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Geological Observations in the Central Elburz, Iran

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With 41 figures in the text and 2 plates

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Abstract

The Alam Kuh uplift in the Central Elburz coincides with the oldest formations known in the whole Elburz range. Metamorphic rocks with quartzmonzonitic and granitic intrusions are overlain by unmetamorphic Cambro-Ordovician sediments. The latter initiate a miogeosyncline to shelf type sedimentation characteristic for the Elburz where, except for the Pre-Cambrian, eugeosynclinal deposits are not known. After the Pre-Cambrian orogenies mayor diastrophisms are missing until the late alpine orogeny. A Plio/Pleistocene morphogenetic uplift is responsible for the present mountain-range, which does not conform with the southwards increasing tectonic features extending beyond the Elburz chain.

Zusammenfassung

In der Alam Kuh Kulmination des Zentral-Elburz treten die ältesten Gesteine der ganzen Elburzkette auf. Auf metamorphe Ablagerungen mit quarzmonzonitischen und granitischen Intrusionen folgen unmetamorphe cambro/ordovizische Sedimente. Die letzteren leiten eine für den Elburz charakteristische Sedimentation von Miogeosynklinal- bis Shelfcharakter ein. Eugeosynklinale Ablagerungen sind ausser im Präkambrium im Elburz nicht nachgewiesen. Abgesehen von präkambrischen Orogenesen fehlen regionale Faltungsphasen bis zu dem spätalpinen Diastrophismus. Die heutigen Bergformen sind durch plio-pleistozäne morphogenetische Hebungen gebildet worden. Sie entsprechen aber den südwärts sich verstärkenden alpinen tektonischen Komplikationen in keiner Weise.

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A. Introduction

The central part of the 800 km-long chain of the Elburz culminates in a mountain group of alpine morphology known generally as the Takht i Sulaiman or, according to its highest peak of 4840 m, the Alam Kuh group. Only the quaternary volcano Dämavend with its 5670 m[1]) surpasses the Alam Kuh in hight, the latter being most probably the second highest and certainly the highest non-volcanic elevation in Iran, followed by the Savalan volcano in Azerbeidjan and the Zarde Kuh in the Zagros mountains. The Alam Kuh group contains the largest glaciers in Iran, still small compared to an alpine scale, but nevertheless of great glaciological interest. Other minor glaciers are known from the NE face of Dämavend, from the Savalan volcano and the Zarde Kuh.

In the Alam Kuh uplift the oldest fossiliferous formations of the Elburz range are exposed, transgressing still older metamorphic rocks, the latter intruded by quartz-monzonites and granites with outstanding thermal contacts.

In spite of this attractive geological setting, the culmination of the Elburz mountains had geologically been greatly neglected. Actually prior to the authors investigations it was hardly visited by geologists.

East of the Chalus road, crossing the Central Elburz in a NS direction, and connecting the Iranian capital with the Caspian Sea, the Elburz region was investigated by RIVIÈRE (1934) in a comprehensive stratigraphical and tectonical study. A later survey was carried out by geologists of the former Anglo Iranian Oil Co. in connection with a coal research for the Iranian government in the same area during the second world war, but unfortunately the results have so far not been published.

West of the Chalus road, separated by a steep gorge and wild forested cliffs lies the Takht i Sulaiman-Alam Kuh group. Through the merit of the Austrian geographer BOBEK, this group is now covered by a modern photogrammetric map of the scale 1 : 100 000, the result of tedious field work during the year 1934. Through this investigation, one of the least-known sectors of the Elburz mountains, where previously only highly inaccurate quarter-inch maps of the Survey of India existed, is covered by one of the best topographical maps of Iran. During his survey work BOBEK was able to carry out important morphological, glaciological and even some geological observations, and was the first to collect Ordovician fossils on the south side of the Alam Kuh. His findings were published in a preliminary paper (1937).

[1]) 5771 m according World Aeronautical Chart 1 : 1 000 000.

The outstanding alpine character of the Alam Kuh group has a certain touristic attraction, and in spite of its somewhat inaccessible position the mountains were visited on several occasions since the first ascent by BORNMÜLLER in 1902. Except for BOBEK's explorations no scientific investigations were, however, carried out.

The authors visited the Alam Kuh group for the first time during the month of August 1954 and carried out geological and petrological investigations of the northern approach and the main group. During the summer 1955 GANSSER, accompanied by the Iranian engineer FAKHRAY, made a traverse of the central Elburz following the Sehezar Valley from Sashawar on the Caspian, cossing the W side of the Alam Kuh group and continuing into the Taleghan valley to the S. Again, in October 1956 GANSSER, with engineer KALHOR, visited the S-central part of the Alam Kuh, entering the area from the N. All these investigations were made while working for the Iran Oil Co. partly during leave periods, partly during geological reconnaissance. For the permission to publish these results the authors are indebted to the Managing Directors of the Iranian Oil Company.

During our field investigations we prepared our own reconnaissance maps, which were partly based on aerial photographs. Only after this field work did we obtain the excellent topographical map by BOBEK, to which our photogeological sketches where adjusted together with the respective field observations. This adjustment was necessary owing to the great distortions of the photographs caused by the marked changes in elevation (1000—4800 m). The geological and petrological information presented in this paper is based on our own observations only. For regional deductions we were drawing on the geological results from published information and unpublished studies by our colleagues as well as our own. The recent publication by STÖCKLIN (1959) on a cross-section through the eastern Elburz gives an excellent account of the new ideas regarding the stratigraphy and tectonics of that part of the range. Up to now it is the only modern paper dealing with the Elburz in this respect. New regional information on Iran was published with the new geological map of Iran by the geologists of the Iranian Oil Co., to which publication an up-to-date bibliography is attached (1959).

Dr. KÜNDIG has read the manuscript and the authors thank him for his corrections and constructive criticism.

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B. The Regional Geology of the Central Elburz

From the N to the S the Central Elburz can be subdivided into the following main structural and stratigraphical elements (Fig. 1).

1. The Caspian Plain.
2. The northern Mesozoic borderzone rising southwards and merging into 3.
3. The Paleozoic Central Range thrusted against 4.
4. The Tertiary Central Zone.
5. The Southern Paleozoic/Mesozoic Zone.
6. The Southern Tertiary Zone.
7. The Southern Frontal Depression.

This regional subdivision, for the units of which local names have been purposely avoided, holds only for the central part of the Elburz range. Owing to the oblique strike of most major tectonic features and the arching of the Elburz mountains as a whole, some of the existing central elements disappear westwards and eastwards and new features set in. In a general way, the western Elburz becomes less complex while new Caspian elements set in in a eastern direction. In the Elburz mountains all geological stages are represented, from the Pre-Cambrian to the Quaternary, the latter still strongly affected by the youngest orogeny. Except for the Alam Kuh mountains, the E Elburz and NW Elburz, metamorphic and intrusive rocks are generally rare. Shelf-type sediments represent the bulk of the marine deposits.

1. The Caspian Plain

The Caspian Plain, including the southern shorezone of the Caspian sea, comprises a Tertiary area which gradually rises towards the east and forms the foothill structures E of Chalus. Further E they are bordered to the north by a new major element, the Nika Uplift, forming a broad gentle spur, with Pre-Devonian cristalline schists (Gorgan schists) transgressed eastwards by successively older formations (Upper Jurassic to Devonian) (Stöcklin, 1959). This Nika Spur projects WNW-wards into the Caspian, and the younger transgressions over the old core are most significant for a possible structural interpretation of the southern Caspian basin. Together with the peculiar divergence of the western Kopet Dagh from NW, into a SW and even S direction and the regional gravity rise from the Elburz foothills northward into the Caspian, they may indicate the presence of a more resistent hidden mass occupying the present southern Caspian sea. Only in Post-Eocene time did the actual Caspian basin form, and, considering the thick marine Quaternary deposits, it is still subsiding though recent fluctuations with regional rises are well known. Such an interpretation would conform to the relatively gentle tectonic features exposed in the northern foothills of the Elburz chain, which contrast strikingly with the intricate and accentuated tectonics of the southern border.

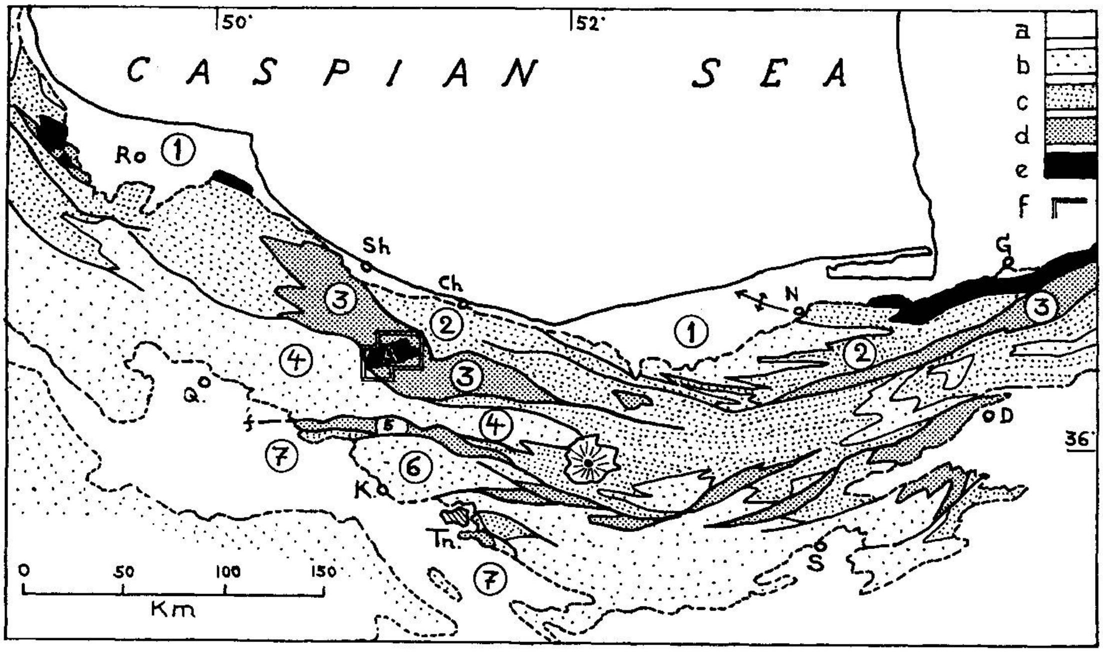

Fig. 1. Geological sketch map of the Central Elburz.

a	Alluvial regions	A	Alam Kuh Uplift	Q	Qazvin
b	Tertiary	Ch	Chalus	R	Resht
c	Mesozoic	D	Damghan	S	Semnan
d	Paleozoic	G	Gorgan	Sh	Shahsawar
e	Pre-Paleozoic	N	Nika	Tn	Teheran
f	Mapped area shown on table I	K	Karadj		

Numbers in circles correspond to subdivisions listed under chapter B (p. 587)

2. The Northern Mesozoic Borderzone

In the Central Elburz, where the Tertiary structures are mostly burried under the Caspian alluvial plain, the northern foothills consist predominantly of Mesozoic limestone structures. Only locally occur young Tertiary to Quaternary conglomerate zones. In spite of the abrupt morphological aspect of the northern foothills, the structures form gentle anticlines, with broad flanks dipping northwards into the plain (Chalus area). They mostly consist of Upper Jurassic to Lower-Middle Cretaceous limestones, which form a comprehensive rock sequence. Local longitudinal faulting does sharpen the contrast between the alluvial plains and the densely wooded foothills (Chalus-Amol). In the investigated cross-section of the Sehezar Rud the Mesozoic foothill structures are poorly exposed, but they rise to the E, forming broad anticlines towards the Chalus river. Southwards and mountainwards successively older formations crop out (Lower Jurassic and Triassic), which in the Sehezar cross-section were not clearly recognized. At the village of Ashmahalleh (northern Sehezar valley) a sudden change occurs. A steeply N dipping white marmorised limestone covers a zone of complex, highly altered volcanic rocks (altered tuff, tuffbreccias, diabasic rocks veined with epidote and calcite) which already belong to the complex Paleozoic Central Range.

3. The Paleozoic Central Range

This main structural element of the Elburz range has already been recognized by RIVIÈRE and its importance was stressed by STÖCKLIN (1959). The Paleozoic Central Range has formed an important barrier since the Upper Cretaceous, and was well outlined in the Tertiary (GANSSER, 1955). The present watershed lies mostly S of it. In the Central Elburz the best exposures are found in the Chalus-gorges to the E of our area. Since RIVIÈRE (1934) no account has been published of this section, though many geologists have passed through its deep gorges. A systematic study of the numerous fossil horizons and new determinations of the faunas in connection with careful structural investigations s urgentlyi needed. An investigation on these lines by the Geological Institute of the ETH Zürich is planned for 1962.

The Paleozoic formations exposed in the Chalus section, the oldest of which consists of green siliceous slates of the Pre-Devonian, rise westwards to the regional culmination of the Alam Kuh group. This culmination is already apparent in the northern Sehazar valley, as well as in the Sardabrud valley N of the Alam Kuh mountains, where older formations, unknown in the Chalus section to the E, are exposed below the Devonian.

The northwards-directed steep thrusts within the Paleozoic, well exposed in Chalus gorge, are less evident in the western section, though a northwards-directed imbrication structure is still recognizable, particularly in the more central zones. This north vergence of the structural elements changes southwards of the main Central Range, where a steep south-directed thrust borders the Tertiary formations.

The Pre-Devonian formations of the wider Alam Kuh area form highly fractured broad uplifts in the more northern part, changing into more schuppen-like elements further to the south. These features are well exposed in the Sehezar Valley, while in the Alam Kuh mountain batholitic intrusions introduce a new structural element, but still with a consistent north directed fracture system. The Pre-Devonian sedimentary uplifts show a regional, though slight metamorphism and their fracture system is accentuated by a dense dike and sill network of diabasic composition. Metamorphism is completely lacking in the southern Predevonian formations where Ordovician fossils occur.

4. The Tertiary Central Zone

The Tertiary Central Zone is particularly well developed south of the Alam Kuh uplift. The predominantly pyroclastic sediments with its dikes, sills and flows have never passed the Paleozoic Central Range, which formed a conspicuous barrier. They also are unknown in the central Caspian region. They mainly consist of marine tuffs of lower Oligocene and Eocene age, which are intensely folded and faulted. The structural elements are south directed, contrasting with the northern trend of the Paleozoic Central Zones. Along marked longitudinal fault zones occur synclinally arranged clastic Miocene sediments in westwards-deepening graben-like belts. The coarse, reddish basal conglomerates indicate a near shore facies of the Miocene formations, which were deposited on a strongly eroded lower Tertiary surface. Bordered by the southern Paleozoic and Mesozoic zone the Central Tertiary Zone narrows towards the E, and the Miocene belts pinch out.

5. The Southern Paleozoic-Mesozoic Zone

This zone is well exposed south of the Chalus pass in the upper Karadj valley, just ESE of our area of interest. It strikes WSW and dips regionally towards the NW, with older sediments gradually coming in from the south. Known are upper to middle Cretaceous limestones transgressing on Upper to Middle Jurassic, which overlie coal-bearing Lower Jurassic, a thin Triassic belt, Permocarboniferous limestones and shales and a thick Devonian section with clastic red beds in its lower part. Of special interest are Pre-Devonian formations below the Devonian quartzites, consisting of fetid smelling dolomites with black and red shales and a large complex of greenish schists. Dike intrusions of basic porphyrites and diabases are frequent. They do not enter the Upper Devonian. The sediments are hardly metamorphosed and resemble somewhat the Ordovician of the Alam Kuh, but so far yielded unfortunately no fossils. These oldest formations are steeply thrust over the southwards adjacent Southern Tertiary Zone. This region is at present being investigated by members of the Geological Institute of the ETH Zürich with interesting new results to be published in the near future.

Since the WSW-ENE strike of this zone is oblique to the southern Elburz front, the southern Paleozoic-Mesozoic Zone leaves the Elburz range and is cut off by the southern depression near Ab i Yek between Karadj and Qazvin. It parallels the thrust zone of the Tertiary over the Plio-Pleistocene Teheran fans.

6. The Southern Tertiary Zone

It resembles the Central Tertiary Zone and comprises similar pyroclastic sediments and volcanic activity. Of special interest are large sills of monzonite, one of which forms the site of the large Karadj power dam. The folding is very similar to the one of the more northern zone. A marked south directed thrust brings this Lower Tertiary in contact with uptilted Plio-Pleistocene clastic deposits of the Teheran region.

7. The southern Frontal Depression

This depression is bordered in the north by the steep thrust of the Southern Tertiary Zone. Plio-Pleistocene and Recent fan deposits fill this depression, under which strongly folded and faulted older formations continue southwards. Some of the latter rise in complex wedges in an easterly direction. This frontal depression delineates the southern morphological border of the Elburz range, yet does not coincide with its tectonical south border. The intense orogeny, increasing southward and represented in eastern uplifts such as RIVIÈRE's Anti Elburz (RIVIÈRE, 1936), and the wedge with Paleozoic rocks south of Teheran (RIEBEN, 1955) weld the Elburz mountains into the complex orogeny of Central Iran (GANSSER, 1955). In the eastern Elburz, this fact has been clearly stressed in the recent study by STÖCKLIN (1959).

Within the Elburz mountains the degree of deformation increases rather than decreases in a southern direction. The gentle folds of the northern foothills contrast strongly with the complex imbrications of the southern border.

After this regional picture we may now procede to discuss the main culmination of the Elburz chain, the Alam Kuh region, the main purpose of this paper.

