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The Taftan Volcano (SE Iran)

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ABSTRACT

The Quaternary volcanism in Beluchistan (SE Iran and SW Pakistan) is represented by the Bazman, Taftan and Kuh-i-Sultan volcanic groups. While the Bazman volcano sits in the southern Lut Block the Taftan volcano covers the complicated East Iranian Eocene flysch and ophiolitic Cretaceous ranges. Most important fault zones border these ranges and separate the three volcanic centres.

Taftan as the most "active" volcano of Iran is in a strong fumarolic stage. The prehistoric eruptions began 25 km to the NW of the present main summit. The lavas produced are andesitic and of a typical pacific suite. The strong postvolcanic activity on the main summit has not changed in the last 18 years. Here andesitic lava flows and large pyroclastic fans are well preserved. The trend of the Quaternary volcanism in Beluchistan has no relation to the complicated pre-volcanic structures.

1. Introduction

Quaternary volcanoes are widespread in Iran. All of them are more or less extinct, and in spite of a well preserved morphology only a few are still in an active postvolcanic stage, exhibiting fumaroles, solfataras and some hot springs. Of particular interest are the volcanoes Damavand and Taftan, both with strong postvolcanic activities. While Damavand is situated in an easily accessible part of the Elburz mountains in North Iran, the more active Taftan volcano in the remote Beluchistan of South East Iran is very little known.

The Quaternary volcanoes in Iran are distributed as follows (Fig. 1):

1. A north-western volcanic centre in Azerbeidjan.
2. The single but impressive Damavand in the Central Elburz mountains of North Iran with a small satellite 50 km to the east–south-east.
3. Small volcanic cones in the Bidjar area (West Iran).
4. Small volcanoes west of Kerman.
5. Two small centres west of the Lut Block and some doubtful Quaternary lavas within the Block.
6. The outstanding volcanic centre of Beluchistan (South-East Iran) with the large volcanoes of Taftan and Bazman.

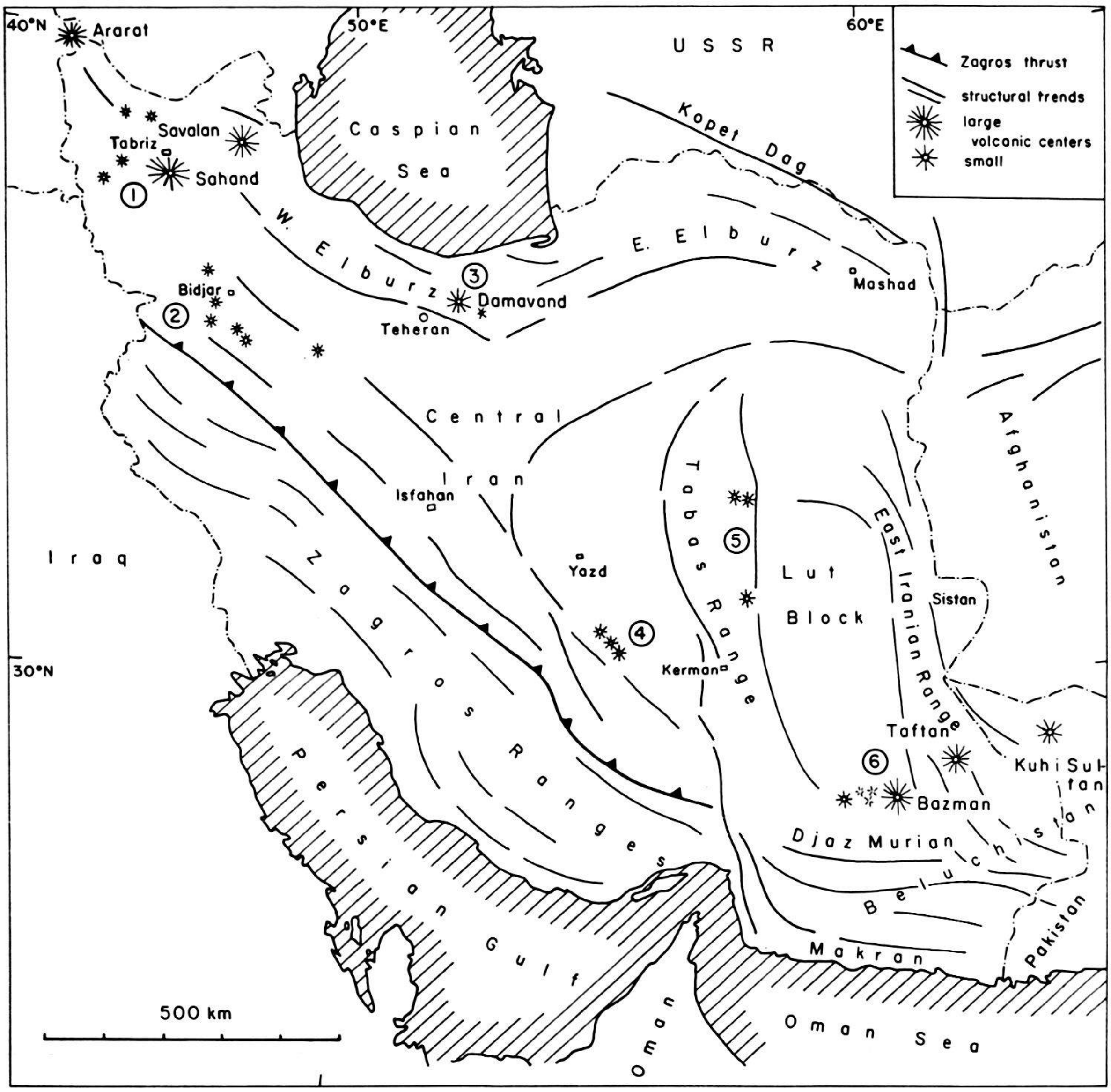

Fig. 1. The Quaternary volcanoes and main structural trends of Iran.

The north-western volcanic centres can be correlated with the Ararat region of North-East Turkey, while the Beluchistan volcanoes have their counterpart in the Kuh-i-Sultan group of West Pakistan.

The Taftan volcano is situated 100 km south–south-east of Zahedan and about 45 km north of the small village of Khash. The latter place is accessible from Zahedan by two motor roads, one passing to the west, the other to the east of Taftan mountain. Nomadic Beluch tribes camp on the slopes of Taftan, but migrate downwards during the winter season, when temperature and winds become prohibitive on this isolated 4,000 m high volcano. From the south-eastern summit of Taftan issues a whitish cloud of sulfurous vapour and steam, which varies in its apparent intensity according to weather conditions (increasing during moist periods and a low pressure) and which is visible from a distance of over 100 km. For this reason, the Taftan has often been regarded as an active volcano, though no normal volcanic activity is known in historical time. In this connection it is interesting to know that in the high valleys surrounding Taftan ancient monuments of a now extinct civilisation exist (GABRIEL 1952). However, the name "Taftan" could have been derived from "Taft", which in the ancient Iranian literature was used for "semi liquid flowing material", like molten ore. The verb "tafteh" refers to moulding of semisolid material. This interesting information, for which I thank Dr. H.K. Afshar of Teheran University, could indicate that ancient dwellers in this area had noticed some flowing lava and that after all some volcanic activity persisted into the oldest historical time.

