds have been determined by ROSSI-RONCHETTI & FARIOLI-MIRELLI (1959) as the microfossils Praeradiolarites. CITA & RUSCELLI (1956) describe a foraminifera fauna consisting of Textulariidae, Valvulinidae, Miliolinidae, *Orbitoliina* sp. and *Orbitolina discoidea* GRAS. The authors consider an age assignment to the Upper Barremian as well as to the Lower Aptian, whereby the latter age seems to be more probable.

The Reshun Conglomerate has to be taken as a product of the underlying compact Cretaceous limestones. These Aptian limestones were deposited during a short marine transgression phase ("ingression"), which was again followed by regression.

4.2. Basic and Ultrabasic Rocks

In Chitral two separate belts of basic to ultrabasic rocks occur which follow the extension of prominent geotectonic structures and fault zones.

The southern belt strikes within a fault zone of 2 to 3 km in width through the lower Shishi Valley. The continuation to the Northeast into the Laspur Valley is still not known. Within this region a number of lenses of basic intrusive rocks have been mapped. The maximum length of the individual bodies does not exceed 6000 m, the maximum thickness averages around 100 meters. The predominating rock types are serpentinized peridotites and serpentinites and, to a lesser extent, fine- to medium-grained gabbros (GAMERITH, 1980).

The northern belt, which also extends into the map area, generally follows the tectonic border between Atak Formation and Series of Owir, which is known as "Tirich Mir Fault". Between the Shah-Jinali Gol and the Tirich Gol some single outcrops of basic to ultrabasic rocks occur. This belt consists of a few separate lenticular and elongated intrusive bodies.

The maximum extension of 15 to 20 km is shown by an intrusive body between the middle Shah Jinali Gol and the upper Rich Gol. The maximum thickness measures a few hundred meters but is usually much less. Its constituents are predominantly fine- to medium-grained gabbros, foliated or banded gabbro-amphibolites and, to a lesser extent, also serpentinites.

In the map area, along the southwestern slope of the Tirich Mir Massif, between the Sunitz Gol and Luthko Gol, a belt of some 20 km length and up to 2.000 meter thickness is exposed. It is inserted along the border between Wakhan Formation and Tirich Mir Granite and consists of medium- to coarse-grained gabbros, diorites, foliated to banded gabbro-amphibolites and some very coarse-grained hornblendites.

The basic to ultrabasic rocks have been intruded pre- to syntectonically and exist today in the form of gabbro-amphibolites and heavily tectonized serpentinites. Some of them show intrusions of late- to posttectonic granitic rocks (cf. GANSSER, 1979), e. g. the granitic dykes and sills within the gabbroid rocks in the map area.

4.3. Momi Gneiss

Not very much is known about the Momi Gneiss, which occurs between the Tirich Mir Granite and the Series of Owir in the area between the Arkari and the Mastuj Valley. It was mentioned for the first and only time in a paper by DIEMBERGER (1968) which contains a geological sketch map of approximatley 1 : 300000. However, no description is given there.

As far as we know from field observations, the genesis of the pegmatite- and aplite-bearing Momi Gneiss should be similar to that one of the Qal'a-e Ust Gneiss (BUCHROITHNER, 1978, 1980), which can be derived from its partly sedimentary and partly intrusive transitional habitus. BUCHROITHNER & SCHARBERT (1979) give a history of formation for the Qal'a-e Ust Gneiss which might be seen in correspondence with the age of 115 million years of the Tirich Mir Granite (DESIO, GUY & PASQUARÈ, 1968) which intruded into the Series of Owir.

4.4. Intrusive Rocks of Granitic and Quartzdioritic Composition

Apart from mostly pre- to syntectonic quartzdiorites to granodiorites and late- to posttectonic granites, most of the intrusive bodies of batholitic size and of the smaller granitic bodies consist of late- to posttectonic granodiorites.

The granodioritic rocks show a distinct magma differentiation from older mafic to younger SiO_2-rich types within one individual intrusive body belonging to the same orogenetic sequence. However, field observations are not always conclusive, since most probably some younger granitic rocks have intruded into older granitoid rocks, and assimilation of extensive portions of the older country rocks has thus taken place.