C. The Geology of the Alam Kuh Culmination

Within the Paleozoic Central Range of the Central Elburz occurs the Alam Kuh (Takth i Sulaiman) Group which exposes the oldest formations of the Elburz chain together with conspicuous granitic batholite intrusions. This region is covered by the enclosed geological sketch map (Plate I) to which we refer in the following description.

The oldest outcrops consist of complex metamorphics intruded by granitic and monzonitic rocks. They border, with a tectonical contact, coupled with a marked change in metamorphism, non metamorphic or only slightly metamorphic sedimentary deposits of Cambrian to Permian age. These can be divided into Cambro-Ordovician and Devonian to Permocarboniferous sediments.

I. The metamorphic and igneous rocks of the Alam Kuh

Their distribution is shown on the attached sketch map, Plate I. Our limited field investigations left many problems unsolved; in particular the areal extent and the contact relations with the younger sedimentary deposits. This is particularly true for the eastern extension and the relation with the thick Paleozoic sediments of the Chalus section. It is hoped to include this key area in a forthcoming investigation of the Upper Chalus valley.

a) THE METAMORPHIC ROCKS

They can be subdivided into the following units:

1. The Barir formation (Fig. 2)

These steeply-dipping, metamorphic, bedded rocks are well exposed in the valley of Barir in a thickness of over 1000 m between the Akapol quartz-monzonite and the marbles (see below). They strike SW-NE and are more or less parallel to the larvikitic rim of the batholite. At Barir, the metamorphic rocks are quartzites, medium-to coarse-grained, white and gray marbles and fine-grained biotite-hornfels-schists. The metamorphism of these rocks is most probably older than the intrusion of the Akapol quartz-monzonite. Similar to the Barir formation are the metamorphic rocks of the Naft e Chal valley, on the south side of the Akapol quartz-monzonite. They strike WSW-ENE and dip to the SSE and are intruded by apophyses of the Akapol quartz-monzonite and by NNE SSW striking dikes of a dioritic and granite-porphyric nature (Fig. 3).

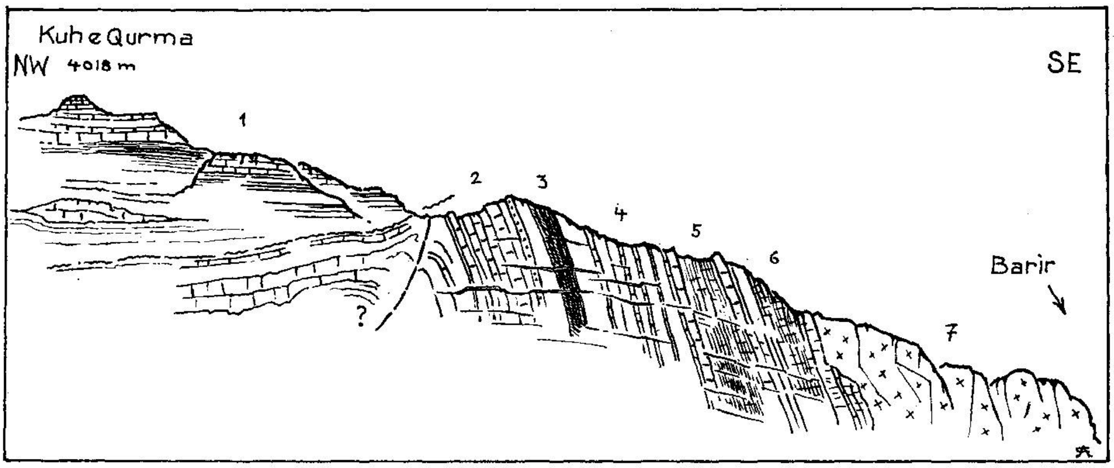

Fig. 2. The Barir Formation and its relation to the Paleozoic of Kuh e Qurma.

1 Paleozoic, predominantly Devonian
2 White marbles
3 Reddish slates and quartzites
4 Banded siliceous shales and marbles
5 Yellowish calc-schists and marbles
6 White banded marbles
7 Quartz-monzonites (Akapol type)

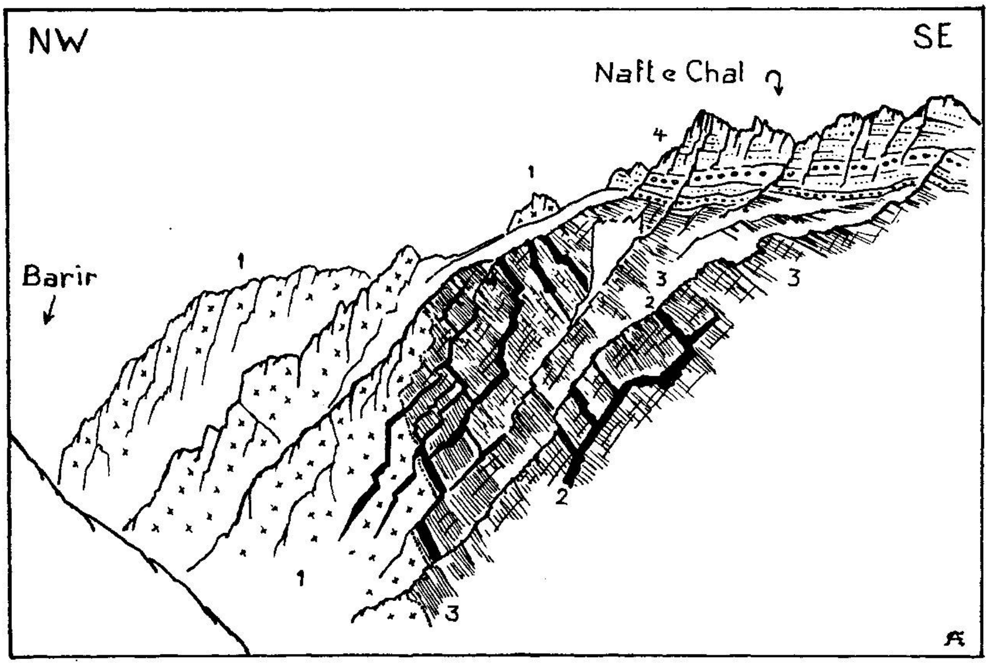

Fig. 3. The contact of quartz monzonite and marbles N of Naft e Chal.

1 Quartz-monzonite of Akapol
2 Basic dikes and sills (diabases and dolerites) cutting through monzonite and marbles.
3 Marble zone
4 The clastic deposits of Naft e Chal

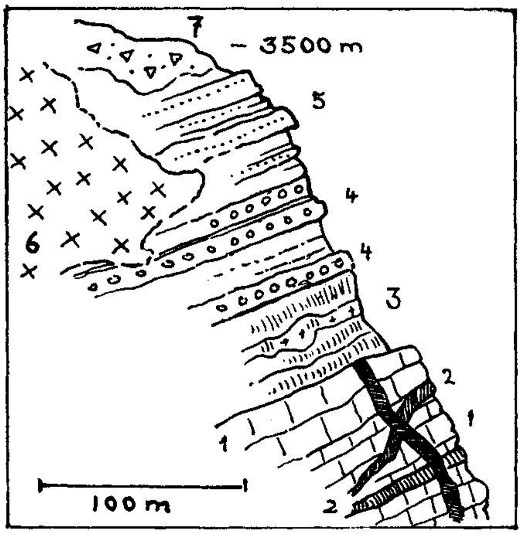

Fig. 4. The clastic Naft e Chal deposits on white marbles. Lower Naft e Chal valley.

1 White marbles
2 Basic dikes. They do not enter the Naft e Chal clastics
3 Altered tuffaceous deposits
4 Conglomerates
5 Quartzites
6 Quartz-monzonite of Akapol
7 Moraines

The sequence of Naft e Chal consists, from bottom to top of (Fig. 4):

a. Marbles, intruded by diabasic dikes (see below).
b. Biotite-sericite schists, slightly carbonaceous and containing larger quartz grains and occasional aktinolitic hornblende granoblasts.

These larger elements occur in a fine-grained quartz, sericite and chlorite matrix.

c. A zone of harder, pebbly to gritty quartz conglomerates. The quartz pebbles have diameters of 5 to 20 mm and are made up of xenoblastic, clear quartz cristals. The pebbles are subrounded by and imbedded in a matrix of finely-granoblastic quartz, sericite and chlorite, with occasional sphene and magnetite grains. The conglomerate forms a more competent ledge in the valley and is strongly and densely striated by glacial action and carved into roches moutonnées.

d. Above the dark conglomerates follow spotted phlogopite-sericite-albite schists of lepidogranoblastic texture, which most probably are derived from siltstones or graywackes. These darker schists make up the prominent summit, 4490 m, N of Chalan, and may partly pass into the more massive metamorphic tuffs? of Siahkaman.

2. The marbles

Besides the bedded marbles in the Barir formation, larger complexes of massive, yellow-gray-weathering, white or bluish marbles make up the base of the Kuh e Qurma, the slopes and east summits in the lower Sardabrud valley and the NE slope of Kalijeram. These carbonate rocks are most probably also of Pre-Ordovician age and unconformably covered by massive dolomites? S of Kuh e Qurma, which are followed by Paleozoic (Devono-Carboniferous?) sandstones and shales. W of Naft e Chal, similar marbles are overlain by schists and conglomerates (see above). Many diabase dikes have intruded the marbles NW of Barir and NE of Kalijeram along an old fracture pattern. These basic dikes are however not related to the Akapol quartz-monzonite and are younger than its intrusion.

3. The metamorphic tuffs and basic hornfelses

On the Siahkaman ridge (E of Alam Kuh) and again NE of Kalijeram, massive, splintery, dark, fine-grained, metamorphic rocks were observed, the origin of which is difficult to determine. Thin sections show partly hornfelsic structures, with xenoblastic quartz, albite?, biotite, zoisite to epidote and tourmaline crystals and larger, accessory magnetite grains. These basic hornfelses are in contact and partly mixed with coarser-grained, heterogenous, porphyritic, metamorphosed tuffaceous rocks in which pseudomorphs of plagioclase occuring in a fine-grained quartz-feldspatic-chloritic groundmass or matrix, and containing abundant iron ore grains, are still recognizable.

4. The calc-schists and lime-silica rocks S of Kalijeram (Fig. 5)

At Kalijeram, the more or less pure, massive N-dipping marbles are underlain by, or partly change along strike into, calc-schists, which are also intruded by apophyses of the Alam Kuh granite. The calc-schists and calc-silica rocks continue SSE-ward into the rock spur East of Takht i Sulaiman.

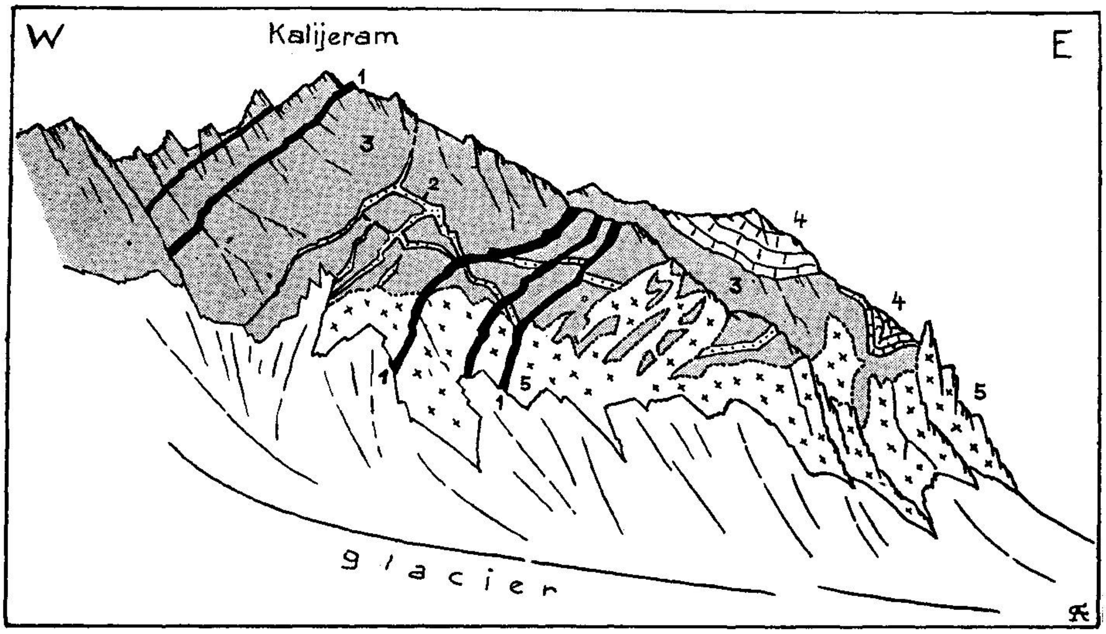

Fig. 5. The intrusive contact of the Alam Kuh granite at Kalijeram.

1 Diabase and Dolerite dikes. Younger than granite
2 Aplitic dikes. Older than the granite
3 Barir formation, undifferentiated, incl. lime-silica rocks
4 Banded marbles
5 Alam Kuh granite

Along the small, aplitic dikes and granite apophyses S of Kalijeram the calc-schists and marbles are recrystallized, white or lighter-coloured and of coarser grain structure. This zone of contact-metamorphism and recrystallisation is however only 5 to 20 cm wide (Fig. 6, 7). The metamorphism of these sediments must be older than the intrusion of the

Fig. 6. Quartz-porphyry dike cutting lime-silicate layers and basic sills in Barir formation at Kalijeram, just above granite contact. Note bleached border along dike. (For detail see Fig. 7.)

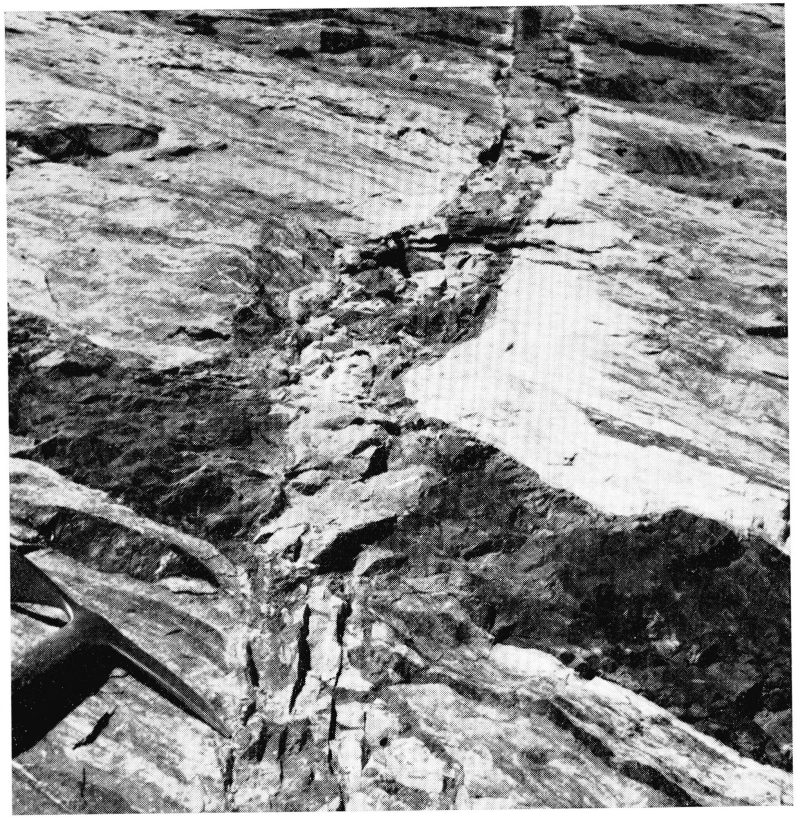

Fig. 7. Quartz-porphyry dike cutting through diabasic sill in lime-silicate layers of Barir formation. Note bleaching of lime-silicate schists along contact with dike. (Detail of Fig. 6.)

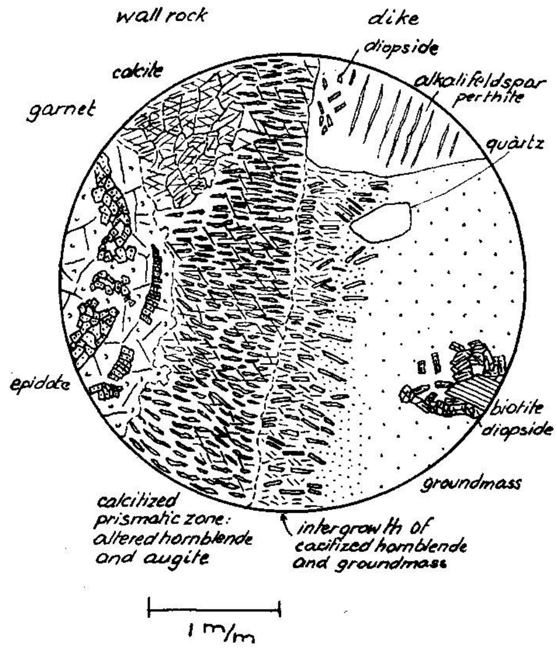

Fig. 8. Contact of quartz-porphyry with lime-silica rocks from Barir formation at Kalijeram.