I investigated the Taftan volcano and the surrounding area in 1952 and 1956 during reconnaissance work for the Iran Oil Company. After the devastating earthquake of Dasht-i-Biaz in the northern Lut (East Iran) in 1968 (GANSSER 1969) it was repeatedly reported that the Taftan volcano showed an increased activity. The Geophysical Institute of Teheran University wanted to check these rumours, and since I had to visit Iran in the fall of 1970, I proposed to investigate Taftan again, in order to compare its actual performance with my previous observations of 18 years ago. In addition to the field work much information was gathered from aerial photographs and incorporated in the attached maps. I take this opportunity to thank Dr. H.K. Afshar, Director of the Geophysical Institute for the efficient assistance he gave me during my recent investigations in Beluchistan.

2. The geology of the Taftan area (Fig. 2)

The Taftan volcano is 4,100 m high and the highest of the three large andesitic volcanoes of the Iranian and Pakistani Beluchistan area. 170 km to the east-north-east we find the Kuh-i-Sultan volcanic group with the Miri summit of 2,510 m and 130 km west-south-west the Kuh-i-Bazman 3,490 m high[1]). All three volcanoes show a very complex geological history which, due to the strong erosion, is not easily recognized. They are sitting on intensely tectonized ranges of Paleogene to Upper Cretaceous age consisting of synorogenic flysch-type sediments with zones of a slightly older ophiolitic suite and locally developed Colored Melange (GANSSER 1955, 1969). They were intensely folded and faulted prior to the volcanic activity, which seems to bear no relation to the structural trend.

Widespread basic igneous activity began in Iran in the Upper Cretaceous and belongs to the ophiolitic suite, related with its peculiar pelagic sedimentation to more or less narrow zones of major tectonic importance (GANSSER 1969, STÖCKLIN 1968). Older sediments are unknown along these belts, but they often border them. They are sometimes even of Precambrian age. Surprisingly rapid changes in facies and sedimentary thickness are related to these zones (STÖCKLIN 1968).

[1]) The heights above sea level are still approximate. The heights of Taftan and Bazman (checked with altimeter) are lower than indicated on the 1:250,000 USAF aeronautical charts (ed. 1957), where Taftan is recorded with 4,350 m and Bazman with 3,740 m. The height of Kuh-i-Sultan of 2,510 m is taken from the 1:253,440 Geological Map of Pakistan (1960).

Volcanic rocks characterize the Eocene and Lower Oligocene of most of Iran as subsequent events, following the first major orogenic phase of Alpine type. This volcanism was mostly submarine and produced thick sections of pyroclastics, which in the southern Elburz and in Central Iran are over 3,000 m thick. They are, however, not of the ophiolitic type. Volcanic activity locally continued into the Neogene but not as widespread as during the Eocene climax. Towards the end of the youngest Pliocene folding movements the phase of volcanic activity began which persisted into Recent time and produced the large volcanic centres, of which Taftan is one example. However, this sequence of events, well exposed in Central Iran, is less evident in eastern Iran and the bordering area of Afghanistan and Pakistan. The geology of East Iran is dominated by the relatively stable north–south aligned Lut Block, more than twice the size of Switzerland, which is covered by extensive Eocene volcanics and is underlain by gently folded and reduced sections of Mesozoic and Paleozoic rocks. Locally Precambrian has been observed, and further work may increase these finds (Stöcklin 1968). The western Lut is dissected by north–south directed fracture zones – a northern continuation of the Oman lineament – which were already active in the early Mesozoic. On all sides, mobile ranges border the Lut Block to which the Djaz Murian basin is included as its southern extension. They are particularly well exposed on its south-eastern side, where the highly complicated Beluchistan ranges divide, running north–south on the east side of the Lut Block and east–west on its south end. (See also Geological Map of Iran 1959.)

All borders of the Lut Block are characterized by a strong mobility expressed in strike slip movements along major disturbances (Freund 1970). They limit sediments of differing facies. The Eocene volcanics of the Lut Block change south–east-wards into thick flysch-type sediments of the East Iranian ranges, where volcanism is strongly reduced. The platform facies of the Mesozoic changes into mostly pelagic, partly ophiolitic oceanic sediments. Further to the east – limited by a major disturbance east and north-east of the East Iranian ranges – Eocene volcanism and shallow sediments reappear in westernmost Pakistan. On the south-western border of the East Iranian ranges a striking belt of marine Oligo-Miocene sediments with sharp north–south aligned narrow structures passes between the Bazman volcano and the East Iranian ranges and merges into the southern Lut (Fig. 2). Along the vertical north–south fault zone, which separates this belt from the East Iranian ranges, tectonized lenses and narrow zones of serpentine occur. The flysch-type sediments show a slight increase in metamorphism towards this fault zone. These are further facts underlining the importance of these north–south directed structural trends.

The subrecent volcanism of the Bazman, Taftan and Kuh-i-Sultan volcanoes is subsequent to such major tectonic disturbances, as will be seen by the alignment of those volcanoes across the main structural trends (Fig. 1 and 2), the Bazman being situated on the southern Lut Block, the Taftan in the middle of the East Iranian ranges and the Kuh-i-Sultan in Pakistan to the east of the latter. No subrecent volcanic activity is related to these tectonic alignments, except the small volcanoes on the Naiband-Tabbas trend of the western Lut (Stöcklin 1968). This fact must be emphasized when considering a possible relation between tectonic trends, earthquake activity and recent volcanism (Ambraseys 1969, Gansser 1969).