In the western and southern part of Chitral extensive processes of migmatization and granitization of adjoining country rocks have occurred, following the intrusion of the late- to posttectonic granitic rocks (see also section 6).

Apparently, all granitic rocks of the Chitral District belong to the Cretaceous to Tertiary orogenic cycle. The existence of older granitic rocks is not known and unlikely, since there are no indications for older orogenies except the Alpidic one (GAMERITH, 1980).

4.4.1. Pre- to Syntectonic Quartzdiorites and Granodiorites

In the southern portion of Chitral an extensive body of quartzdioritic to granodioritic rocks, which is known as "Mirkhani Granite", has intruded into the rocks of the Shishi Series.

In the region of Dommel Nissar (southernmost Chitral District) locally large areas of porphyritic rocks have been mapped occurring within the Mirkhani Granite. At present, the geological relationship to the granites is not clear. Beside distinct inclusions of older greenish (meta-) volcanics of the Shishi Series, some of the porpyhritic rocks seem to be younger than the Mirkhani Granite. Therefore, this granite is likely to be pre- to syntectonic and probably originates from the same magma as the porphyrites (co-magmatic).

4.4.2. Late- to Posttectonic Granodiorites

These large batholitic intrusions predominantly consist of leukocratic to mesocratic, medium- to coarse-grained hornblende-biotite granites. In some portions, e. g. in the Tirich Mir Massif, hornblende is predominant, in others biotite. Moreover, within one intrusive body, e. g. in the Hinduraj, the distribution can vary considerably. In some granites, e. g. at the Dorah Pass or in the Buni Zom Group, also older, coarse-grained remnants of mafic composition can be observed. They obviously belong to a previous magmatic phase.

Younger mica- or tourmaline-bearing pegmatites are rare (Hinduraj) or completely absent (Buni Zom Group). Dark porphyric dykes are found in some places.

Some granites, e. g. in the Buni Zom Massif, show porphyric feldspars. Other granites, as in the southern Tirich Mir Massif, are particularly characterized by a porphyric structure in marginal amounts. This indicates (? late-magmatic) assimilation processes along the border to the metamorphic country rock.

4.4.2.1. Tirich Mir Granite

South and southwest of the Keshnikhan-Mandaras Intrusives, and separated from these by a small strip of dark slates, the predominantly granitic rocks of the Tirich Mir and Istor-o Nal Batholite are exposed. This batholite reaches from the Lower Atak Glacier in the Northeast to the Lutkho Valley east of the village of Garam Chasma (Hot Springs), where the batholite plunges to the southwest under metamorphic slates (fig. 4). The intrusives of this batholitic body discordantly intruded into the calcareous and phyllitic rocks of the western Wakhan Formation and Atak Series (cf. DIEMBERGER, 1968).

In the central part of the batholite granites to aplite granitic rocks predominate, whereas towards the southwest the habitus shows a gradual transition to fluidally textured rock types and granitic gneisses respectively. Aplite granite from the summit of the Tirich Mir is described by GAMERITH & KOLMER (1973: 167). The samples in question are medium-grained, very light-grey aplite granites with muscovite agglomerations. The mineral composition consists of 36 % quartz, 28 % plagioclase (11 % An) and 25 % alkali feldspar, which in the thin-section shows features of slight dissolution, documented in the rock analysis in the form of a surplus of alumina. Furthermore, some 7 % muscovite, 2 % biotite with transitions to chlorite, as well as apatite, magnetite and tourmaline can be observed as accessories.

Fig. 7: Alluvial plain below the tongue of the Owir Glacier. Rock faces consist of Tirich Mir Granite.

Although the Tirich Mir Batholite has a heterogeneous structure with probably several intrusive phases, its age position can rather precisely be defined by rubidium/strontium dating. According to DESIO, GUY & PASQUARÈ (1968), who analysed the above mentioned rock sampled by Kurt DIEMBERGER close to the summit of the Tirich Mir, this radiometric dating resulted in an age of 115 ±4 million years. This points to an intrusion during the Lower Cretaceous.

A certain similarity exists between the Tirich Mir and the Kafiristan Batholites with regard to their mineral composition. Also from the aspect of their geological position, the Kafiristan Batholite can be considered as an indirect continuation of the Tirich Mir Batholite.