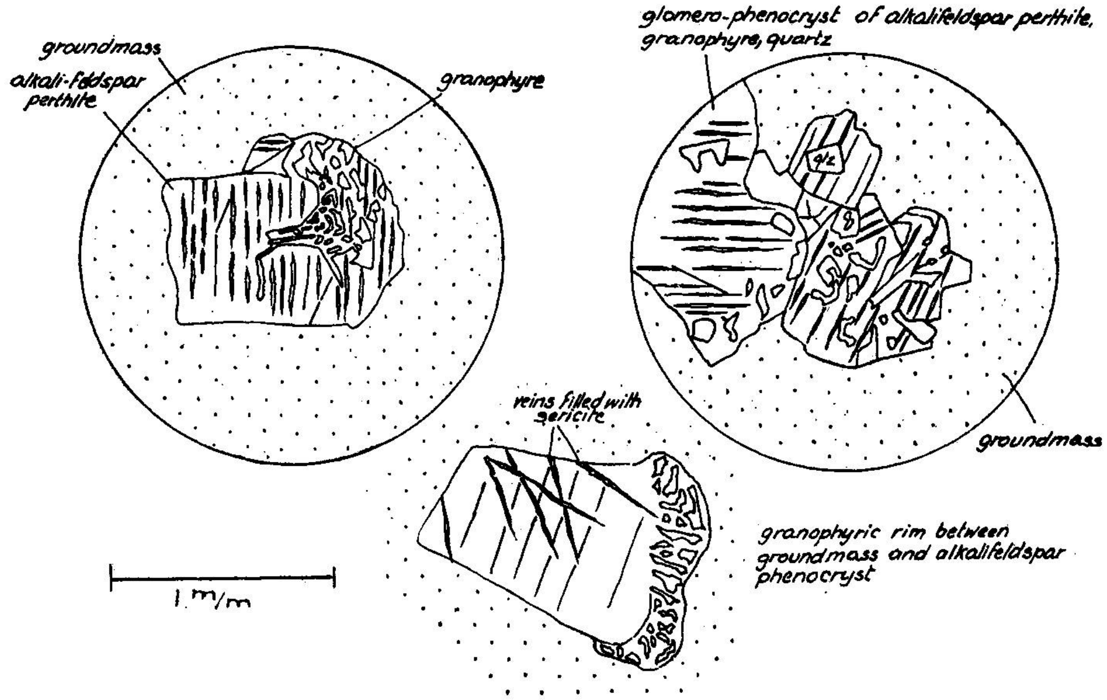

Fig. 9. Details from quartz-porphyry dike in Barir lime-silicate rocks at Kalijeram.

apophyses and aplitic dikes. In the contact zone of a quartz-porphyry dike, with alkalifeldspar-perthite and granophyric quartz phenocrysts, the following succession could be observed (Fig. 8, 9):

a. Groundmass of dike. Near the contact, the biotite-phenocrysts are partly surrounded by diopside crystals.
b. Along contact: intergrowth of calcitized hornblende and augite rim.
c. In wall rock: prismatic contact zone of hornblende and augite.
d. Epidote rim.
e. Coarse-grained garnet and calcite.

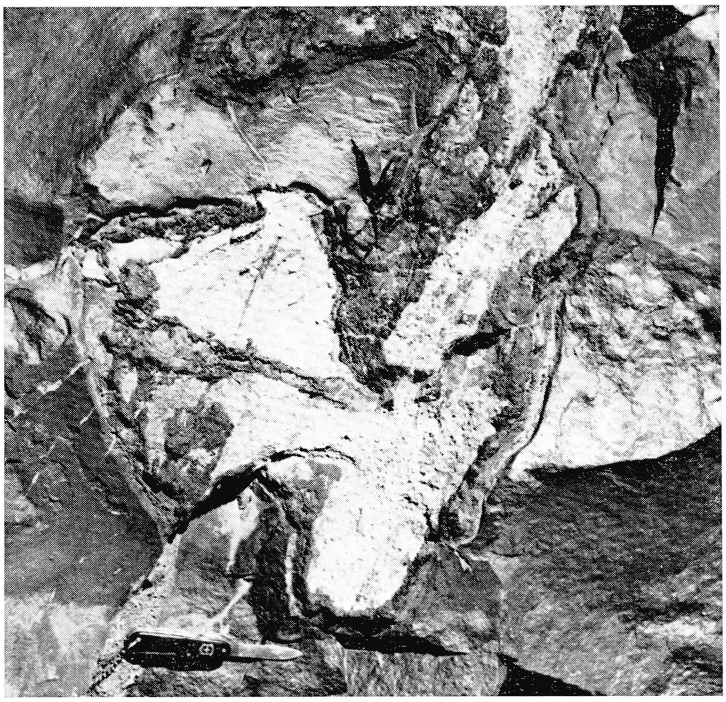

Fig. 10. Lime-silicate lenses in basic sills within Barir formation, near granite contact, Kalijeram.

Besides calcite-garnet rocks, epidote marbles, diopside-vesuvianite-garnet marbles and schists, containing garnet, epidot, diopsid and occasional vesuvianite could be observed. The calc-silica minerals are partly recrystallized along tension fissures, partly they are present as clear porphyroblasts (Fig. 10, 11).

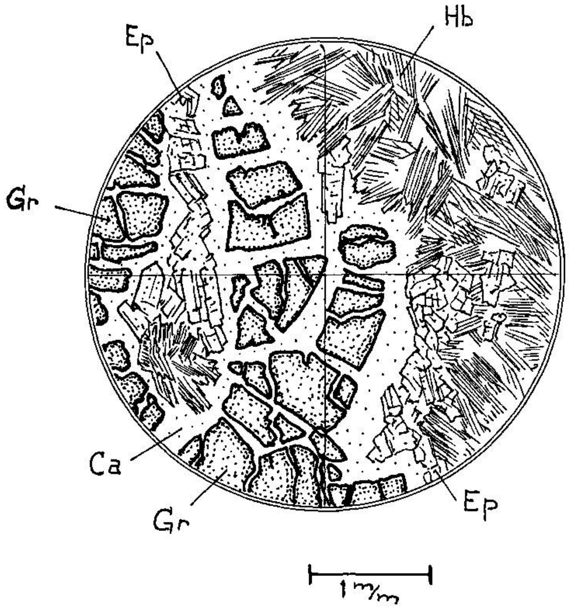

Fig. 11. Lime-silicate zone in Barir formation near granite contact N of Alam Kuh.

Hbl. = actinolitic blue-green hornblende
Ep = Fe-rich epidote
Ca = large calcite crystals
Gr = yellow-green lime garnet (Andradite)

b) THE INTRUSIVE ROCKS AND ASSOCIATED DIKES

1. The Akapol quartz-monzonite

Good exposures of this massive, medium- to coarse-grained plutonic rock are observed along the Sardab Rud valley between N of Akapol and S of Vanderaban. The batholite is limited by faults W of Barir and on the SE side (Fig. 12).

N of Akapol and between Vanderaban and Barir, a coarse-grained border facies of larvikite was observed. This leucokrate perthitic alkalifeldspar-oligoclase (albite) rock contains large, yellow, idiomorphic crystals of sphene and green alkali augite (Fig. 13).

The quartz-monzonite of Akapol contains besides alkalifeldspar and oligoclase, hornblende and biotite as femic minerals, and apatite, sphene and some iron ore as accessory minerals.

In the lower Naft e Chal valley, darker "schlieren" in this quartz-monzonite have a hornblende-gabbro-dioritic composition.

Besides aplitic veins the Akapol quartz-monzonite contains numerous basic dikes of lamprophyric nature. Between the massive monzonite wall rocks, the softer dikes have been tectonized almost beyond recognition and are now highly schistose biotite rocks. Probably these dikes were originally kersantitic lamprophyres. W of Naft e Chal, a basic dike in spotted schists and quartzites is holocrystalline and of gabbro-dioritic nature, containing andesine, green hornblende, accessory quartz, large

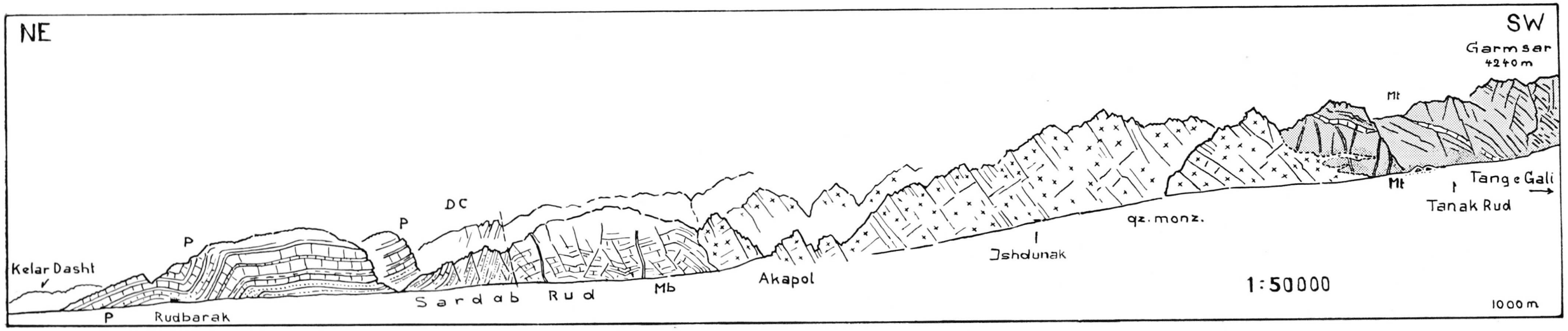

Fig. 12. Composite geological section along the Sardab Rud valley.

P = Mostly Permian limestones of Rudbarak
DC = Devonian, may include some Lower Carboniferous
Mb = Marble zone with diabase dikes, borders Akapol quartz-monzonite
Mt = Metamorphic Barir zone including green shists

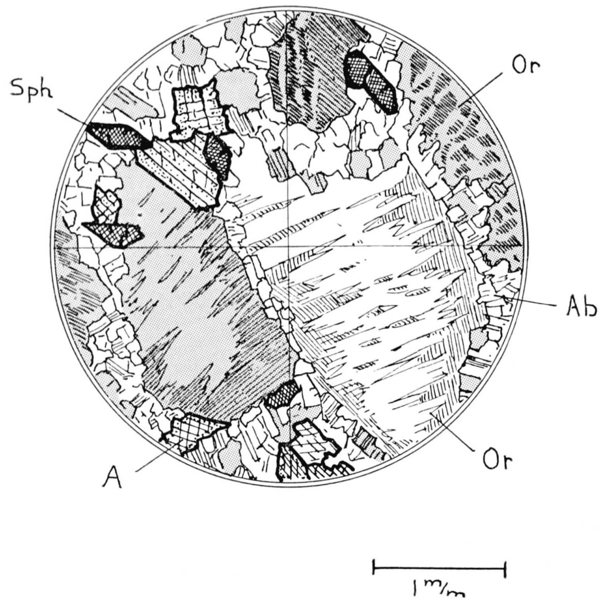

Fig. 13. Larvikitic border facies of quartz-monzonite. Akapol batholite.

Or = alkalifeldspar perthite-checkerboard albite
Ab = rim of small albites around larger alkalifeldspars
A = green alkali augite
Sph = idiomorphic sphene

sphene and apatite crystals. It closely resembles the dark schlieren in the Akapol monzonite.

Surrounding the Akapol quartz-monzonite occur a great number of predominantly diabasic dikes. They are particularly frequent in the marble zone and concentrated in clusters without any marked prevalent direction. Large dike swarms of diabase composition are visible north and east of Barir and again northeast of Kalijeram. Other swarms, visible on the air photos, occur north of Shahrezamin and south of Kandechai, again in the marble zone. Acid dikes, in a strictly parallel pattern cut the metamorphics between Naft e Chal and the Khurramdasht valley. They show the same NNE strike as similar dikes W of the Alam Kuh granite NE of Barur. Dikes are often associated with sills, both interconnected and of the same age and composition (Fig. 3, 5).

The diabase dikes are younger than the lamprophyres and the aplites of the Akapol quartz-monzonite. The latter are strictly related to the batholites, while the younger diabases are in no direct connection with the main batholitic intrusion.

2. The Alam Kuh granite (Fig. 14, 15)

The Alam Kuh granite forms the high summits of Takht i Sulaiman (4620 m) and Alam Kuh (4840 m) and the high, serrated crest W of the Alam Kuh surrounding the cirque of the NW Alam Kuh glacier. Apophyses of this granite batholite extend NW along the valley floor towards Barur and along the NW-striking crest towards the upper Sehezar Rud valley (Fig. 16). Huge, fresh blocks of the granite were observed in the moraine of the NE Alam Kuh glacier (Fig. 17).

The Takht-i-Sulaiman is formed by a somewhat coarser-grained, partly porphyry-like biotite-granite variety (Fig. 18, 19), whereas the steep N-wall of the Alam Kuh is a leucocrate, massive alkaligranite, consisting predominantly of perthitic alkalifeldspar, intergrown with clear quartz grains with a slightly undulating extinction. The feldspar is partly transformed into chequerboard albite and contains clear albite rims and inclusions. The average grain size is 2 to 3 mm. The only femic mineral is biotite, which is partly chloritized. Needle zeolites, calcite and zoisite were encountered as secondary minerals. As accessory minerals, sphene, iron ore and occasional apatite and zircon were observed (Fig. 20, 21).

In open tension fissures, free-growing adularia, smoky quartz, pink, fluorite and chlorite were observed, an assemblage which closely resembles

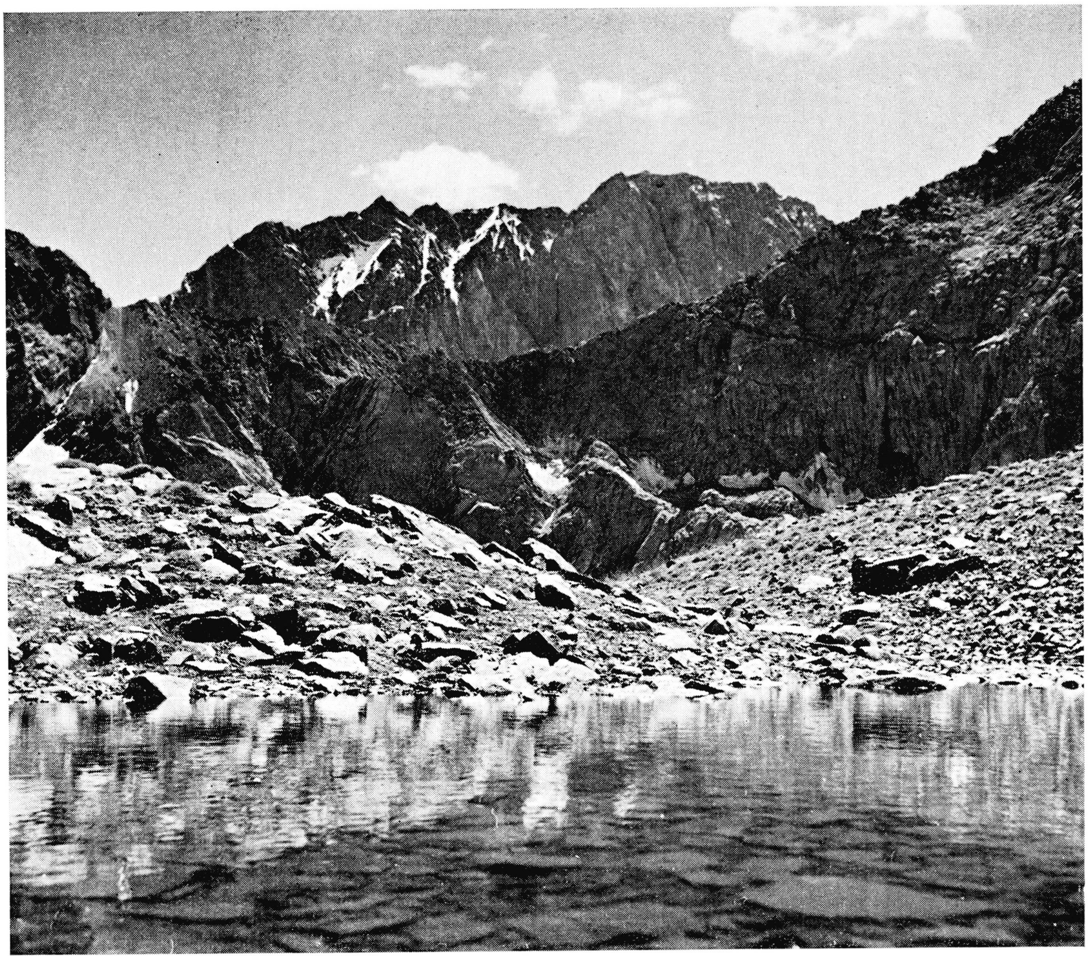

Fig. 14. The Alam Kuh group seen from the moraines NE Takht i Sulaiman. E-dipping intrusive granite contact against metamorphics visible also on left side of ridge in foreground. View towards S.

the minerals found in the fissures of the Central Aar granite (Switzerland).