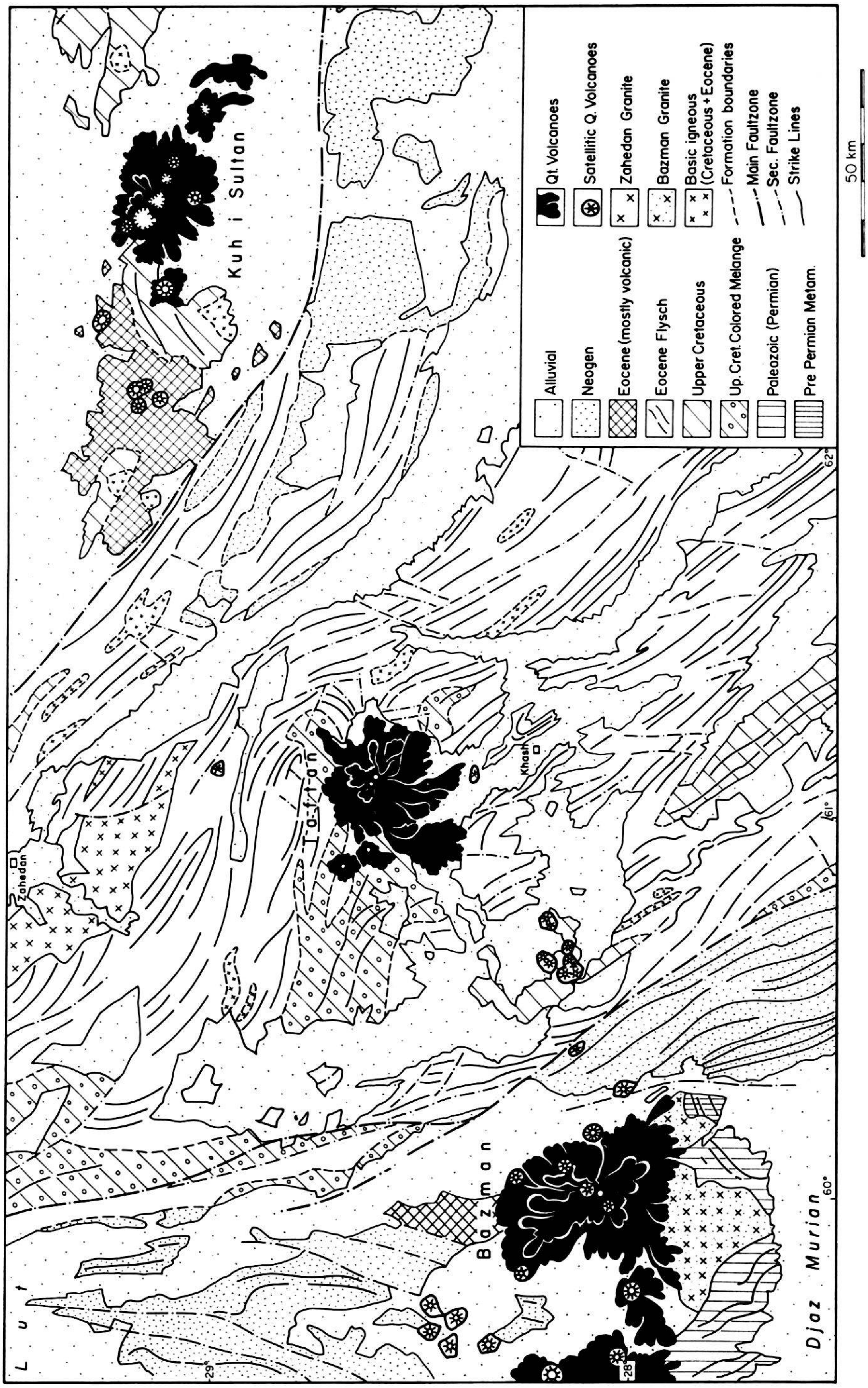

Fig. 2. Geological map of the Beluchistan volcanoes (SE Iran/SW Pakistan).

In eastern Iran the subrecent volcanism began towards the end of the Pliocene in the Sistan area (170 km north of Zahedan), where basalt sills and flows intrude and cover Pliocene deposits consisting of gypsiferous silts, sands and conglomerates with Paleogene pebbles towards the top. The basalt flows form the legendary plateau mountain of Kuh-i-Khwadja, rich in remnants of an ancient civilisation and surrounded by freshwater lakes in the centre of the Sistan plain (STEIN 1916). The sills consist of olivine basalt to olivine dolerite with zoned labradorites (oligoclase rim). The thick basalt flow of Kuh-i-Khwadja exposes a highly vesicular top flow with pumiceous intercalations. The vesicles are partly filled by calcite and zeolites. The main basalt layer is free of vesicles, and contains phenocrysts of olivine and a ground mass of middle basic plagioclase, brown augite and fine magnetite. This olivine basalt shows a chilled base and has caused fritting on the underlying silts. The exposures of the Sistan area indicate that the subrecent volcanism began with a rather basic (olivine basalt) activity. The following volcanic events, leading to the large Beluchistan volcanoes, are more acid, and the latest small satellitic volcanoes produced again olivine basalt (GANSSER 1966).

The volcanic rocks of the Taftan cover an area of approximately 1,050 km^2. This is to be compared with 1,200 km^2 for the Bazman and 1,000 km^2 for the Kuh-i-Sultan volcano. The prevolcanic rocks underlying Taftan belong all to strongly folded Eocene flysch formations and Upper Cretaceous Colored Melange rocks. They both form here the north–north-west striking East Iranian ranges with added structural complications in the wider Taftan area. Intercalated in the Eocene flysch we find steep reef limestones rich in *Alveolina* and *Nummulites*, outcropping in the wild mountains north of Khash. In the Taftan area, the flysch is mostly of Middle to Lower Eocene age. Further south it becomes younger and includes Lower Oligocene (Makran area). To the north (Sistan area) the flysch facies reaches into the Paleocene. Towards Zahedan one observes a slight metamorphism altering the argillaceous sections into lustrous phyllites. Into this metamorphic flysch intrudes the Zahedan granite with a hornfels-type contact metamorphism causing a high enrichment of biotite. The regional metamorphism is not directly related to the granitic intrusion. The medium to fine grained biotite granite is quite uniform and shows surprisingly little sign of stress. Parallel, north–south directed hornblende dolerites cut the granite in great quantity and extend partly into the flysch. The clearly exposed intrusive flysch contact (visible south of Zahedan) and the weak tectonization of the granites support its young post Eocene age. No upper age limit is yet known and radiogenic ages are not yet available. Some dark slates near the granite north-west of Zahedan are somewhat different from the normal phyllitic flysch, and the question arises if some older sediments are intercalated in the steeply dipping phyllites.

On the south-east, the north-east and the west side of Taftan, Upper Cretaceous sediments outcrop, which are developed as Colored Melange with all the sedimentary, volcanic and igneous basic and ultrabasic rocks intimately mixed. Thick radiolarite bodies are frequent on the west side of Taftan. Similar Colored Melange rocks follow the western fault zones of the East Iranian ranges west and north-west of Taftan.

To the south-west of Taftan and west of Khash sharp and rugged peaks are formed by upper Cretaceous limestones, a facies differing from the Colored Melange but reminiscent of the Upper Cretaceous uplift of Kuh-i-Birg south of Khash with pelagic *Globotruncana* limestones (Fig. 2). Through these wild limestone mountains cut small volcanoes displaying perfectly preserved craters with lava flows of olivine basalt. They form a young volcanic link between Taftan and Bazman volcanoes.