4.4.3. Late- to Posttectonic Pegmatite Granites

These pegmatite granites were intruded after the granodioritic intrusions which are of roughly the same age. They have particular wide distribution in the western part of Chitral. The main rock types are leukocratic fine- to medium-grained muscovite (biotite-tourmaline-garnet) granites, well-exposed in the Ushuti and Luthko Valleys, followed by numerous pegmatites of similar composition. These pegmatites are found within the granites and also in the adjacent metamorphic country rocks.

5. Structural Development

Clarification of the tectonic structures of the map area strongly rely on the knowledge of the regional tectonic structures of the Chitral District, which are, at present, only known in general. More detailed statements depend on more knowledge concerning the chronostratigraphic structure of the different geosynclinal sequences.

As mentioned before, the geosynclinal sequences of Chitral can be subdivided into seven geological units which are to a great extent separated by tectonic lineaments or faults and bodies of intrusive rocks. The (Upper) Palaeozoic series on one and the Mesozoic (to Tertiary) series on the other side can be compared and at least partly correlated. On the basis of that comparison a few regional synclinal and anticlinal structures, which more or less correspond with the original sedimentation areas, can be roughly plotted and demarcated. Thus, the Mesozoic geosynclinal basins of the Arkari and Atak Series and of Reshun Formation, Chitral Slates and Shishi Series are thought to correspond with tectonic synclinoria, while the sedimentation areas of the Awireth Series and the Series of Owir as well as those of the Golen Gol and Darkot Series may correspond with orogenetic anticlinorial structures.

During the Cretaceous to Tertiary orogenetic activities the initial geosynclinal structures have been strongly compressed and isoclinally folded with a distinct southeast- to south-vergent trend. Important longitudinal fault zones have developed between the individual series, and in particular between the Arkari/Atak Series