Besides widespread aplitic dikes, rich in tourmaline and fine-grained, granophyric veins, outwardly resembling luxullianites (Fig. 22), several quartz-porphyry and sericitic, tectonized quartz-porphyrite as well as diabase dikes were observed on the south crest of Takht i Sulaiman. These dikes are well exposed along the sharp south ridge of the Takth i Sulaiman, where they strike in a EW direction. They cut sharply through the granite and are surprisingly little affected by subsequent tectonic movements. Predominant are fine-grained hornblende (biotite) diabases with a fine ophitic texture (Fig. 23). Less frequently occur muscovite-

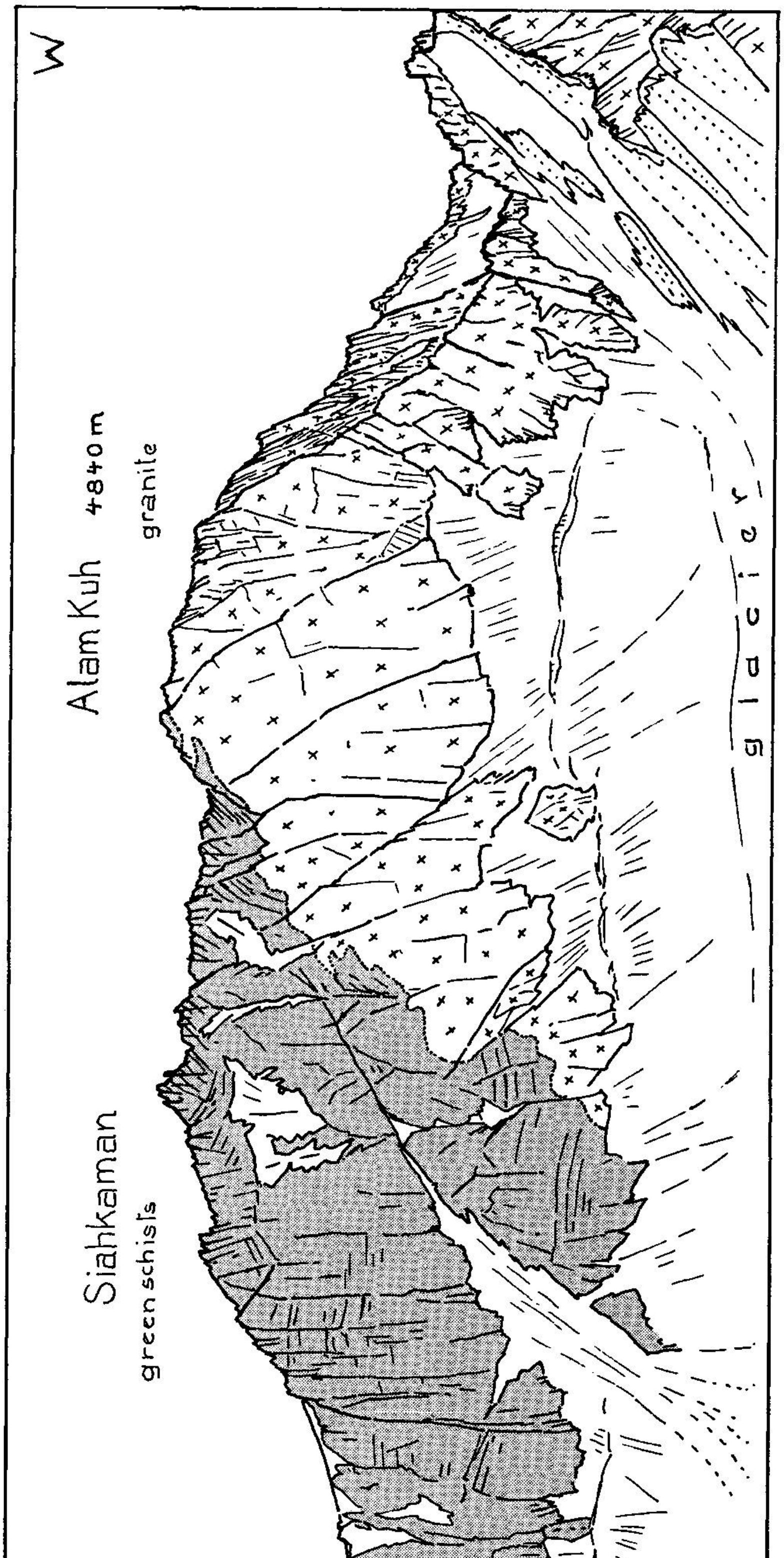

Fig. 15. The Alam Kuh, seen from the north.
Intrusion of Alam Kuh granite into Pre-Cambrian green schists and hornfelses with marbles of Siahkamen.

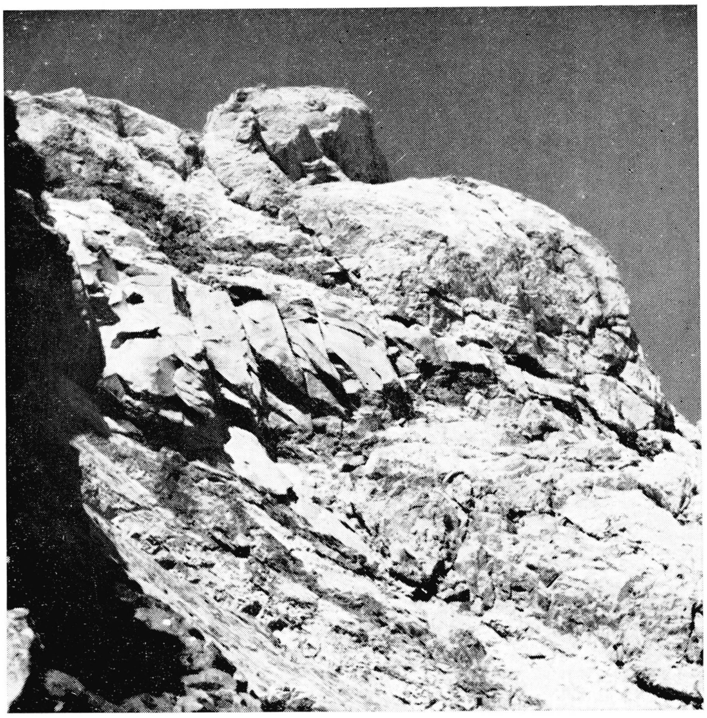

Fig. 16. Intrusive contact of Alam Kuh granite with Barir formation at Kalijeram. Note fracture cleavage in granite apophyse.

bearing quartz-porphyrites and somewhat more basic biotite-porphyrites. Of particular interest is a dike resembling a hornblende-dolerite. In a cryptocrystalline matrix, which still contains a great amount of slightly altered glass, occur idiomorphic acid andesines, basaltic hornblende and magnetite crystals (Fig. 24). This dike resembles somewhat a hemicrystalline rock in the Carboniferous in the southern Hezarcham (see below), except for its feldspars.

South of the Alam Kuh granite occur other dikes within the Cambro-Ordovician and the Carboniferous. They resemble the already-mentioned dikes from the Alam Kuh granite, and, most probably, they have the same age. They are certainly younger than the Lower Carboniferous, but most of them are probably older than the Permian.

South of the Hezarchal basin and E of Pt. 4400 m outcrops a most peculiar dike, which is striking by its green glassy luster. Within a still completely glassy groundmass occur idiomorphic crystals of a sanidinic alkalifeldspar with a rather small axial angle (Fig. 25). The sanidines are surrounded by a darker microgranular zone of olivegreen glass, while the main mass consists of a ligter greenish glass without any recognizable

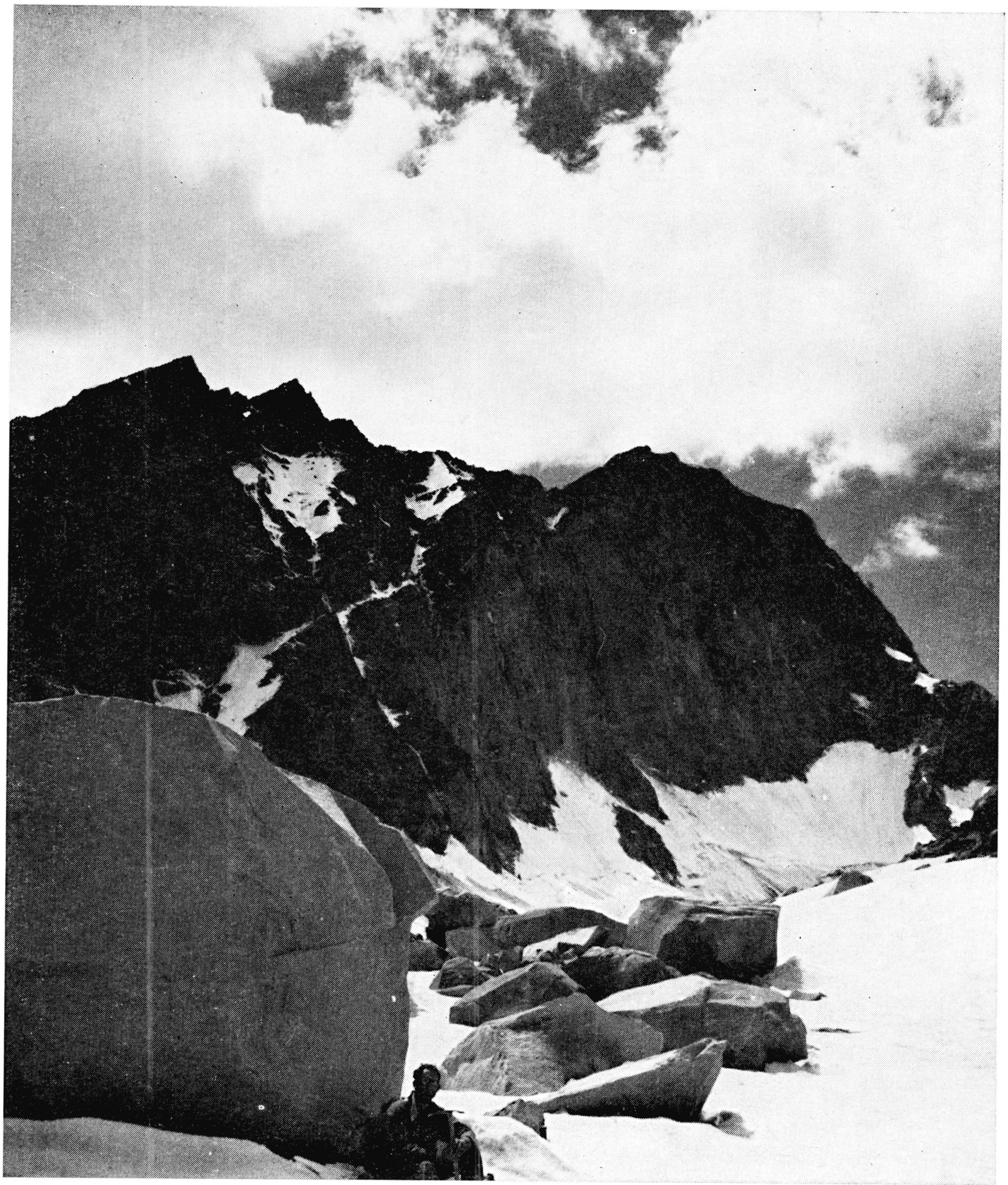

Fig. 17. The NNE wall of Alam Kuh seen from the NE. Visible intrusive contact of granite with green schists. In foreground aplitic alkaligranite boulders on north Alam Kuh glacier.

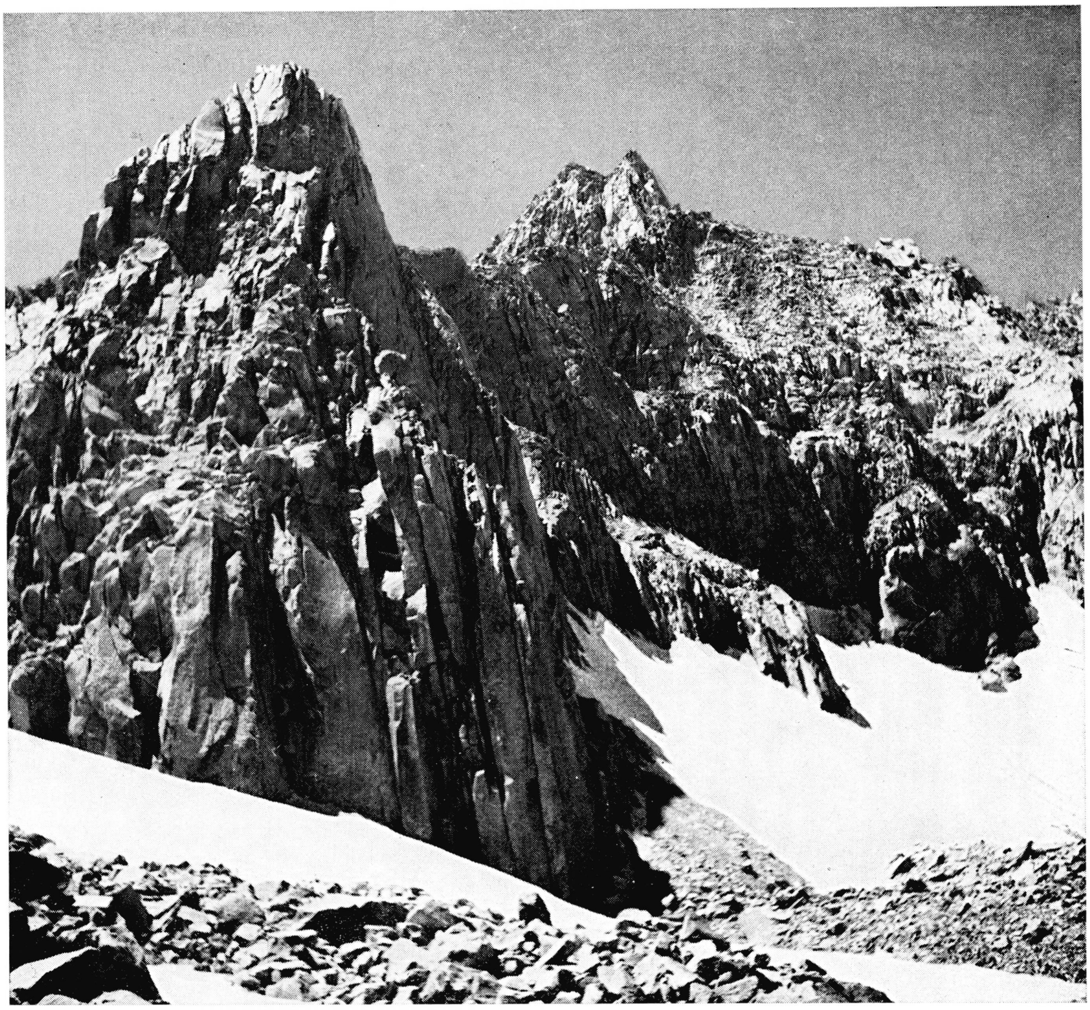

Fig. 18. The E spur of Takht i Sulaiman with cleavage hading steeply north in granite.

microlites. The presence of such a glass mass in an apparently Paleozoic dike is of particular interest. The dike occurs near the main thrust zone which borders the Paleozoic against the Eocene volcanics. The composition of this dike is unlike anything known from the Eocene. The dike cuts through Carboniferous rocks in a zone where even the Cambro-Ordovician has not been metamorphosed, but where strong subsequent tectonic movements are manifest.

The age of both intrusions, the Akapol quartz-monzonite and the Alam Kuh granite can not definitely be determined by contact relations. Considering the schistosity, it may be concluded that the Akapol quartz-monzonite is older than the Alam Kuh granite. The NW-extensions of

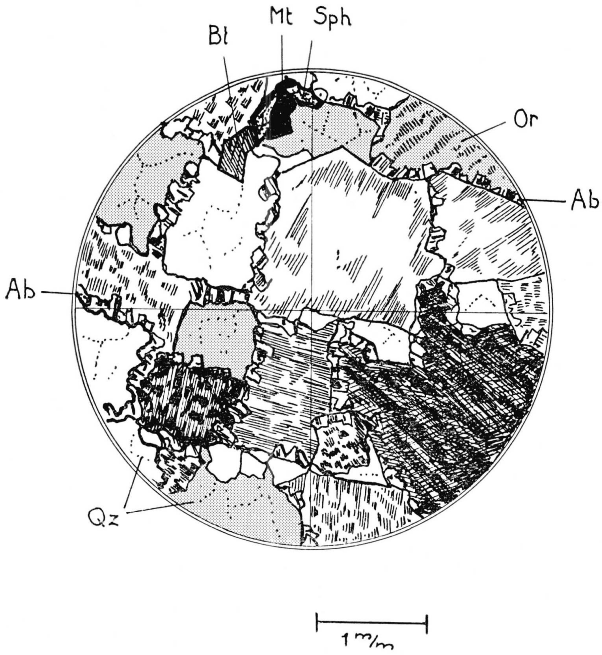

Fig. 19. Biotite alkaligranite (Takht i Sulaiman).

Or = Orthoclase perthite and chequerboard albite
Ab = Small albite rim around orthoclase
Qz = Quartz
Bt = Biotite
Sph = Sphene
Mt = Magnetite

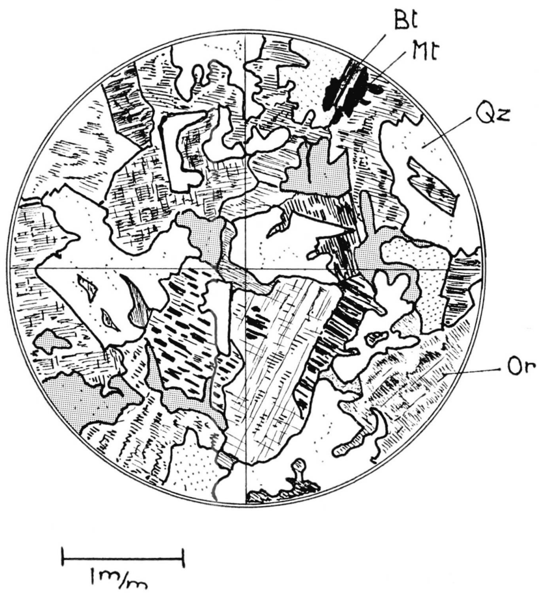

Fig. 21. Granophyric alkaligranite (North wall Alam Kuh).