2 *a) The Taftan volcano (Plate I)*

The first activity of the Taftan began at a volcanic centre approximately 25 km to the west–north-west of the present summit forming a highly dissected peak of 3,100 m (A)[2]). Flat-lying andesitic flows with agglomeratic layers at their base are still well preserved, capping the steeply folded flysch and Colored Melange ranges. The outline of these flows can be observed in several isolated flat topped peaks, which indicate that this volcanic centre covered with its lava flows a minimum area of about 400 km^2. The base of these flows lies approximately 500–800 m above the present surrounding alluvial level and it seems likely that this western volcanic centre has been uplifted after its activity, and consequently strongly dissected. The more basic, basaltic initial phase, such as mentioned from the Sistan area, seems not represented in the Taftan volcano.

Following this first activity a subsequent centre can be recognized 7 km to the south–south-east in the Kuh-i-Anar (B)[2]). Here we find a similar original extension of the flows as in the first one. In both these older volcanic centres are indications of a renewed activity with less eroded lava flows, which may have been simultaneous with the next larger activity further to the east. Some highly dissected lava remnants occur locally further to the south-east and may indicate a restricted older activity in this area.

This centre (C)[2]) about 10 km to the west of the main Taftan summit must have had a considerable activity and seems responsible for the largest visible flow of andesitic lavas and agglomerates extending for nearly 30 km to the south. Nothing is left of the central vents. Only a rugged area of intensely autometamorphic andesitic rocks (altered through volcanic gas activity) remains. Similar altered volcanic rocks can be followed into the main Taftan centre, where they are covered by younger lava flows and are difficult to separate from similarly autometamorph andesites belonging to the recent fumarolic alterations. All these earlier volcanic centres have produced andesitic lavas, which seem similar to the youngest flows of the main Taftan centre.

The highest part of the Taftan volcano (D)[2]) consists of two summits of approximately the same height of 4,100 m, and are about 2 km apart. The north-eastern one has well preserved lava flows and two craters, but lacks any postvolcanic activity (No. 4 and 5 on Fig. 3). The northern larger crater (No. 5) has produced more lavas than the southern somewhat higher crater (No. 4) with a more pyroclastic cone. Compared to the south-eastern main summit the north-western centre is stronger eroded.

Of particular interest is the south-eastern main centre of Taftan. Here we find a very strong postvolcanic activity with well preserved lava flows and craters in spite of a strong erosion, which affected particularly the eastern slope of the main crater. All these facts indicate that the volcanic activity of the Taftan volcano sensu lato

[2]) These letters are indicated on the enclosed detailed map of Taftan (Plate I).

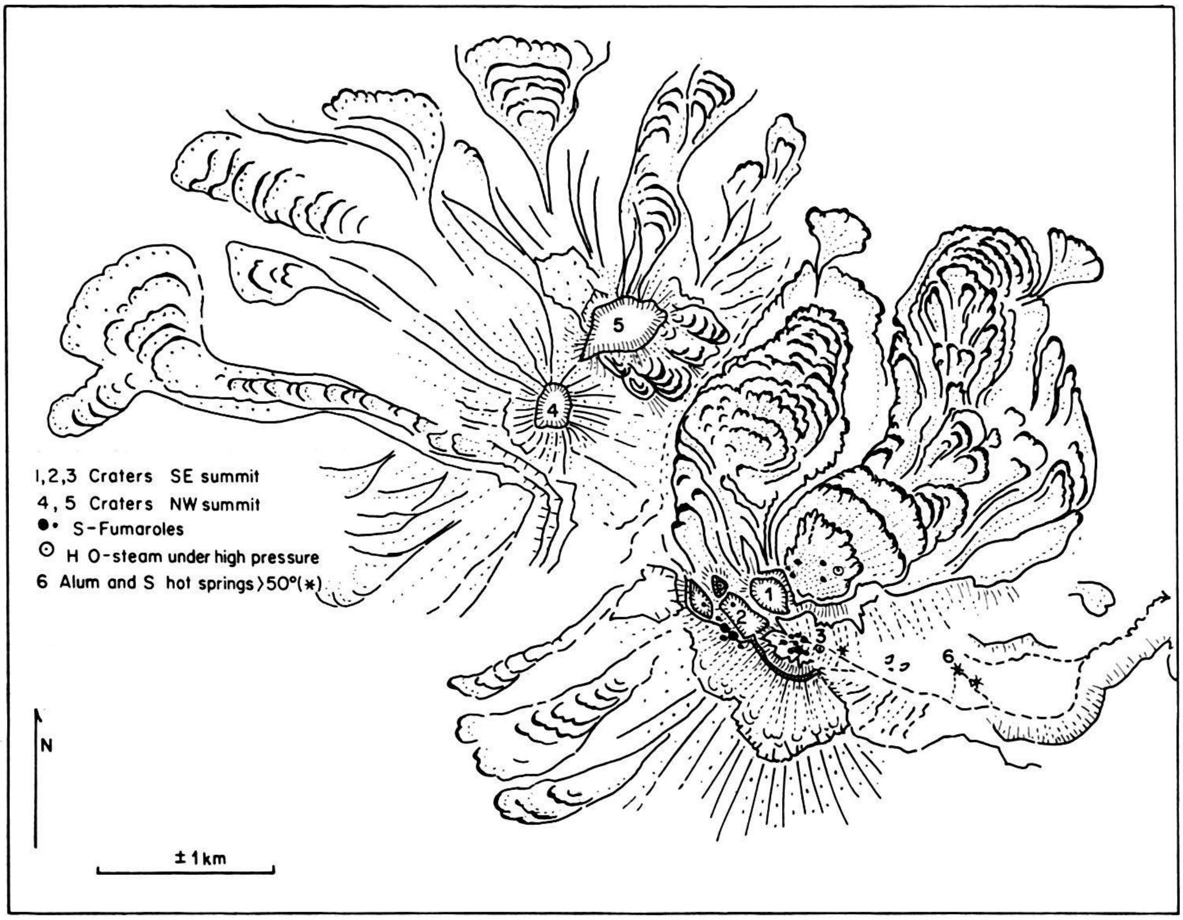

Fig. 3. Taftan volcano summit area.

began on its west–north-west end and migrated in subrecent time 25 km to the east–south-east, where it produced the presently "active" centre. During this migration some renewed activity must have occurred in the older centres, a fact supported by the presence of some less eroded lava flows. The present centre consists of three main craters (No. 1, 2 and 3 on Fig. 3) and two smaller secondary craters. They are all situated on the 4,100 m high main summit. The eastern crater (No. 3) exposes a perfectly preserved crater rim with well bedded lavas and pyroclastics on its south side, while the eastern part is completely missing (Fig. 5). It may have been blown off by an eastwards directed explosion, forming a very steep ravine, which drained the summit and through which flows some sulfuric hot water to the east. From crater No. 1 issued the two largest and youngest lava flows with perfectly preserved flow features. Both descended the northern slope of the main summit and are well visible from a distance (Fig. 4). They were preceded by somewhat older north, north-east and eastwards directed flows, which descended over 12 km and are still well preserved, exposing characteristic flow features.