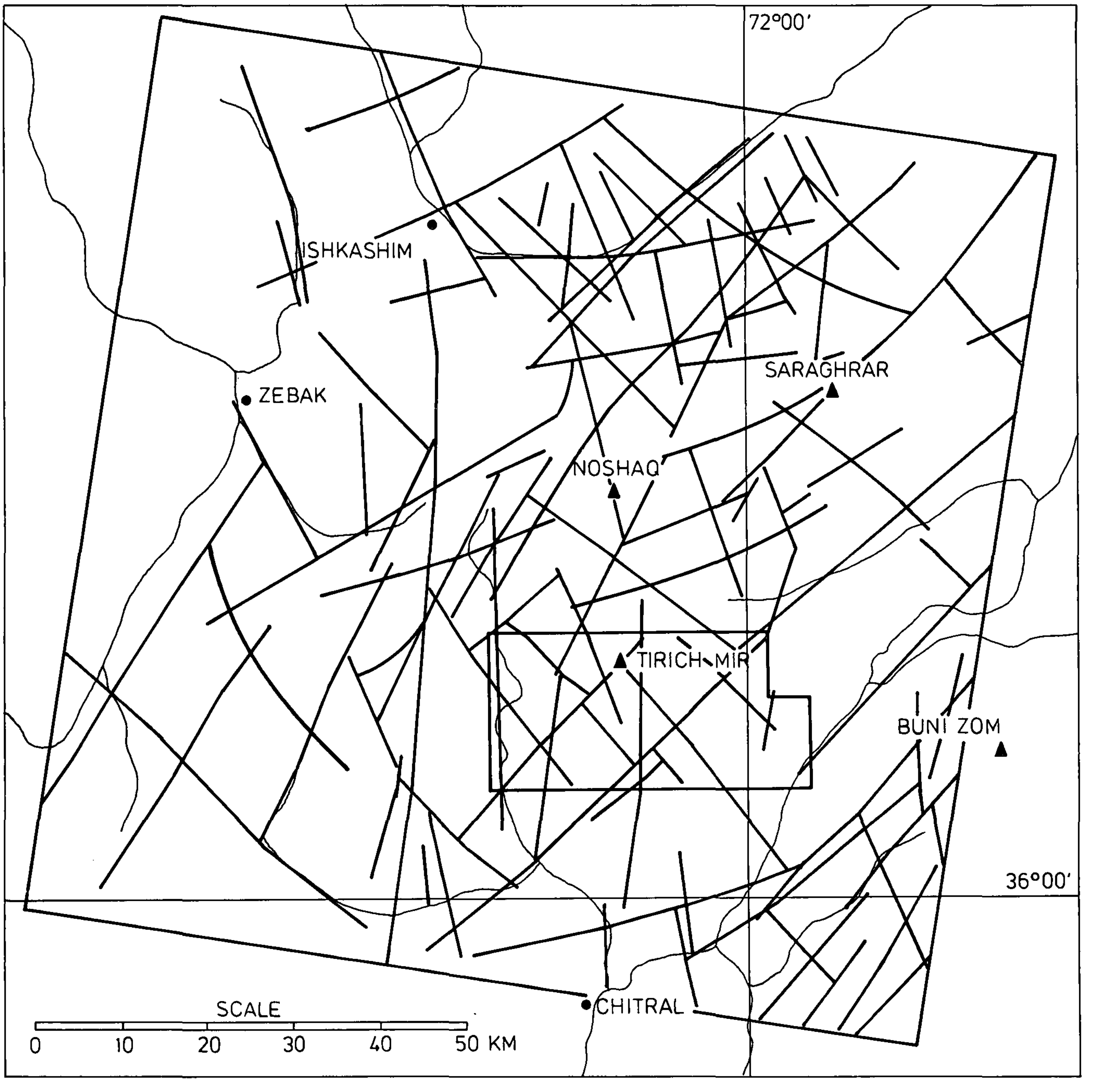

Fig. 8: Main faults of the Tirich Mir area and surroundings. Compilation based on field evidence and evaluation of Landsat MSS imagery. Explanation see text.