Or = Orthoclase perthite and chequerboard albite. Some alkalifeldspars display albite rims
Qz = Quartz, intergrown with feldspars
Bt = Biotite
Mt = Magnetite

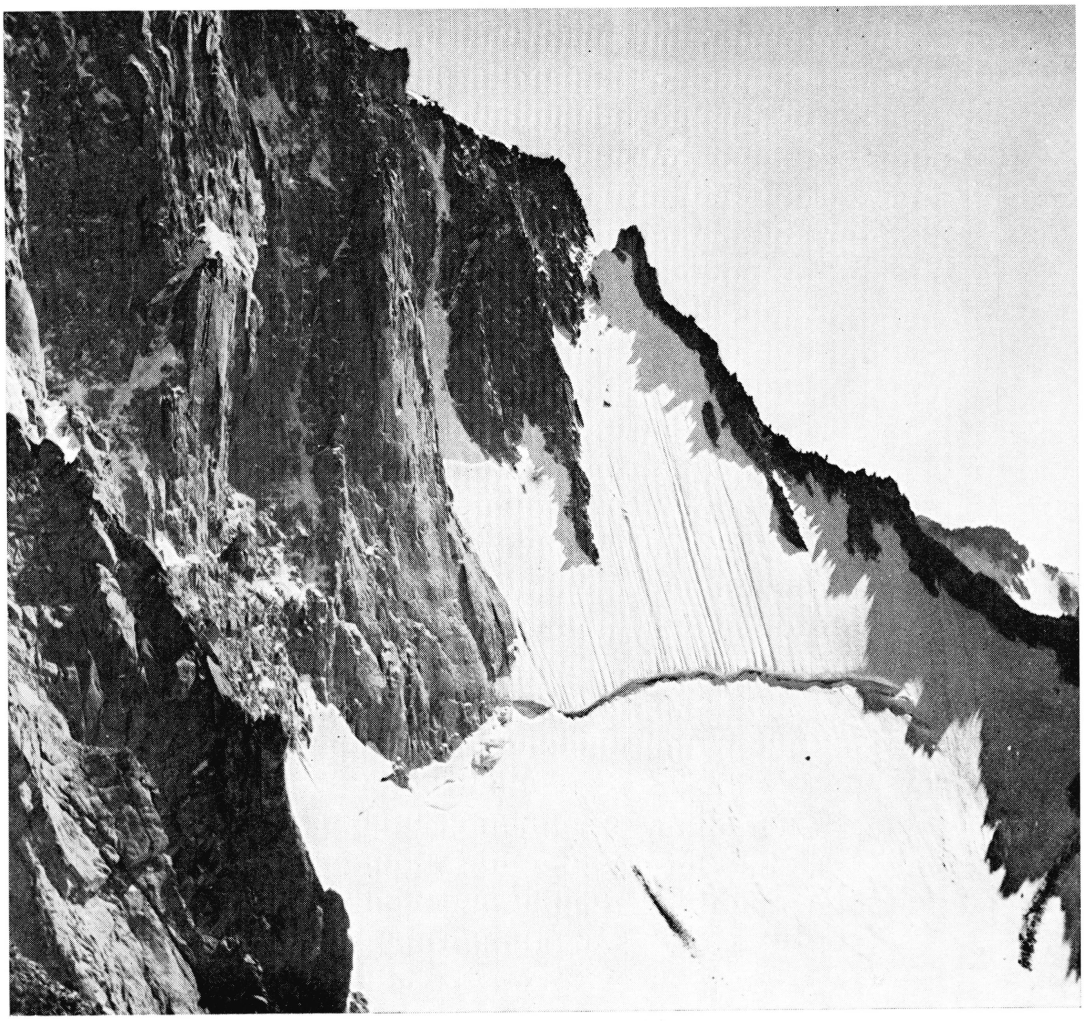

Fig. 20. The steep granite north wall of Alam Kuh with Alpine-type glaciation.

the Alam Kuh granite are in contact with slates, limestones and shales, which contain brachiopods of a probably Upper Devonian age (near Darjan) and the intrusion may thus be of Post-Ordovician, Paleozoic age. The granite is however not in direct intrusive contact with the dateable Cambro-Ordovician rocks of Hezarchal, which show a unconformable contact or are faulted against calc-schists and quartzites south of the granite contact.

The Paleozoic diabasic dikes are younger than the batholitic intrusions and some cut through the lower Carboniferous, which is, however, an exception. Generally they end within the red quartzites of the Devonian, a fact of regional significance in the Elburz mountains. The acid dikes

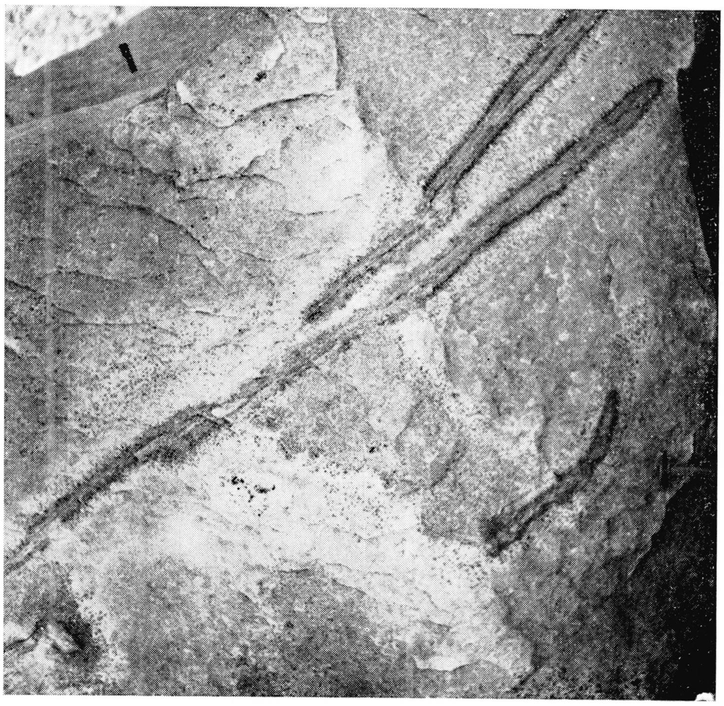

Fig. 22. Aplitic veins and irregular patches with radial black tourmaline in fine-grained white alkaligranite from Alam Kuh north face.

Fig. 23. Diabase dike cutting through granite on Takht i Sulaiman S ridge.

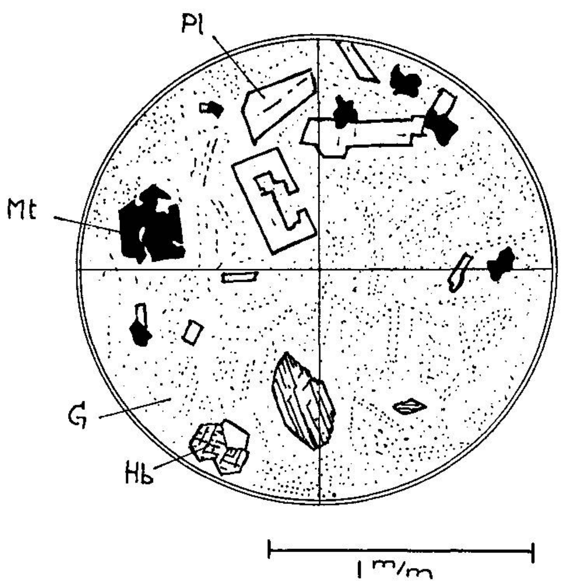

Fig. 24. Hornblende-dolerite (South ridge Takht i Sulaiman).

Pl = Acid andesine	Mt = Magnetite
Hb = Basaltic hornblende	G = Cryptocrystalline matrix

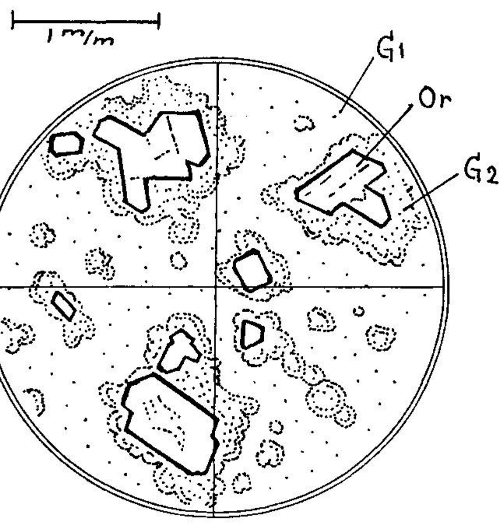

Fig. 25. Hemicrystalline sanidine porphyry E Pt. 4400 m, southern Hezarchal basin.

Or = Sanidinic alkalifeldspar
G 1 = Greenish glass
G 2 = Darker microgranular glass

are more strictly related to the batholites and of a similar or slightly younger age.

II. The Cambro-Ordovician

During his cartographic work in the Alam Kuh mountains Bobek (1934) found some fossils, which were determined by Dietrich (1937) to be of Ordovician age. From the same region one of us (G), in 1956, made a stratigraphic investigation and collected additional material. The fossiliferous sediments occur south of the main Alam Kuh granite mass and form the 4200 m high Lashkerak Peak. This is the only locality in the whole Elburz chain, where Cambro-Ordovician has so far been proven by fossils, while large tracks of undated Pre-Devonian deposits are well known. The Cambro-Ordovician group can be divided into two separate formations, well distinguished by their lithological character. Since corresponding sections have always been referred to as Pre-Devonian, it may be useful to introduce local names for the fossiliferous outcrops of the Alam Kuh region.

a) The Lower Hezarchal formation

The wide morainic basin of Hezarchal, on the south side of the Alam Kuh mountain is bordered by yellow-brown, finely crystalline dolomites. They form massive to thick-bedded, often lenticular outcrops and are locally siliceous. Reddish silty to sandy shales occur as intercalations and coat locally the yellowish dolomites with red. As far as could be ascertained, reddish shales form also the lowest horizons, near the tectonically disturbed contact with the Alam Kuh metamorphics. The contact with the Alam Kuh granite was not observed.

The dolomites with red shales are at least 500 m thick, and seem to increase in thickness along the Saman ridge towards the steep thrust zone of Tang e Gali (Fig. 26, 27).

No fossils were observed in the dolomites and shales. They resemble similar dolomites below the Devonian quartzites in many old uplifts of the Elburz mountains. Since they are overlain by Cambro-Ordovician quartzites, it seems reasonable to place the Lower Hezarchal formation into the Cambrian.

b) The Upper Hezarchal formation

The Lower Hezarchal dolomites are overlain, with a sharp and apparently unconformable contact, by reddish thick to well-bedded quartzites,

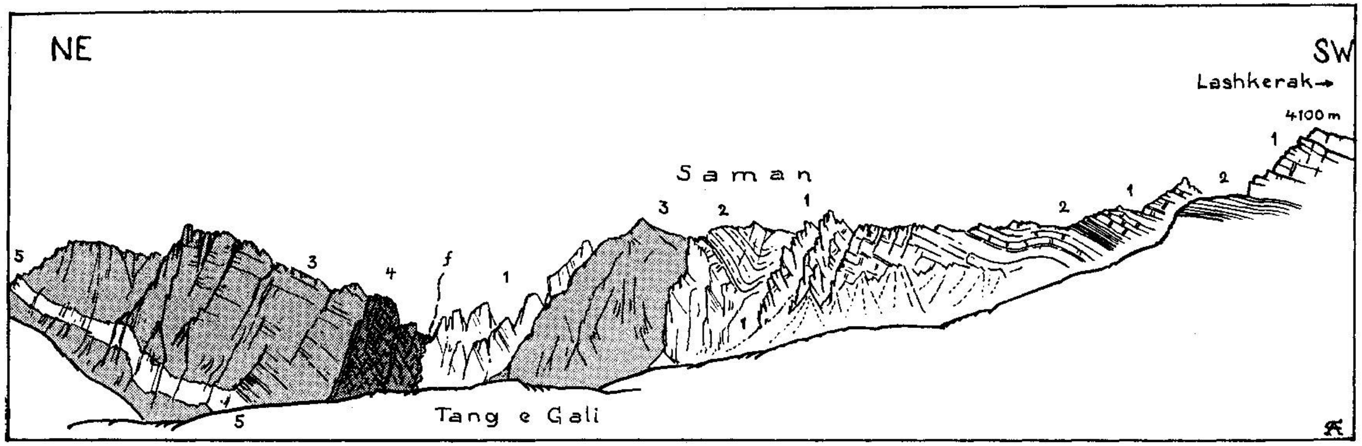

Fig. 26. The eastern Hezarchal mountain range.

1 Yellow dolomites } Lower Hezarchal formation
2 Reddish shales } Lower Hezarchal formation
3 Green schists and marbles with hornfelses
4 Basic to ultrabasic rocks along major fault zone
5 Main marble beds in green schists

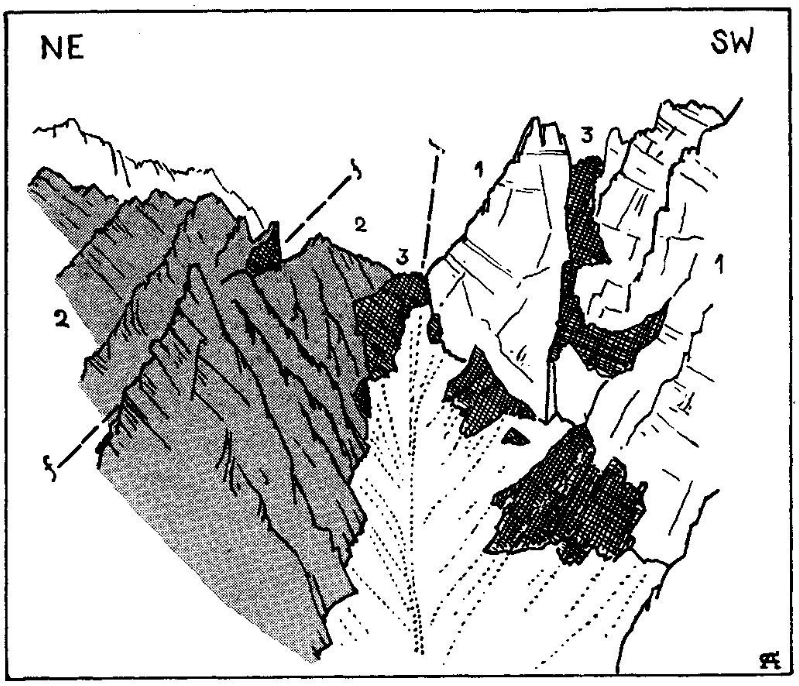

Fig. 27. The right face of Tang e Gali.

Complicated contact along major fault zone with ultrabasic intrusions between Hezarchal dolomites and green schists with marble zones.

1 Hezarchal dolomite
2 Green schists with marble layers and hornfelses
3 Ultrabasic rocks

which on the NW slope of the Lashkerak Peak contain well preserved *Cruziana* sp. They resemble closely Cruzianas from the Khabour quartzite-shale formation in N Iraq (visited by one of us [G]) and which according to the Stratigraphical Lexicon of Iraq (Vol. III, Asie) are placed in the Cambro-Ordovician. The Hezarchal Cruziana beds are followed by 200 m of quartzites and somewhat concretionary sandy shales and are topped by a conspicuous white quartzite member.

c) The Lashkerak formation

Above this quartzite follow, with a sharp, but conformable contact, dark gray silty shales overlain by reddish silty nodular limestones. The upper part of these thin limestone beds grades into red nodular calcareous marls which contain well-preserved fossils of Ordovician age. Dark well-bedded silty shales overlie the marls and are followed by rusty

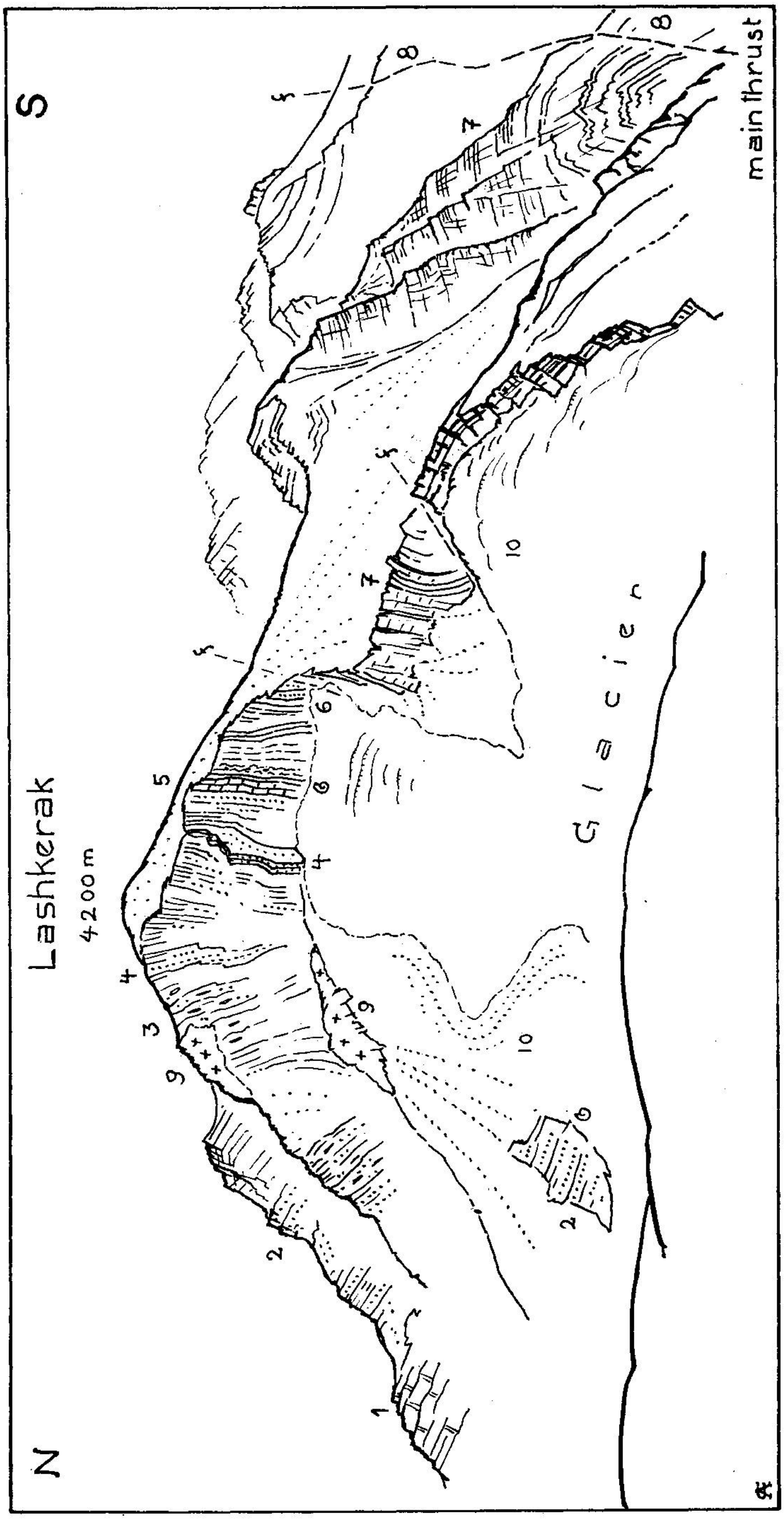

Fig. 28. The Lashkerak Area S of Alam Kuh.