A strong fumarolic (solfataric) activity is concentrated around the eastern half crater No. 3 and at the rim of crater No. 2. Single fumarolic vents occur within crater No. 2 and in the smaller craters to the west. Further vents are situated in the upper part of the major lava flow. On three places, in the upper lava flow, the lower part of

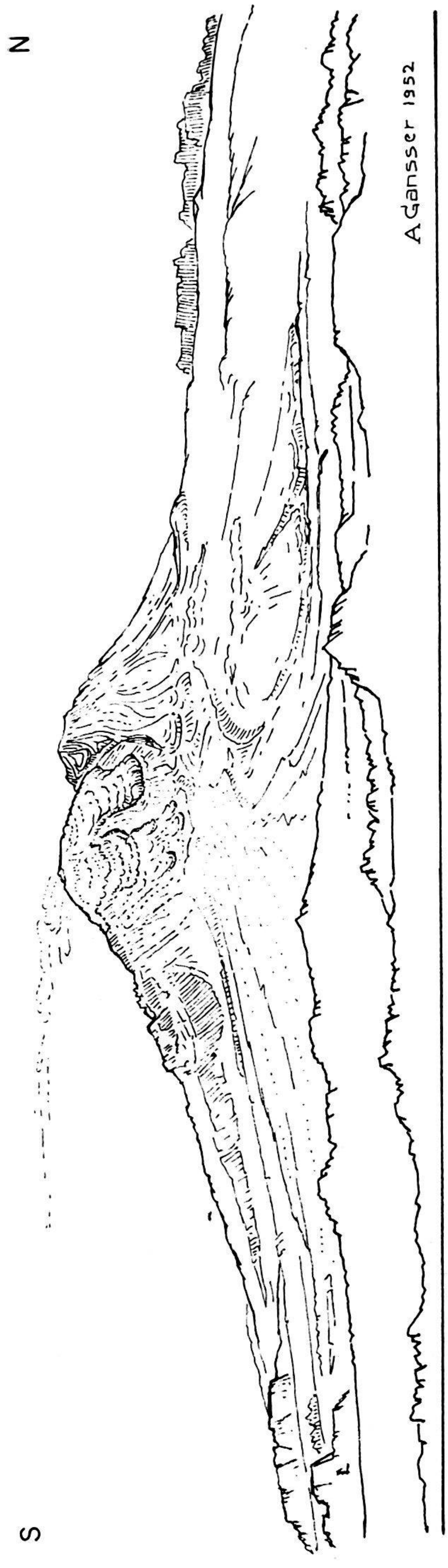

Fig. 4. The E side of Taftan volcano with SE and NW summits. Foreground flysch outcrops.

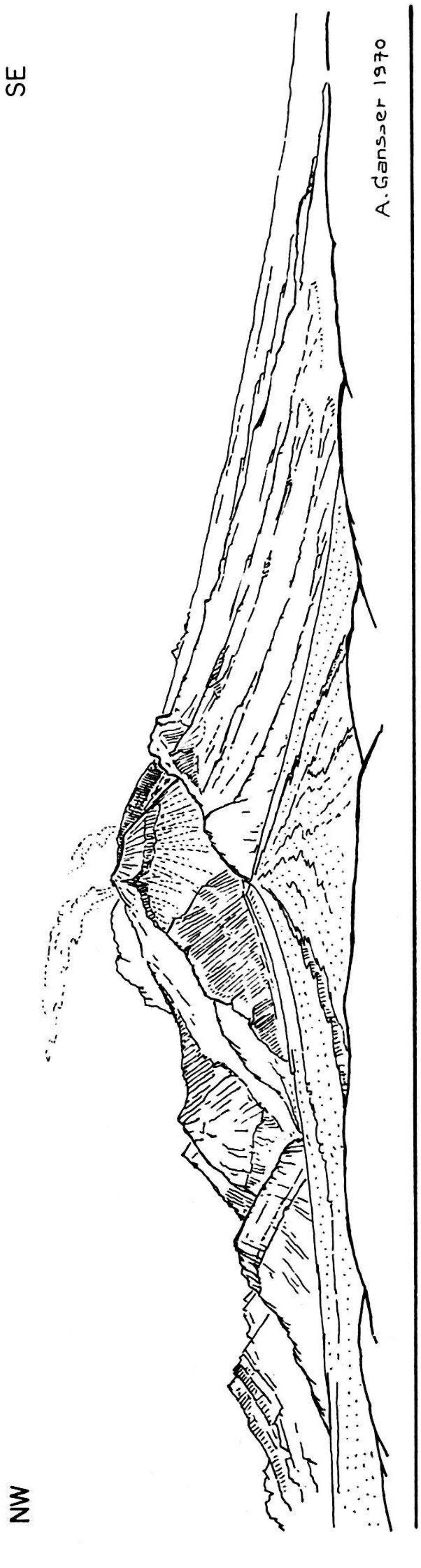

Fig. 5. Taftan volcano seen from Takht-i-Rostam.

crater No. 3 and in the small crater west of No. 2, high pressure gas and steam with only a little sulfur issues with a strong hissing noise. The normal fumaroles vary in size from very small holes to vents of 1 m diameter. The latter occur in the eastern half crater No. 3 and along the outer rim of crater No. 2. A considerable amount of sulfur is concentrated at the large fumaroles. Several thousand tons of sulfur have been accumulated along the main summit of Taftan. The fumarole and solfatar activity have altered the pyroclastic rocks as well as some of the andesitic flows. These highly colourful autometamorphic rocks are well exposed on the east slopes of Taftan summit.

The youngest lavas connected to this main summit consist of gray to dark gray medium grained andesites. The middle basic plagioclases are mostly idiomorph and form up to 1 cm large phenocrysts. They are zonar with a more basic rim. Larger basaltic hornblendes and some biotite form other phenocrysts, while rhombic as well as monoclinic pyroxenes are of a smaller generation. In some of the andesites I found inclusions of older rocks such as chlorite schists and a fine banded biotite gneiss, which contained some nests of diopside. Along the contact towards these inclusions the andesites show a 1 cm broad fine grained reaction rim. These rare inclusions are, however, most significant, since they represent metamorphic rocks unknown from the surrounding pre-volcanics of the Taftan area.

On the southern upper slopes of Taftan occur highly dissected flows and pyroclastic layers, locally strongly autometamorphosed, which are older than the main Taftan volcanics and may be related to the older and more western eruptive centre (*C* on the map Plate I).

Preliminary results of chemical analysis of the youngest Taftan lavas indicate an andesitic to dacitic composition of a strictly Pacific magma suite. This contrasts, for instance, with the Damavand lavas, where a more mixed association with Atlantic tendencies has been reported (ALLENBACH 1966). Lack of sufficient samples and corresponding analysis does not allow us to recognize a progressive differentiation in an acid direction from the older to younger volcanic activity, which is well established in the Damavand volcano. Chemically the Taftan lavas are slightly more acid than the results of the thin section investigation would indicate. The higher silica content is most likely concentrated in the glassy ground mass, as is often the case in middle basic hemicrystalline volcanic rocks. However, the basic rim of the zonar plagioclases may indicate a more basic tendency for the last crystallization, contrary to the Damavand trend but more in line with the youngest basaltic volcanism of the satellite vents of Bazman volcano.