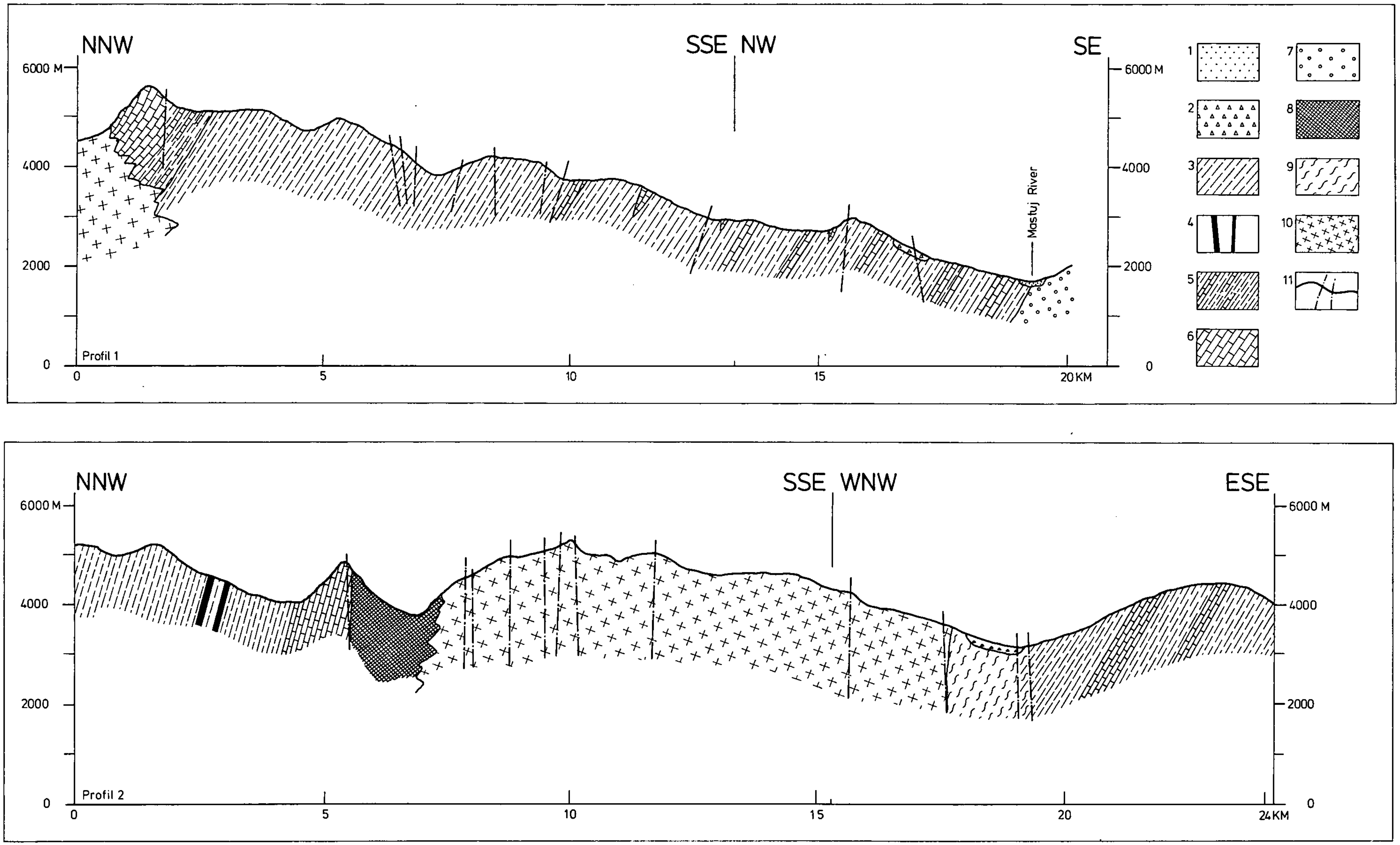

Fig. 9: Cross sections through the southern Tirich Mir Massif. For location see fig. 4.
1 = Alluvial; 2 = Prominent talus, scree; 3 = Wakhan Fm.; 4 = Quartzitic layer; 5 = Series of Owir; 6 = Atak Series; 7 = Reshun Conglomerate; 8 = Basic and ultrabasic rocks; 9 = Momi Gneiss; 10 = Tirich Mir Granite; 11 = Faults.

and the Awireth Series/Series of Owir, between the latter one and the Chitral Slates and the Golen Gol Series, further along the northern and southern boundary of and also within the Shishi Series. Along these tectonic zones overthrusts towards the Southeast and South have taken place. In central Chitral between the Reshun Formation and the Chitral Slates an overthrust has developed from a longitudinal fault in the southwestern Chitral District (DESIO, 1979).

The steep-dipping faulting tectonics of the greater Tirich Mir area is characterized by some major and several minor faults which trend subparallel and perpendicular to the general strike direction of the Hindu Kush range. A second conjugate fault system with N-S striking elements is less pronounced (fig. 8).

Field evidence shows good correspondence with the evaluation of tectonic lineaments in the Karakorum, Pamir and Hindu Kush region from Landsat MSS imagery (EBBLIN, 1976; BARTOLE, 1978). Figure 8 represents a more detailed lineament study of the area investigated (prepared by M. F. B.).

Regionally important longitudinal faults, which in particular occur along contact zones of rock inhomogeneities, e. g. the contact between limestones and slates, are also common within the series. Such faults, in Central Chitral, feature the mineralizations of Awireth, Krinj, Pakhturi, etc. Major cross faults are less frequent. A prominent cross fault runs along the (south-)eastern side of the Tirich Mir Massif, another smaller one cuts through the limestone belt in the upper Arkari Valley.

The occurrence of the Tirich Mir batholitic body, which discordantly intruded into the Upper Palaeozoic to Lower Mesozoic sedimentary series (fig. 9), is partly controlled by the pre-existent anticlinal structure and (re-activated?) distinct longitudinal or cross faults (cf. DESIO, 1976; EBBLIN, 1976, 1978; BARTOLE, 1978, fig. 4,8).

6. Metamorphism and Granitization

The metamorphism of the geosynclinal sequences in the central and northern part of the Chitral District is rather low and does not proceed beyond the lower greenschist facies. Most of the sedimentary series in this area have undergone only weak epimetamorphism, and no albitization can be detected with the naked eye. At a few places, e. g. in the middle Turkho and in the middle Arkari Valley, metamorphism has resulted in the formation of phyllitic slates, quartzites and crystalline limestones. The alteration of (greenish) volcanics resulted in greenish rocks of the lower greenschist facies.