1 Dolomites, Lower Hezarchal formation
2 Quartzites with Cruziana, Upper Hezarchal formation
3 Nodular quartzitic shales
4 White quartzite
5 Pink nodular limestones and marls with Ordovician fossils
6 Ferruginous to white quartzite
7 Undifferentiated Post-Ordovician Paleozoic
8 Eocene
9 Melaphyr (Paleozoic)
10 Moraines and glaciers

weathering yellowish quartzites (Fig. 28). The contact against the younger Devonian and Carboniferous formations is tectonically disturbed and conspicuous by dike intrusions. The newly-collected fossils have been determined in a preliminary way by Prof. R. Trümpy in Zürich, to whom the authors are indebted. Well-preserved are trilobites *Illaenus (Illaenus)* sp., *Asaphus* sp. and other indet. *Illaenidae (Panderia?)* as well as cystoids *(Sinocystis* cf. *loczy* COWPER-REED), and *Spyroceras* sp. and *Orthoceras* sp. The trilobites indicate Lower to Middle Ordovician and the cystoids most probably of Middle Ordovician age. They compare with some of the specimens collected by Bobek and determined by DIETRICH (1937).

d) The Devonian, Carboniferous and Permian

Our investigations were mainly concentrated on Pre-Devonian formations and igneous and metamorphic rocks. Devonian to Permian deposits are well known in the Elburz mountains and cover large, though more marginal areas of the Alam Kuh uplift. South of the Alam Kuh, red quartzites and dark gray, often crinoidal limestones represent scattered Devonian remnants and most probably Carboniferous but not Permian formations. The outcrops are tectonically disturbed along the main southern thrustzone. More time is needed to unravel the stratigraphy of this region. Carboniferous fossils include large Carninia and Zaphrentia corals, Spiriferidae and Productidae.

North of the Alam Kuh group, in the Sardabrud, the already-discussed marble formation is followed to the north by green and reddish banded slates, gray calcareous quartzites and dark gray calcareous shales. A sharp fault zone forms the contact.

In gray to wine-red slaty silty shales fenestellids, brachiopodes, lamellibranchs and trilobites were found. The fauna points to a Middle to Upper Devonian age, but a detailed investigation by specialists has not yet been made. On top follow sandy shales, quartzites, a conspicuous gray limestone and red yellow and gray banded quartzites. To the north thick-bedded, dark to black limestones with calcareous shale bands form the mountains of Rudbarak and border the Kelardasht basin. Fusulinids in the limestones indicate Permian age (Fig. 29).

Most likely all the carbonate rocks which cover the shaly and quartzitic Devonian are predominantly Permian, and little or no Carboniferous seems to be present in the northern part of the Alam Kuh, contrasting strongly with the Carboniferous S of the main uplift.

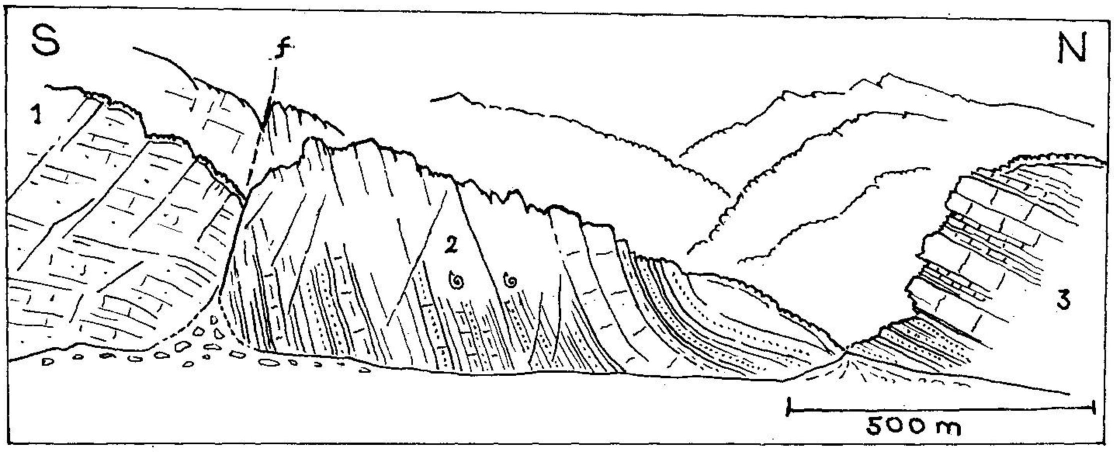

Fig. 29. The contact of the white marbles with the Paleozoic in the lower Sardab Rud.

1 White marbles, with fault contact against 2
2 Middle to Upper Devonian
3 Predomiantly Permian (may include some Upper Carboniferous)

e) The Tertiary formations

Except for the badly exposed, detrital basin fill of the Kelardasht just N of Rudbarak no Tertiary deposits are exposed N of the Alam Kuh group. The Kelardasht deposits seem to represent, together with similar formations outcropping more to the east in the Dasht i Nazir, marginal young Tertiary horizons.

South of the Alam Kuh mountain group, however, bordered by the steep southern thrustzone, follows the complex Paleogene belt mentioned already under 4, the Central Tertiary zone.

1. *The main thrustzone of the S Alam Kuh thrust* represents one of the major structural elements of the Central Elburz. S and SW of the Alam Kuh uplift, the steep thrustzone hades to the N but already east of the Alam Kuh culmination a steep southerly hade of the thrust is recognized (S of the Dalir valley [Fig. 30]). Owing to the culmination of the Alam Kuh the oldest formations border the Eocene volcanics just S of the central part of this uplift, but westwards as well as eastwards, successively younger formations form the upthrusted elements. Apart from vertical movements, a strong horizontal component is recognized and the visible thrust is just a combination of both movements. The vertical displacement is most probably younger than the horizontal displacement.

At and near the thrustzone occur conspicuous lenses of gypsum (anhydrite) which can be recognized over a great extent of the Central

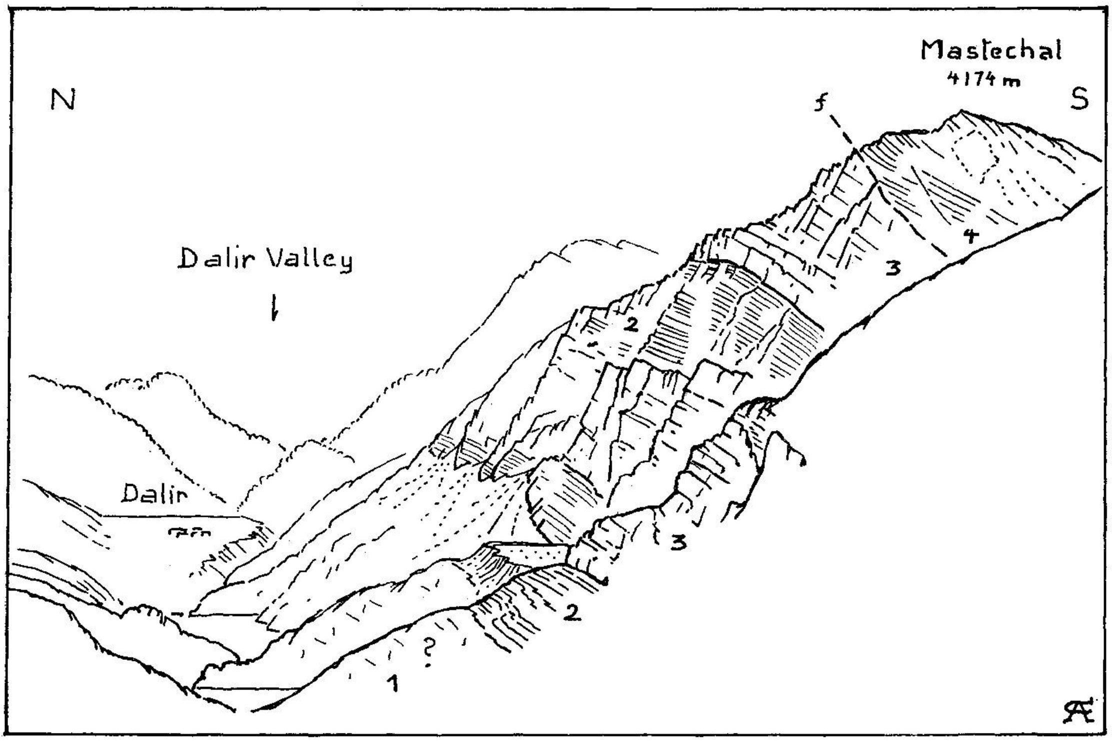

Fig. 30. The Dalir Valley towards the Chalus gorge.

1 Questionable undifferentiated Paleozoic and older
2 Red shales } Hezarchal formation (lower part)
3 Yellow dolomites } Hezarchal formation (lower part)
4 Eocene volcanics, in fault contact (steep thrust) against Hezarchal formation

Elburz. They have most certainly favoured the tectonic movements and have been further accumulated in a more or less diapiric manner. Gypsum occurs further in more local thrustzones (mainly disharmonic) between the predominantly volcanic zones and the thinner bedded, more sedimentary base of the Eocene, well exposed in the head waters of the Sehezar river at Garm-ab and in the Narghiz Kuh (Plate II B).

Gypsum outcrops are also well known from Gach e Sar in the upper Karadj valley, where they follow abnormal contacts between the Eocene and younger beds.

South of the main thrust follow the Paleogene formations, consisting of an intense mixture of pyroclastic marine sediments and intercalated volcanic flows, sills and less frequently dikes. These formations, which in detail are highly complex, are regionally monotonous and were previously called "green series", owing to their predominantly green colour.

Baily (1948) has so far given the best detailed description of these Oligo-Eocene deposits, calling them "green beds", a term preferable to green series. STAHL (1897) has already classed the green beds as Oligocene, and was followed by RIVIÈRE (1934) and BAILEY (1948). Based on our regional studies we prefer a range from Lower Eocene to Lower Oligocene. Lower Tertiary volcanics of Central Iran are predominantly Lower to Middle Eocene and only locally is Upper Eocene present (GANSSER, 1955).

In the eastern Elburz, the northernmost Eocene deposits were described by STÖCKLIN (1959) from the Tedjen river. These northern near-shore deposits consist of glauconitic, nummulitic limestones which alternate with gypsiferous marls and conglomerates, and thus represent a typical near-shore facies. The volcanic influence increases southwards. Only a Lutetian fauna was found in these lower beds.

In our area of interest south of the Alam Kuh group the near-shore facies does not outcrop. It is cut off by the south Alam Kuh thrustzone which brings the older rocks in juxtaposition to already well developed Eocene volcanic green beds.

They are well exposed in the head waters of the Sehezar Rud (lower formations) and in the steep gorges leading southwards into the wide Taleghan valley.

The complex Eocene pyroclastic group consists of two main formations, viz a lower dark shale formation and an upper green (pyroclastic) volcanic formation. These two members, well established in the region south of the Alam Kuh uplift, are less distinguishable in other areas, though a lower fine-grained sedimentary zone is widespread in many sections of the Elburz green beds. Less pyroclastic horizons in form of dark silty shales and reminiscent of the lower shale formation are known as the so-called Maigun shales in the Shemshak valley and are locally highly bituminous, but represent stratigraphically much higher horizons.

2. *The dark shale formation:* It consists of dark to black silty slates and shales with thin intercalations of quartzitic sandstones. They are well exposed in the uppermost Sehezar Rud, forming a well-outlined anticline. The base of the slaty formation is not outcropping, and the northern boundary coincides with the south Alam Kuh thrust zone. Towards the upper part a gradual increase of pyroclastic material can be noted, coupled with an increasing greenish colour. Most conspicuous are fine-grained porphyritic and diabase dikes. They are mostly vertical to very steep dipping and strike generally from NE to SW, a strike direction reminiscent of the dike intrusions in the Alam Kuh granite and older rocks.

Some of the dikes are spilitic and must have been altered by autometamorphism. Very fine-grained diabases are strongly ophitic with fresh plagioclase (Fig. 31) while others contain plagioclase filled with sericite (Fig. 32).

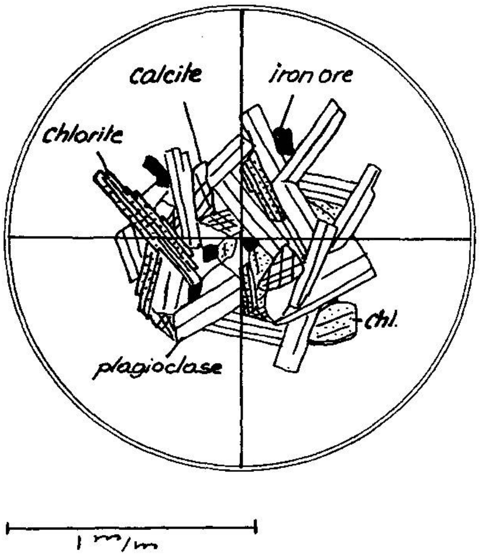

Fig. 31. Fine-grained spilitic diabase (Chloritised). Dikes in shale section of Eocene in Upper Sehezar valley.

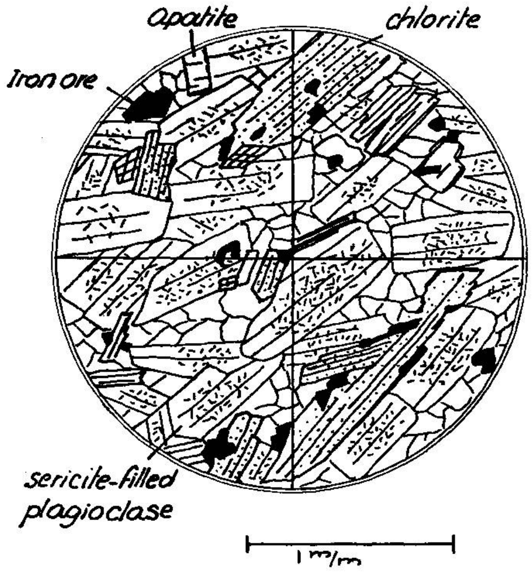

Fig. 32. Autometamorphic altered spilitic diabase. From Eocene shale zone of Upper Sehezar Valley.

The upper limit of the shaly formation has been placed at the base of the first-marked porphyrite flow, from where the main volcanic formation begins. Near this contact, but also below and in some places above it, occur gypsum and anhydrite beds (Plate II B). These horizons were obviously predestined zones of movement, and a considerable amount of tectonical displacement, partly as longitudinal strike-slip faults, can be recognized. Consequently the evaporites are sheared and locally accumulated diapirically in conspicuous lenses. Such a large gypsum mass is outcropping in an anticlinal position N of the Narghiz Kuh and a similar lens can be seen in the upper Alamut valley. Similar well-known gypsum lenses occur N and S of the Kandevan tunnel, at the Chalus road. They follow, but do not actually mark, the main regional thrustfault zone of Paleozoic rocks, of which the S Alam Kuh thrustfault is a component only. Evaporites certainly played a major role in lubricating strike slip adjustment faults in connection with the main thrust tectonics.

The already-mentioned diabase and porphyrite dikes of the lower shale formation do not cut through the gypsum horizons, nor do they cut through the first major porphyritic flow. Since the evaporite layers as well as the base of the thicker porphyrite flows are undoubtedly zones of movement, any previous connections have been disrupted. It can be assumed, but actually not proven, that the vertical dikes in the lower shale formation are actually feeders to the flows in the overlying volcanics. Similar dikes were observed in the overlying green volcanics, abutting against the base of major flows (Shirbash pass, 3600 m, leading from the Sehezar valley to the S).