The Central Taftan mountain is surrounded by wide fans of pyroclastic rocks with included agglomeratic layers. The latter are often cemented by andesitic tuffs with larger feldspars, augites and hornblende crystals. The cementing tuffs of the agglomerates have a similar composition as the andesitic lavas. The middle basic plagioclases show the same inverse zonation, the hornblendes are basaltic, and fine-grained orthopyroxenes are frequent. The same mineral composition is present in the components of the agglomerates, which are also andesitic, but with a more greenish, ordinary hornblende. In the deeper ravines of the south-east and east side of Taftan, where the steeper slopes begin, thinly crossbedded yellow tuffs occur locally below the coarse agglomerates. They are transgressed by agglomerates, which often form irregular pockets. In general finer pyroclastics are not frequent in the Taftan area.

Through the superposition of the pyroclastic fans a relative age relation can be observed. Some of the younger ones occur on the southern slope of the main Taftan volcano and extend over 15 km to the south. Reworked pyroclastic material is frequently found in the wide alluvial fans extending towards the region of Khash. The connection of the pyroclastic fans with original vents has been completely obliterated by erosion. Pyroclastic cones are rare on the steeper slopes of the mountains and are mostly absent around the older volcanic centres A, B and C.

2 *b) Takht-i-Rostam*

25 km to the south of the Taftan main summit, just south of the largest pyroclastic fan, stands a small table mountain, locally called Takht-i-Rostam. Its morphology contrasts with the sharp peaks of the flysch and limestone mountains. The flat top consists of a black basalt layer, transgressing on its western side on steeply dipping flysch. Macroscopic phenocrysts of a fresh green augite and some olivine are visible. The ground mass consists of fine elongated basic to middle basic plagioclases, which are arranged in a marked fluidal pattern. The basalt resembles the basic satellite volcanoes of the Bazman area (GANSSER 1966). A very similar flat topped basalt hill stands at the large fault zone bordering the eastern Lut just east of Bazman volcano. From this unique occurrence it is difficult to decide if Takht-i-Rostam represents the remains of a larger basaltic sheet or a local basaltic extrusion with a flat basalt flow. The latter seems more likely since no other remnants are known. In any case, this basalt flow is not directly related to the main activity of the Taftan volcano. It forms an erosional relic and may even be slightly older than the youngest volcanic activity which resulted in the two well preserved andesitic flows on the north side of Taftan summit.

2 *c) The present activity of the Taftan volcano*

Fumaroles and solfataras

In the foregoing chapters we have already noticed that Taftan is the most active volcano in Iran. We further recognized how the activity began further in the west and wandered within a subrecent time span, the duration of which is not known, 25 km eastwards to the present main summit. The well preserved lava flows are most likely prehistoric, since no historic volcanic activity is known. The presence of ancient cultural vestiges in the northern Taftan area underline this assumption.

At present we recognize only a strong postvolcanic activity in the form of fumaroles, solfataras and hot springs. This activity is, however, surprisingly strong and it is understandable that it led to speculations connected to a recurrence of the main activity. In the relatively short time span in which I have observed the activity of Taftan no overall change has been noted. The sum of the activities has remained constant, while a certain local shift in the intensity of fumarolic production could be noted. In 1952 the fumaroles (solfataras) in the eastern half-crater (No. 3 of Fig. 3) were more active and spread over a wider area. Some of the larger vents with a thick sulfur crust show at present local collapse fractures not unlike small calderas, which may be a further indication of a somewhat reduced production. On the other hand, the fumaroles on the outside (western) rim of crater No. 2 (Fig. 3) have increased their activity and are mostly responsible for the white summit cloud capping the mountain (Fig. 5). Less obvious seems the fact that small secondary vents, rather widespread over the summit area in 1952 appear at present less frequent and a certain concentration of the activity to the two main locations (craters 3 and rim of 2) has been noted. The local shift of postvolcanic activities is of no further significance, and, judging from my previous and present investigations, I must conclude that in spite of these local changes, the overall activity of the Taftan volcano has remained constant. Climatic changes, air pressure, moisture and temperature influence the apparent activity and should be considered when making visual comparisons.

Hot springs

On the east side of Taftan volcano, in the steep valley leading up to the eastern crater (No. 3) occur most interesting alum and sulfur hot springs (No. 6 on Fig. 3). The temperature is over 60 °C and the springs which issue from an agglomerate terrace produce a concentrated alum water with its typical sour and highly stringent taste, mixed with some sulfur. Most striking are the strong colours of the crystallized salts, varying from brilliant red-orange to white. Further up towards the eastern crater a smaller hot alum and sulfur water spring exists, issuing from large andesite boulders fallen from the steep crater walls. The local nomads reported that about 12 years ago (1958?) a strong geiser-like eruption was noted in the eastern half crater, which initiated the upper hot spring, which apparently did not exist before. A certain irregularity in the production of hot water seems evident, noticeable on the water marks in the gorge. Two weeks prior to our visit a sudden increase in hot water production was noted by the nomads, and the river flooded the eastern road north of Sangan. When we passed this spot on our return to Zahedan, alum water was still running over the road, while in the gorge just below the eastern crater only a trickle of hot water was flowing. It seems evident that the hot water production on the east flank of Taftan can be quite erratic. No other hot water springs have been reported in the wider Taftan area.

2 d) The Bazman volcano (Fig. 6)

West of the most important western border fault zone of the East Iranian ranges, limiting the latter against the Lut Block, we find the Bazman volcanic centre. This volcanic group, similar to Kuh-i-Sultan, has again an andesitic composition of the Taftan type. It is, however, situated in the southern Lut Block, and the general setting is strikingly different from the East Iranian ranges (Fig. 2). Precambrian metamorphics, well known Paleozoic horizons (Douglas 1950) and younger granites underlay the volcanic rocks. These granites, which I called Bazman granites (Gansser, unpublished reports), are of particular interest as they may represent a precursory intrusion of the whole southern Lut volcanism. The granite is massive and, similar to the Zahedan granite, very little tectonically affected. It is striking because of its pink colour, caused by finely disseminated haematite flakes in the orthoclases. This pink, medium grained biotite granite contains frequent pink aplites and pegmatites with a graphic granite texture. To the north-west, the Bazman granite is intruded by biotite dacite masses,