From the Buni Zom area the growth of andalusite and cordierite in slates at the contact next to intrusive rocks has been observed (GAMERITH & KOLMER, 1973).

In the western and southern parts of the Chitral District metamorphism is considerably stronger. This can be observed in particular in areas of injected gneisses where the grade of metamorphism is that of the lower amphibolite facies. There exists a close relationship between the injection in wide areas with granitic-pegmatitic rocks and the grade of metamorphism of the adjacent country rocks. At several places it resulted in total granitization of the sedimentary series (GAMERITH & KOLMER, 1973; DESIO, 1979; GAMERITH, 1980).

Some geosynclinal series show a transition from a lower to a higher grade of metamorphism in strike direction. This applies, for instance, for the Arkari and Golen Gol Series. In other regions a gradual increase of metamorphism perpendicular to the strike direction can be observed, as for instance within the Series of Owir south of the Luthko Valley and for the Shishi Series where the increase of metamorphism is rather abrupt.

In the central Arkari Valley the slates show transitions to chloritoid-bearing phyllites and to muscovite-biotite-(garnet-tourmaline-)schists and eventually to gneisses. The limestones and calcareous slates gradually pass into coarse-grained crystalline limestones, marbles and calc-silicate rocks, the greenish volcanics into amphibolites. At some places also staurolithe and chiastolite bearing mica-schists, indicating thermo-metamorphism, have been mapped.

In areas of widespread occurrence of granite and pegmatite the metamorphic series are often migmatitic (block migmatites) or even completely granitized. The transition from micaschists to flasergneiss and of augengneiss to porphyric and coarse-grained granite-gneiss can be observed occasionally (Momi Gneiss).

It is not presently known whether within the course of the granitization a partial or complete anatexis of the rocks also took place. Possibly, the late- to post-tectonic pegmatite- granites of the heavily injected rock types are at least of palingenetic origin.

The geosynclinal series of Chitral in general and of the Tirich Mir area in particular have therefore undergone a low syntectonic (Kinematic) regional metamorphism of the lower greenschist facies in the course of the alpidic orogeny and a meso- to katathermal metamorphism of the lower amphibolite facies in connection with the late- to posttectonic intrusive activity. This metamorphism is directly connected with the Cretaceous to Tertiary orogenesis, and there are no indications of an older metamorphism (GAMERITH, 1980; cf. BUCHROITHNER & SCHARBERT, 1979 and BUCHROITHNER, 1980).

7. Mineral Deposits

From the metallogenetic point of view, it appears that base-metal mineralizations, which locally occur in Chitral, are directly related to mostly epi-hydrothermal solutions derived from the late magmatic activity. As a guidepath, these solutions favoured faults developed along rock inhomogeneities. This is particularly featured by the situation in Awireth and Krinj in Central Chitral.

The numerous and scattered tungsten occurrences and a few molybdenite outcrops, e. g. at Shah Jinali Gol, are of contact-metamorphic and contact-metasomatic origin.

With the exception of the scheelite mineralization, the Chitral District has already been prospected to an extent that allows to exclude the possibility for finding larger new deposits in addition to the ones already known and explored. The scarcity of larger mineral deposits, considering the widespread occurrence of late-magmatic intrusive bodies, can probably be attributed to the rather "dry" nature of the acid residual magma, for which a palingenetic origin is likely (GAMERITH, 1980). This origin corresponds with the scarcity of aplites and extensive pegmatite dykes with related pneumatolitic mineralizations.

The iron ore occurrences in the Buni Zom area are probably of sedimentary origin ("iron stone"). Some of them appear to have been upgraded by contact-metasomatic phenomena.

Scheelite showings in the area west of the Tirich Mir indicate that some source of tungsten contained in the scheelite mineralization is to be found in sedimentary-volcanogenic environments. Such a genesis would be in line with conceptions of origin of initially strata-bound scheelite deposits in Austria and elsewhere (TUFAR, 1980, 1981).

Occurrences of valuable minerals such as beryl in pegmatites are of no economic relevance (cf. FUCHS, MATURA & SCHERMANN, 1974; FUCHS & MATURA, 1976). The same is valid for the siderite finds (cf. BUCHROITHNER, 1980).

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