3. *The volcanic green beds:* This formation, conformably overlying the shales, represents the strongly pyroclastic part with volcanic sills and flows of the well-known lower Tertiary green beds of the Elburz. In the Lalun valley, several 100 m of basal conglomerate underly the pyroclastic green beds directly (E of Shemshak), and transgress over an intensely eroded Jurassic to Devonian surface. Such marked erosional contacts are not very evident in our area of interest, which, on the other hand, displays a stronger volcanic activity, reminiscent of the more southern sections of the Karadj valley, which heralds already the strong volcanism of Central Iran. Just above the lower shale sections occur sills of augite-diabase-porphyrite (Fig. 33). They mainly contain phenocrysts of basic andesine, augite and altered olivine and an intersertial holocrystalline groundmass of smaller plagioclases and iron ore. Some-

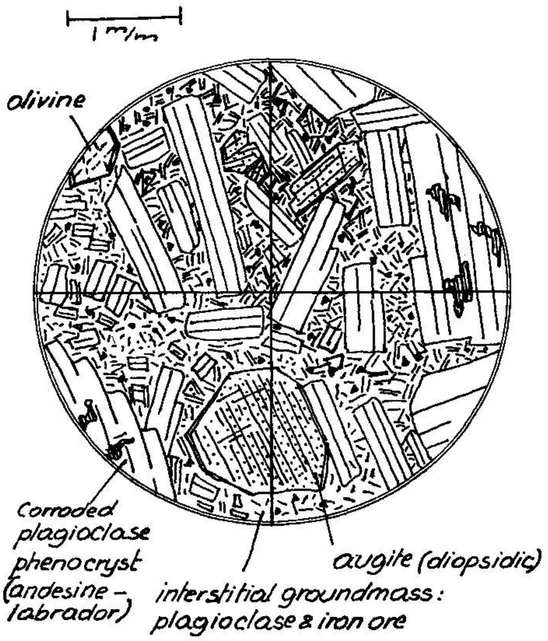

Fig. 33. Augite-diabase porphyrite. Large sill in Eocene volcanics, southern watershed in Upper Sehezar Valley.

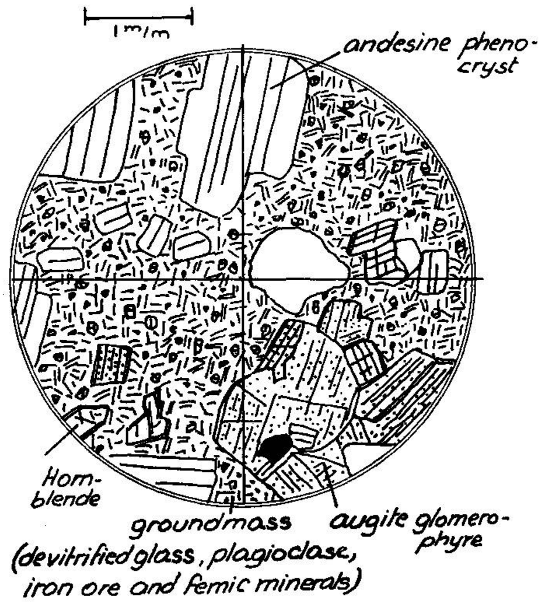

Fig. 34. Porphyric augite-andesite. Sill in Eocene volcanics from Pt. 3520 m south of Upper Sehezar Valley.

what higher in the section, at Pt. 3520 m (Plate II B) we observe porphyric augite-andesites with a groundmass which is partly glassy with plagioclase lathes, iron ore and small augite grains and large andesines as phenocrysts, together with diopsidic augites and occasional hornblende crystals (Fig. 34). Towards the Taleghan valley in the S, the main mass of the Eocene volcanics is formed by an amygdaloidal, porphyry-like augite-diabase with hedenbergitic augite and basic plagioclase phenocrysts in a holocrystalline, fine-grained matrix. The amygdales are irregularly shaped and interstitial between the crystals. They are coated by fine prismatic zeolites (Fig. 35).

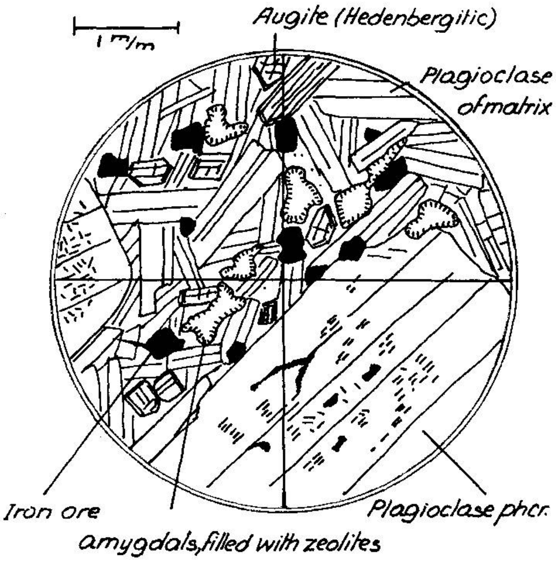

Fig. 35. Porphyric augite diabase. Main mass in Eocene volcanics N of Javestan, Upper Taleghan Valley.

D. Comparison with a Section through the Elburz Range just W of Alam Kuh

In 1955 Gansser, accompanied by engineer Fakhrai, made a rapid reconnaissance traverse of the Elburz just west of the Alam Kuh uplift from Shahsawar on the Caspian to the Taleghan valley in the southern Elburz (Fig. 36). This section gave valuable structural information, but leaves much to be desired regarding the stratigraphical control. We refer to the attached crossection (Plate II A), which in the following is summarily discussed.

Except for Plio-Pleistocene conglomerate ridges at the Caspian foothills, Tertiary formations are not outcropping and if present, they are

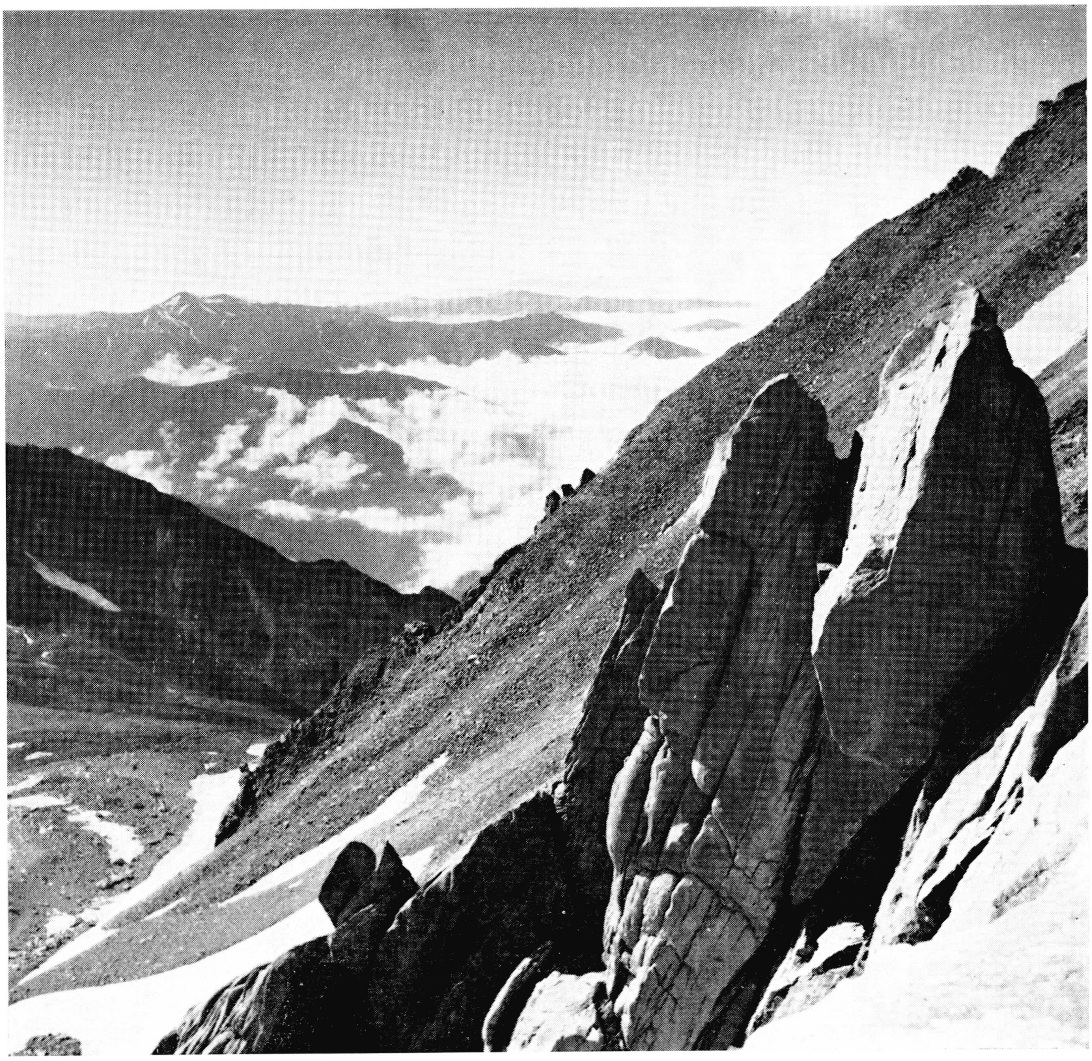

Fig. 36. View towards NW from saddle between Alam Kuh and Takht i Sulaiman to Upper Sehezar Valley with old Paleozoic uplift. Strongly fractured granite in foreground. Note Caspian fog banks.

hidden below the Quaternary plain. Mesozoic limestones, mainly of Jurassic age, form the densely wooded foothills. The Mesozoic increases towards the east (Chalus area), but decreases westwards, where it is covered by the Caspian Alluvial, while NW striking Paleozoic rocks form the foothill belt.

At Varzamin the lower Sehezar Rud crosses a disturbed zone with steeply north-dipping, white marmorised limestones overlying highly altered spilitic diabases and diabase tuffbreccias rich in epidote and calcite veins (Fig. 37). A local metamorphism is evident, but this does not involve the normally underlying black speintery siliceous shales to

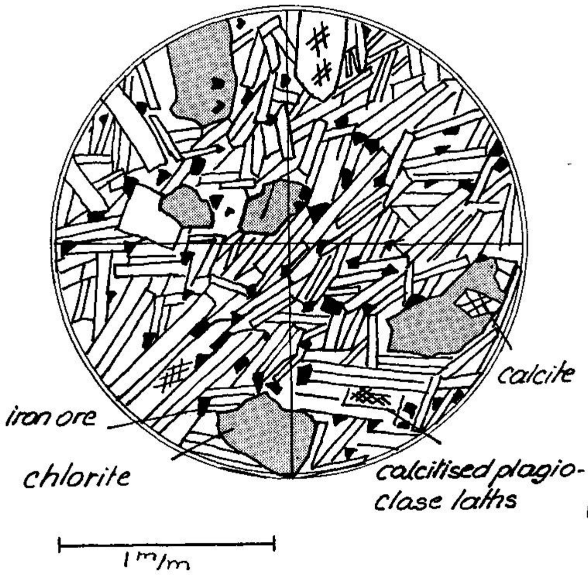

Fig. 37. Spilitic diabase (Varzamin, Sehezar Valley) altered by chloritisation and calcitisation.

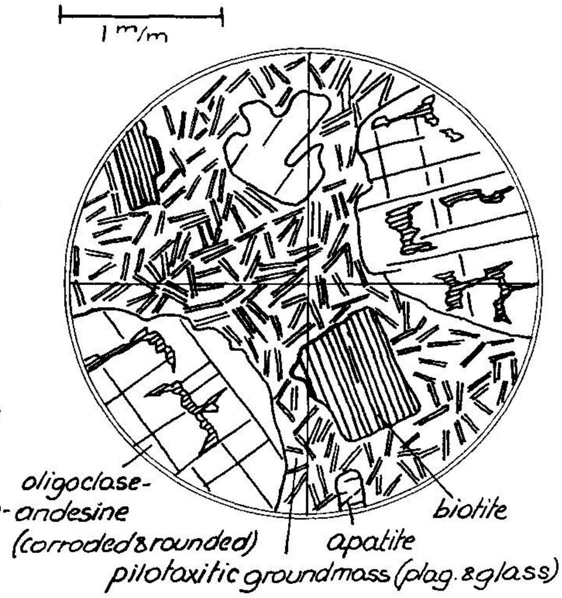

Fig. 38. Biotite-andesite (Anticline I, Sehezar Valley).

slates which rise southwards and include in their lower part an andesitic sill (Fig. 38). They normally cover a large anticlinal uplift, the core of which exposes over 800 m of blue-gray, often dense, dolomitic limestones with siliceous shale intercalations. The steep faulting and fracturing of the limestones parallels a conspicuous dike intrusion of predominantly diabase composition. Under these limestones, in the deepest core of the large anticlinal uplift, appear white to light-gray banded fine quartzites with some red shales underlain by conglomerates, which form here the deepest visible outcrop. The 1—5 cm large well-rounded pebbles consist of yellow dolomites, red siltstones, dark limestones and red quartzites in a matrix of dark blue-green siltstone. Crystalline pebbles are absent. During our rapid visit no fossils were observed in this section. The lithological aspect, the frequent dike intrusions and the tectonical position strongly suggest a lower Paleozoic section, possibly Pre-Devonian, but the pebbles of the deepest conglomerate seem to indicate that still older non metamorphic sedimentary sequences have been eroded.

The Pre-Devonian age suggestion is further strengthened by the next southwards-following huge uplift just north of a western branch valley which leads into the Alamut region. This second uplift consists of about 800—1000 m-thick beds of banded blue-black siltstones, green pyroclastic and siliceous siltstones, all densely criss-crossed by sills and dikes of andesites, dolerites, diabases and locally cut by weathered biotite-hornblende-lamprophyre dikes. The basic dikes are strongly chloritized and calcitised and have a spilitic composition, containing hornblende, chlorite and iron ore as femic minerals. The plagioclase lathes are filled with sericite and zoisite, marking an ophitic-fluidal fabric (Fig. 39).

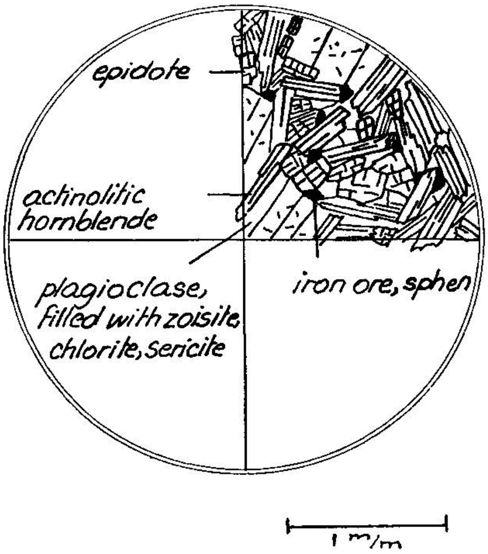

Fig. 39. Epidotised hornblende-diabase (Anticline II, Sehezar Valley).

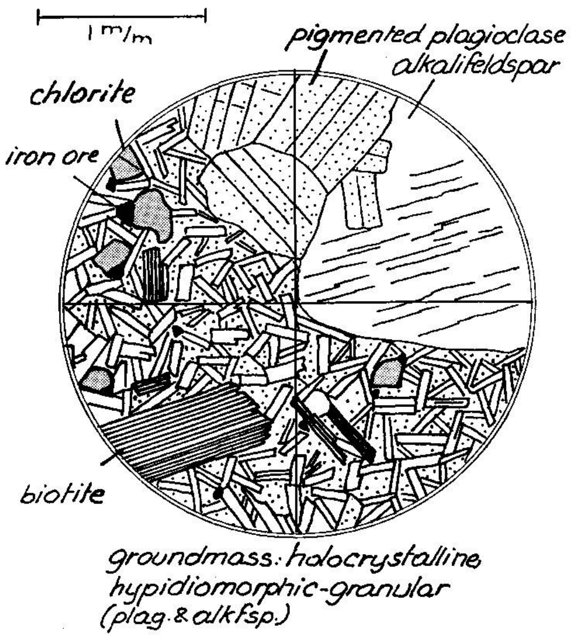

Fig. 40. Biotite-trachy-andesite (Anticline II, Sehezar Valley).

The darker varieties contain also a larger amount of epidote (20 to 30%). The more acid dikes are of andesitic, trachyandesitic and quartzporphyritic nature, containing only biotite and rare hornblende as femic constituents (Fig. 40). Secondary calcite has partly invaded the plagioclase phenocrysts and fills amygdales and geodes. The structure of these dikes is hemicrystalline, with a pilotaxitic to cryptocrystalline groundmass, or they are holocrystalline-porphyric.

At the contact with the dikes, the matrix of a psammitic wall rock from the second large anticline is locally strongly chloritized and epidotized, but otherwise no contact reactions are noticeable (Fig. 41). It is however possible, that the quartz-porphyry and trachyandesitic dikes of the Sehezar valley are somehow related to the monzonitic and granitic rocks of the Alam Kuh area, while the spilitic diabases and altered dolerites are younger, and compare to the dikes which cut through the Takht i Sulaiman granite.

The two above-mentioned large anticlinal uplifts are bordered by steep fault and thrust zones. Their number increases southwards along the section together with a regional steep south dip involving black slates, banded siliceous limestones with chert nodules, thin, well-banded quartzites, the whole intensely subfolded. At least 800 m of this slaty formation are visible. They are overlain, again with fault contacts, by gray well-bedded limestones, in which Zaphrentid monocorals, Spirifers and Pro-

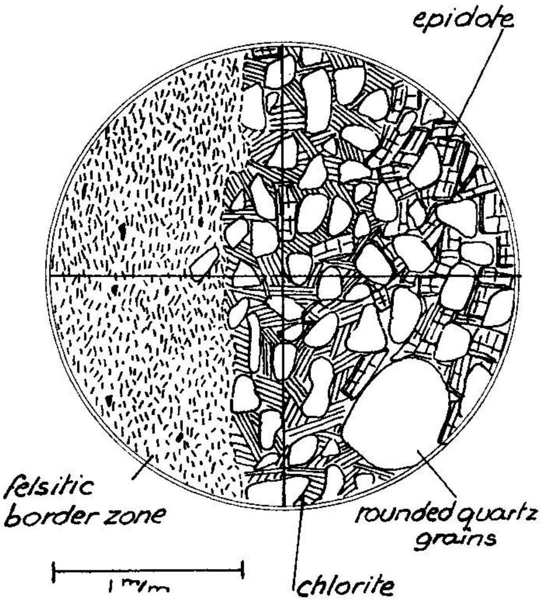

Fig. 41. Contact of felsitic borderzone of trachy-andesite with metamorphosed psammite (dark siltstone). (Anticline II, Sehezar valley.)

ductides were found, suggesting a Carboniferous age. No dike intrusion was observed in the Carboniferous, while the slaty formations outcropping below expose frequently diabasic dikes. This Carboniferous section, though only representing a wedge, bordered by faults, brings further proof for an at least Pre-Carboniferous age of the aformentioned slaty and quartzitic as well as siliceous limestones.