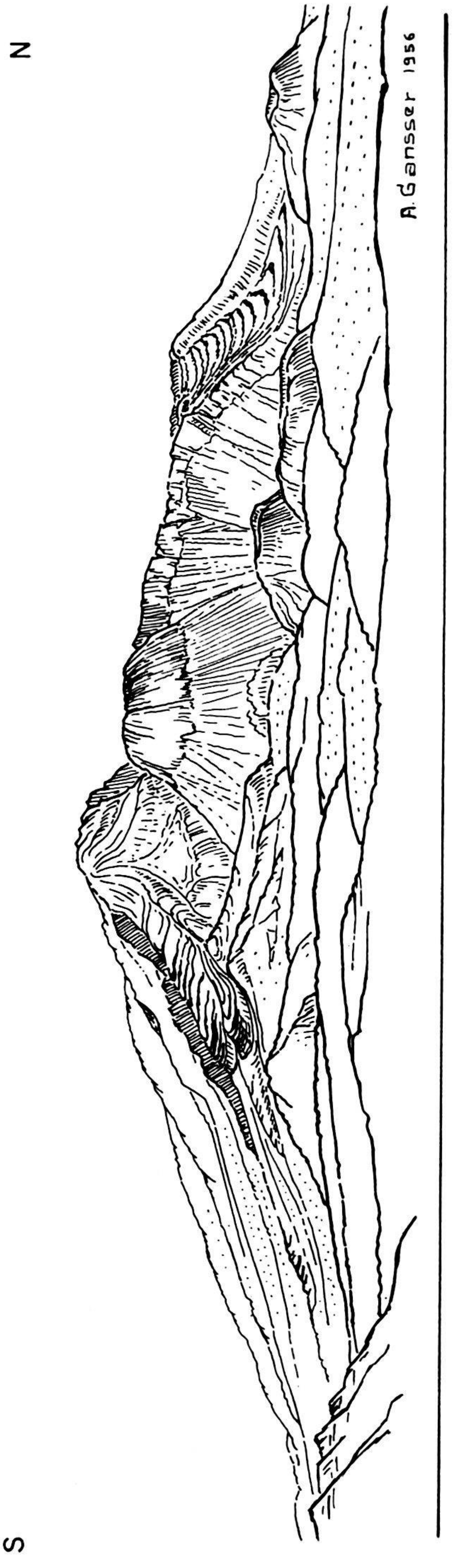

Fig. 6. The east side of Bazman volcano. Note elevated lavaflows and satellite craters.

containing still some devitrified glass in the ground mass. The dacitic rocks, a younger phase of the granitic intrusion, are directly covered by the andesitic lavas and tuffs of Bazman volcano.

In a striking contrast to the Taftan volcano, Bazman, which shows no activity, is pierced on its flank and its footzone by younger satellite volcanoes with perfectly preserved craters and lava flows (Gansser 1966). Some of them show features resembling minute shield volcanoes. All these younger satellites expose black olivine and augite basalts and are considerably more basic than the acid andesites of the "mother" volcano. Very similar small volcanoes have already been mentioned east of Bazman and east of the main fault zone, piercing Upper Cretaceous limestone mountains. Their location east of the Lut border fault and already within the East Iranian ranges is most significant. They show a direct link to the Taftan group, where apart from the mysterious Takht-i-Rostam table mountain no young basaltic rocks are known (Fig. 2).

To the west of the Bazman volcano we find a young volcanic belt studded with numerous small craters and rather viscous though basaltic lava flows covering an area of over 2,000 km². They resemble very much the basaltic satellites of Bazman and may be of the same age, a fact corroborated by their perfect preservation. Locally some small "puy"-type domes occur in the same area. Further west and north-west this young belt is replaced by the extensive Eocene volcanic mountains south of Bam. They belong to the south-easternmost extension of the Eocene volcanic belt traversing Iran from north-west to south-east and paralleling the important Zagros thrust (see Geological Map of Iran 1959).

3. General outline and conclusions

Preceding the Quaternary volcanism in the Beluchistan area, we find a long and most complicated geological history. While the Paleozoic and even older events are relatively well known in the rest of Iran, in the little known Beluchistan this part of the history is still undeciphered. Beginning with the Mesozoic, we note an unconformable transgression of Liassic sediments on probably Precambrian metamorphic rocks in the western Djaz Murian basin, a southern continuation of the Lut Block, as well as strong north–south directed horst and graben movements in the western Lut (STÖCKLIN 1968). They belong to the late Triassic events which are widespread in the rest of Iran.

One of the strongest orogenies in Central Iran, the late Jurassic–pre-Aptian phase, accompanied by a weak metamorphism, is not evident in the orogenic belts of the wider Beluchistan area. Corresponding movements on the Lut Block were more epirogenic than orogenic, while in the East Iranian ranges and locally already in the eastern Lut thick and pelagic sediments of middle to Upper Cretaceous occur (STÖCKLIN 1968). Along certain structural belts the Upper Cretaceous is ophiolitic and displays the chaotic mixture of the Colored Melange together with synorogenic sediments. It reflects the first Alpine orogeny. This is followed after some erosion by 4,000–5,000 m thick flysch-type sediments of Eocene age with local reef limestone intercalations and little volcanic admixture. They strongly contrast with the widespread volcanic Eocene facies covering the Lut Block and again the area east of the East Iranian ranges (Kuh-i-Sultan area). The flysch facies of the East Iranian ranges is limited by the western and eastern fault belts, dividing sharply the two facies areas. The East Iranian flysch ranges, together with the Makran ranges, are thus more closely related to the Beluchistan-Indus ranges and finally to the North Himalaya than to the rest of Iran.

A second Alpine orogenic phase folded and locally even slightly metamorphosed the flysch sediments. This intense folding phase was most pronounced in the Neogene as is witnessed by the steep Bazman sedimentary belt. Subsequent to this phase or even independent from it we find the intrusion of the Zahedan granite with its conspicuous basic dykes. The granite shows very few stress effects. In the southern Lut Block at the base of the present Bazman volcano the Bazman granite might correspond to a similar intrusive phase in spite of its different composition (pink colour, rich in pegmatites but without basic dykes).

A last Alpine orogenetic phase involved the younger Neogene deposits. Its separation from the older major second phase is less obvious in the East Iranian ranges than in the rest of Iran. A most important north–south aligned faulting, combined with strike slip movements cuts all precedent structures and terminates the last major orogenetic phase. The fault belts east of the Lut Block and north-east of the East

Iranian ranges belong to these last events. Numerous secondary faults are associated and occur within the East Iranian ranges.

Unrelated to this structural frame produced through the various Alpine orogenic phases we find the latest event, the Quaternary volcanism, producing the spectacular volcanic centres of Beluchistan. This volcanism may be related to the still active morphogenic phase with regional uplifts often not in line with the previous orogenic trends. Some local east–west aligned subrecent faults near Kosha on the south-west flank of Taftan (Plate I), which cut volcanic fans and older lava flows may be small but significant indications for such a movement. Their northern side is uplifted.