From this Carboniferous wedge southwards to Darjan follow, again with fault contact, red beds, overlain by quartzites, which strongly resemble Devonian, though most of the quartzites are frequently alternating with siliceous shales, and the reddish colour is mostly missing.

In a large boulder, belonging to a shaley intercalation a very large spirifer was found, which seems to indicate that at least a part of this section is of Upper Devonian age.

Quartzites and siliceous shales form the steep mountains in the uppermost Sehezar Rud valley SE of Darjan. They are cut off southwards by the already-mentioned thrustzone, which brings the Tertiary volcanics in contact with the Alam Kuh Paleozoic rocks and eastwards we observe the intrusions of the probably Post-Devonian Alam Kuh granite.

From this uppermost Sehezar Rud valley, and after having crossed the main thrust, our section continues within the Tertiary volcanics southwards into the Taleghan valley. The structural features are evident (Plate II A) and the lithology has already been described in the Tertiary chapter (p. 617).

We may stress the fact, that the folding pattern in this Tertiary area is influenced by the massive to thick bedded volcanic members and that no prevalent folding direction can be detected. Faultzones are very steep, and seem to display strong horizontal elements with strike slip character. Attention is drawn to two synclinal remnants of Miocene formations — both with red coarse basal conglomerates. They are faulted on the N-side while the S-edge displays a normal transgression. Miocene is again transgressing the S-plunging volcanics in the Taleghan valley, but the coarsely clastic transgressive facies has already changed southwards into silty marls, with evaporites as conspicuous intercalations.

Westwards, along the N rim of the Taleghan Miocene basin, the normal contact becomes faulted, and the basin deepens considerably (Plate II C).

Connection of the Sehezar section to the Alam Kuh

As we have already seen, the Sehezar section comprises, up to the southern main thrust, mainly Paleozoic rocks. Most striking are the two huge anticlinal uplifts, of which the northern one continues eastwards into the mountains of the SW Kelardasht (Lower Sardabrud), while the southern one seems to connect with the oldest formations of the Alam Kuh uplift, the Barrir and Marble formations.

Much remains to be done in order to fit the Sehezar section into the Alam Kuh uplift, which will be a difficult but certainly most rewarding task.

E. Conclusions

The Alam Kuh uplift with its oldest ascertained sediments, underlain by metamorphics and intruded by granites and monzonites forms the most important key area of the Elburz chain.

Only after linking this key area with the surrounding regions of the Elburz mountains can we understand its full geological significance. Such a study is planned for the eastern prolongation into the Chalus valley section.

The oldest fossiliferous outcrops indicate a shallow-water facies. Dolomites and quartzites reflect at most shelf conditions. Devonian to Triassic deposits, mostly conformable, are deposited under similar conditions. The coal-bearing Lower to Middle Jurassic and the thick limestone deposits of the Upper Jurassic and the Lower Cretaceous in the northern Elburz again are throughout of shallow marine or locally even terrestrial origin. Up to the Middle Cretaceous, sedimentary conditions seem to have been rather uniform over the Central Elburz. Only at the end of the Middle Cretaceous does the Elburz chain begin to emerge as an elongated uplift, forming a facies barrier, reflected in the Upper Cretaceous facies changes from N to S which become very pronounced with the beginning of the Tertiary. Local movements took place, but they are mostly of an epirogenetic character. Except for the Pre-Devonian orogenies strong phases of folding prior to the Tertiary are hardly noticeable. Even the early Paleozoic orogenetic phases seem to be of more local importance than previously believed. A regional Caledonian phase is hardly recognizable. The complete lack of Hercynian (Variscan) phases was already stressed by various authors (GANSSER, 1955; STÖCKLIN, 1959).

The Alam Kuh region does, however, indicate that a strong Pre-Cambrian orogeny must have existed. Pre-Cambrian deposits are, apart from some doubtful marbles, mostly monotonous schists including metamorphic tuffs and basic hornfelses. The basic rocks can be interpreted as an ophiolitic sequence and thus may suggest eugeosynclinal conditions, contrasting with the miogeosynclinal to shelf and continental deposits from the Paleozoic to the Tertiary. Most of the so called "Caledonian" folding phases of the Elburz may actually be assigned to Pre-Cambrian orogenies. In various areas of the Middle East where Devonian transgressions have been recognized, the Pre-Devonian deposits are actually older, altered Pre-Cambrian rocks. Where older datable Paleozoic deposits are present, Devonian follows, mostly conformably.

The strong metamorphism in the Pre-Cambrian of the Alam Kuh, which, except for some contact metamorphism is certainly older than the plutonic intrusions, contrasts strongly with the complete lack of metamorphism in the Cambro-Ordovician deposits to the south. No Post-Ordovician metamorphism has been noted so far in the whole Elburz chain. The known metamorphic rocks (Resht region, Gorgan schists and Alam Kuh uplift) are at least Pre-Devonian, or, as in the Alam Kuh, *Pre-Cambrian*.

The lack of later metamorphism seems in line with the tectonic development of this mountain range, where miogeosynclinal to platform sediments have not undergone any major orogeny until the Miocene-Pliocene and the Pleistocene phase. Of those orogenies, the late Pliocene phase was evidently the strongest, responsible for a strong compression with a north-directed vergence in the Eastern, a southward vergence in the Central Elburz, while the Western Elburz assumes more a block character with some northwards directed elements towards the Resht embayment in the south-western Caspian. Steep thrusts, formed in the Pliocene, later developed a strong horizontal component, again followed by vertical tectonics. The present elevation of the mountain range is very young, and resulted from Pliocene and *mainly Plio-Pleistocene vertical movements,* excellently expressed in the steep folds, faults and steep thrusts visible in the Plio-Pleistocene fan deposits of the foothills north of Teheran.

This youngest movement represents a typical *morphogenetic phase,* which created the present mountain range. The Pre-Pleistocene orogenetic phases do not conform to the subsequent morphogenetic phase, a fact well expressed by the aberrant trend of the main tectonic features when compared with the morphology of the main range. The Paleozoic Central Range strikes in a NW direction into the Caspian plain. The southern Paleozoic and Mesozoic Zone strikes at Ab i Yek in a westward direction into the Southern Depression while the morphogenetic mountain range here strikes NW. The discrepancy of orogenetic and subsequent morphogenetic features in mountain ranges is still little understood. The Elburz range in particular is an excellent example, since, as already mentioned (Gansser, 1955; Stöcklin, 1959), the geological Elburz has no south border, on the contrary, the intensity of the orogenies increases southwards, culminating in the strongest phase of the Middle East, the late Jurassic to early Cretaceous orogeny, concentrated in the so-called Central Iranian "Median Mass" of earlier writers.

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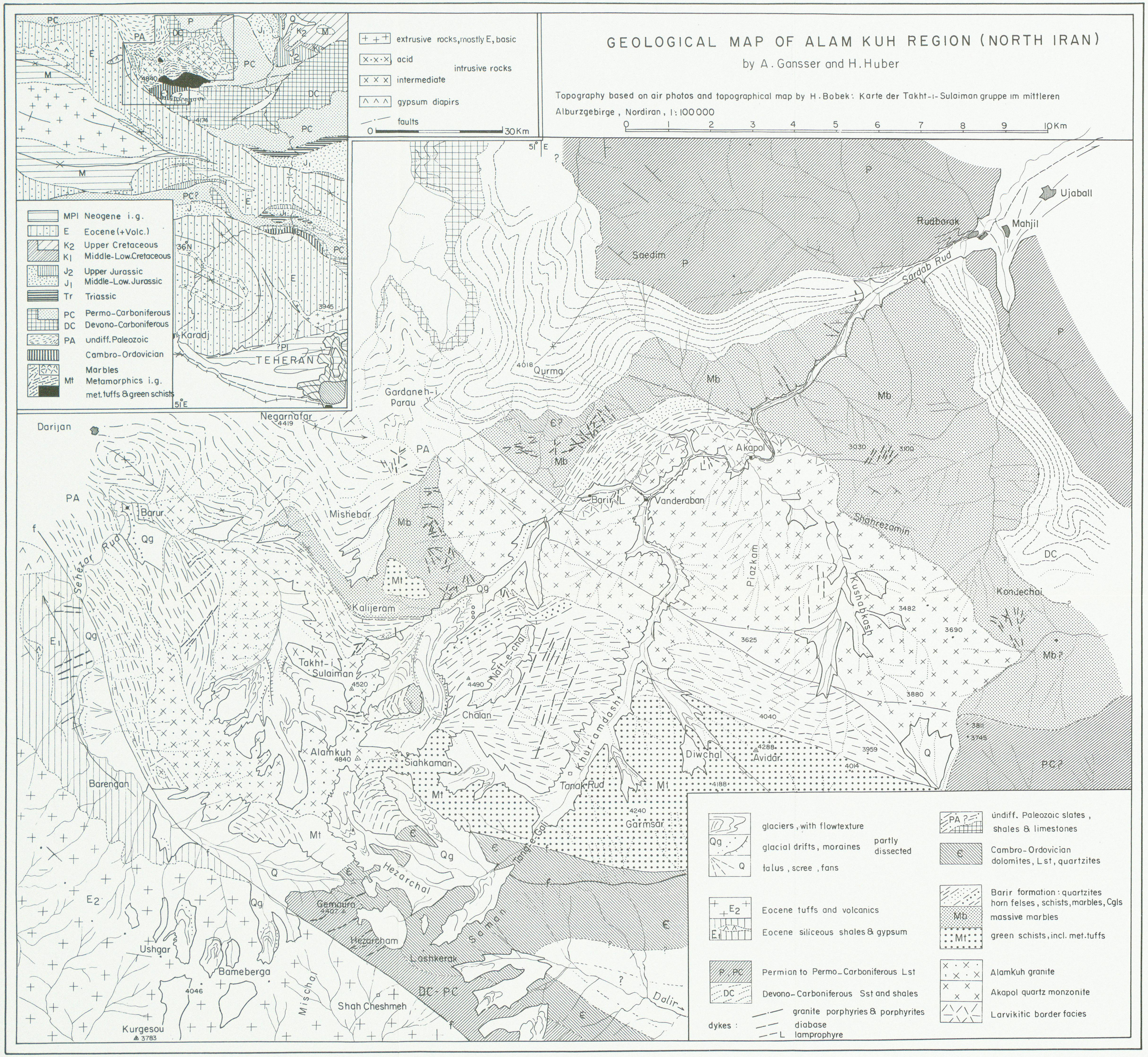
GEOLOGICAL MAP OF ALAM KUH REGION (NORTH IRAN)
by A. Gansser and H. Huber
Topography based on air photos and topographical map by H. Bobek: Karte der Takht-i-Sulaiman gruppe im mittleren Alburzgebirge, Nordiran, 1:100000
0 1 2 3 4 5 6 7 8 9 10 Km
extrusive rocks, mostly E, basic
acid
intermediate
intrusive rocks
gypsum diapirs
faults
0 30 Km
MPl Neogene i.g.
E Eocene (+Volc.)
K2 Upper Cretaceous
K1 Middle-Low.Cretaceous
J2 Upper Jurassic
J1 Middle-Low. Jurassic
Tr Triassic
PC Permo-Carboniferous
DC Devono-Carboniferous
PA undiff. Paleozoic
Cambro-Ordovician
Marbles
Mt Metamorphics i.g.
met. tuffs & green schists
Karadj
TEHERAN
36 N
51 E
glaciers, with flowtexture
Qg glacial drifts, moraines
partly dissected
Q talus, scree, fans
E2 Eocene tuffs and volcanics
E1 Eocene siliceous shales & gypsum
P, PC Permian to Permo-Carboniferous Lst
DC Devono-Carboniferous Sst and shales
dykes: granite porphyries & porphyrites
diabase
L lamprophyre
PA? undiff. Paleozoic slates, shales & limestones
Cambro-Ordovician dolomites, Lst, quartzites
Barir formation: quartzites horn felses, schists, marbles, Cgls
Mb massive marbles
Mt green schists, incl. met. tuffs
Alamkuh granite
Akapol quartz monzonite
Larvikitic border facies
Ujaball
Mahjil
Rudbarak
Sardab Rud
Saedim
Qurma
Gardaneh-i Parau
Negarnafar
Darijan
Barur
Mishebar
Akapol
Barir L.
Vanderaban
Shahrezamin
Konjechal
Piazkam
Kushakkash
Kalijeram
Sehezar Rud
Takht-i Sulaiman
Naft-e-chal
Chalan
Alamkuh
Siahkaman
Khurramdasht
Diwchal
Avidar
Tarak Rud
Garmsar
Barengan
Hezarchal
Gemaura
Hezarcham
Lashkerak
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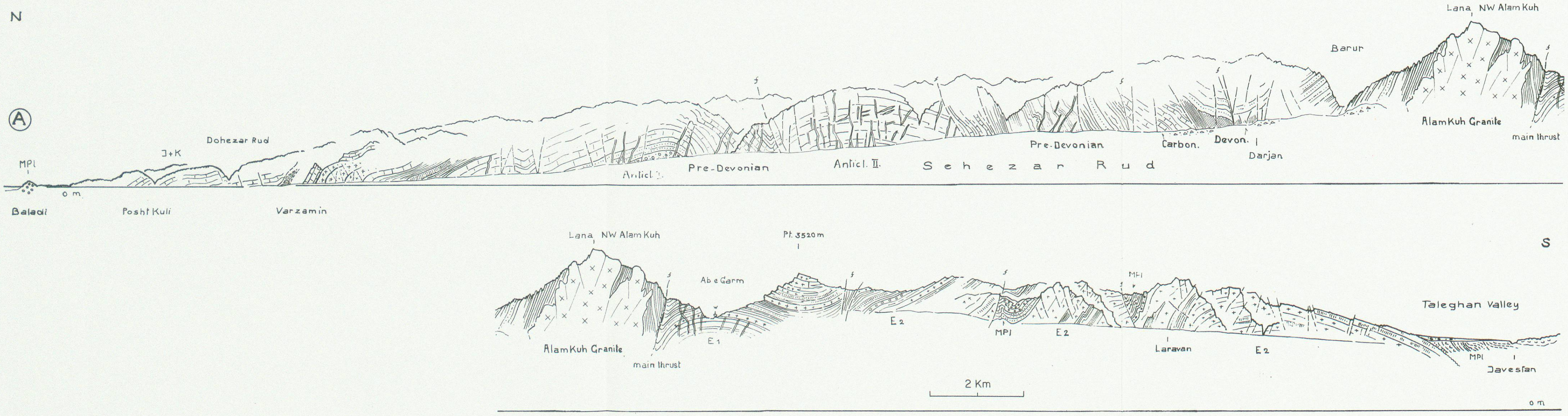

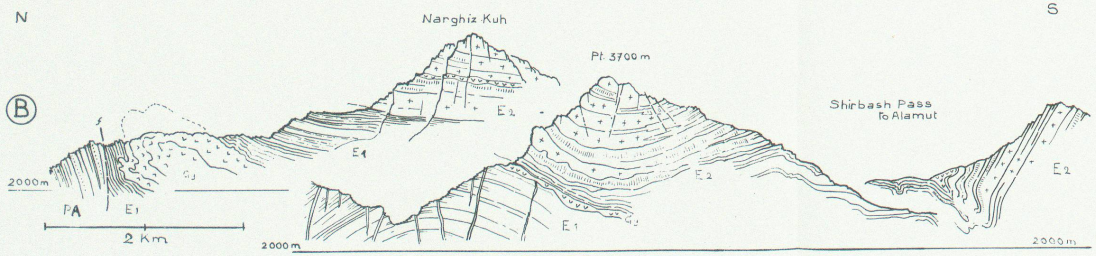

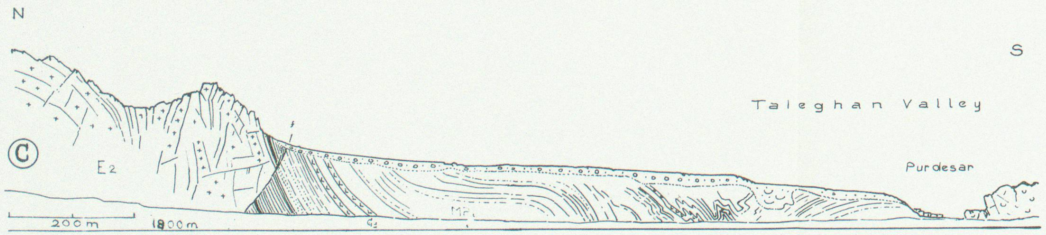

A Composite geological section from the Caspian plain to the Taleghan Valley (Legend same as geol. map on Table I)

B Sections in Eocene of Upper Sehezar Valley S of main thrust

C Detail of contact of Eocene volcanics with Mio-Pliocene of the Taleghan Valley (Legend same as geol. map Table I)