A glance at our Figures 1 and 2 shows that the largest Quaternary volcanoes of Beluchistan, the Bazman, Taftan and Kuh-i-Sultan form a volcanic belt extending from west–south-west to east–north-east over a distance of 300 km. All three volcanoes have surprisingly similar dimensions, less evident in their different elevations than in the extent of lava coverage, and the main centres are somewhat evenly spaced. All three volcanoes are connected through small satellitic vents of a more basic composition, well outlined between Taftan and Bazman. East of the north-eastern fault zone we find the Kuh-i-Sultan volcano situated in a less tectonized segment of the Pakistan Beluchistan ranges. The Kuh-i-Sultan resembles very much the Taftan volcano with its fumaroles and solfataras, its andesitic compositions and younger and oldeı eruption centres, and a corresponding strong erosion. Smaller satellite vents within the mostly volcanic Eocene are known 60 km west of the main summit and indicate a certain link towards the Taftan group.

Two major tectonic trends separate the three volcanic centres: the eastern border fault zone of the Lut Block between Bazman and Taftan and the north-eastern border of the East Iranian ranges between Taftan and Kuh-i-Sultan. These mobile conspicuous fault belts display a considerable horizontal shift apart from steep vertical movements. The facies changes on both sides of the fault zones, the presence of a local weak metamorphism as well as highly sheared ultrabasic rocks underline the importance of these structural trends. They are known to have been very active and have outlasted the youngest orogenic movements. Still they have not affected the Quaternary volcanism, a fact clearly shown by the trend of the volcanic belt running with 90° across the fault trend and the complicated strike features of the East Iranian ranges.

Some earthquakes in Iran are related to structural trends. The major quakes, however, cannot be reasonably correlated with major and young structures. Large discrepancies must be assumed between the surface structures and the deeper subsurface. This may be even more true for the Quaternary volcanism, in particular in Beluchistan, where some of the most complicated surface structures seem in no way related to the youngest volcanic activity. The small inclusions in the youngest lavas of the Taftan volcano of metamorphic rocks unknown in this area may be a minor but most significant fact. A relation between earthquakes and recent volcanic activity seems equally unlikely as the relation of the young volcanic trends to their structural frame.

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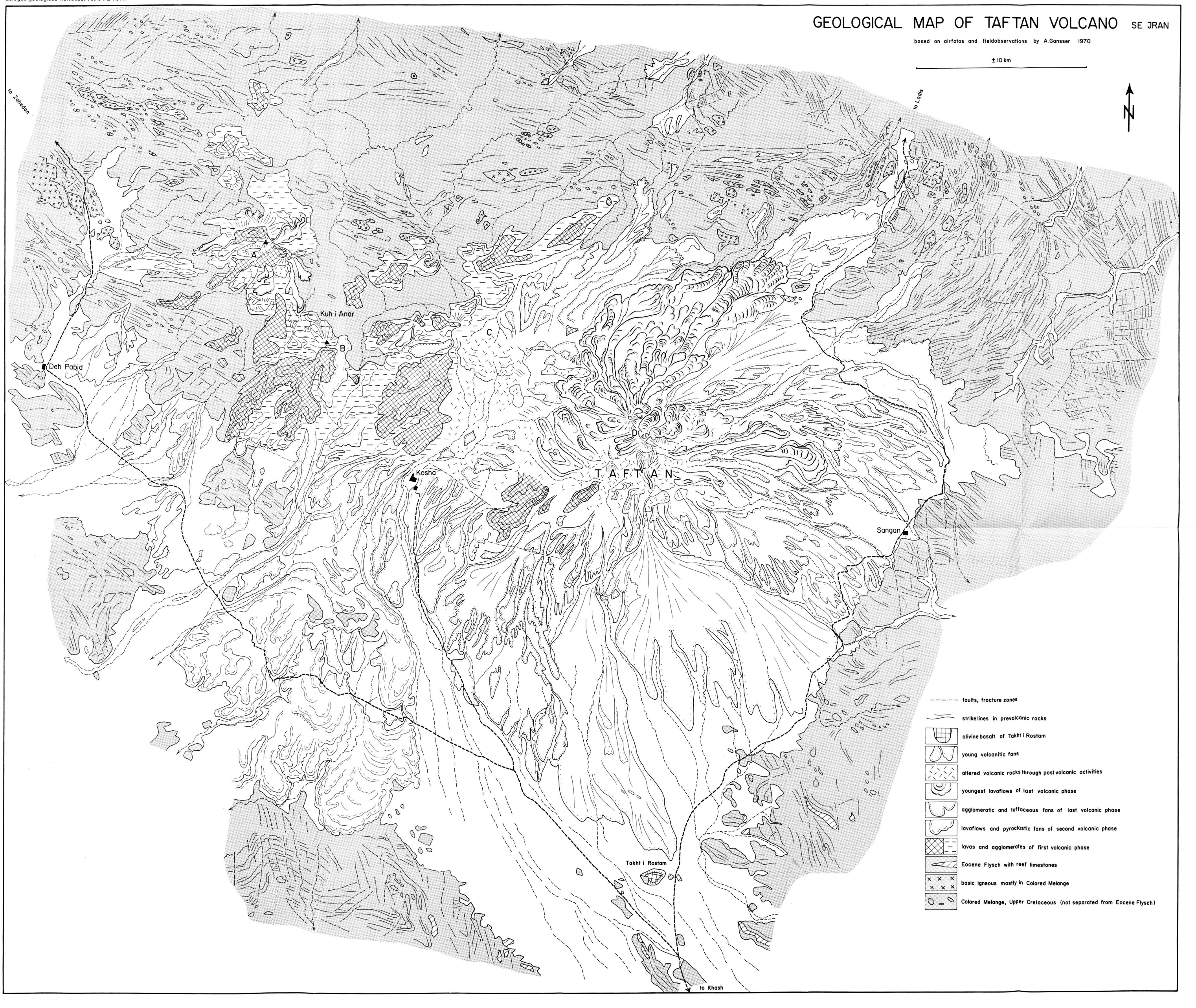
GEOLOGICAL MAP OF TAFTAN VOLCANO SE JRAN
based on airfotos and fieldobservations by A.Gansser 1970
± 10 km
N
to Zahedan
to Ladis
Kuh i Anar
A
B
C
D
Deh Pabid
Kosha
TAFTAN
Sangan
Takht i Rostam
to Khash
faults, fracture zones
strike lines in prevolcanic rocks
olivine basalt of Takht i Rostam
young volcanitic fans
altered volcanic rocks through post volcanic activities
youngest lavaflows of last volcanic phase
agglomeratic and tuffaceous fans of last volcanic phase
lavaflows and pyroclastic fans of second volcanic phase
lavas and agglomerates of first volcanic phase
Eocene Flysch with reef limestones
basic igneous mostly in Colored Melange
Colored Melange, Upper Cretaceous (not separated from Eocene Flysch)