GEOLOGICAL SURVEY OF IRAN

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Managing Director: *Nasrollah Khadem*
Project Manager: *Gordon J. Williams*

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Explanatory text of the Boshruyeh Quadrangle Map

1 : 250,000

From maps and reports by J. Eftekhar-nezhad, A. Hushmand-zadeh, M.H. Nabavi, J. Stöcklin, Sh. Tatevossian and M. Zahedi

Compiled by J. Stöcklin and M.H. Nabavi

Geological Survey of Iran, 1971
Geological Quadrangle No. J7

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ABSTRACT

The Boshruyeh Quadrangle is situated in the Khorassan Province of eastern Iran. It covers part of the Tabas basin, the north-trending Shotori Range, and part of the northern Lut Desert.

The exposed rock sequence starts with limestones and dolomites of the Devonian (Bahram Formation, 500 m), which are followed by mainly sandy and shaly beds with subordinate limestone intercalations ranging from Upper Devonian to Lower Permian (Shishtu and Sardar Formations, about 1200 m). The Sardar is the only formation known so far in Iran to include beds attributable with a high degree of probability to the Upper Carboniferous. It is overlain by the almost exclusively carbonatic Tabas Group (Jamal, Sorkh Shale, and Shotori Formations, 2000 m), which forms the highest peaks of the Shotori Range and is Permian to Middle Triassic in age. The highly fossiliferous Upper Triassic Nayband Formation (0-800 m) is limited to the basinal areas east and west of the Shotori Range. Within the range, the plant-bearing sandstones and shales of the Liassic Shemshak Formation (0-2000 m) rest with pronounced unconformity on various older rocks. They are followed by a richly ammonitiferous limestone marker (Badamu Limestone, 40 m) of Bajocian-Bathonian age and this by marly shale of the higher Middle Jurassic (Baghamshah Formation, 500 m). The Upper Jurassic is mainly reef limestone (Esfandiar Limestone), which changes laterally into the lithologically complex Qal'eh Dokhtar Formation (each about 1000 m). The Cretaceous is represented only by a rudimentary sequence of limestone and clastic deposits (maximum 300 m). The Tertiary section in many places begins with conglomerates (Kerman Conglomerate), which have variable thicknesses and rest with pronounced unconformity on an erosional surface of the previously folded and truncated older formations. Apart from these conglomerates, the Tertiary is represented mainly by a thick sequence of dacitic and andesitic volcanic rocks (? more than 2000 m) in the eastern desert region, where these rocks are conventionally divided into "Paleogene" and "Neogene-Quaternary", and by continental red beds of Neogene age in the Tabas basin. Quaternary alluvial and playa deposits as well as sand dunes cover large areas in the desert plains.

The Shotori Range follows a marked north-south fault trend inherited from Precambrian structure. A predecessor of the range, the "Shotori horst", came into being in Late Triassic time and has acted as an important facies divider. The range displays an intricate fault- and thrust-structure, created by the Alpine orogeny of Tertiary age, whereas the adjoining desert regions belong to the tectonically very rigid Tabas and Lut Blocks and were affected only by gentle warping and faulting during the Alpine orogeny.

The Boshruyeh Quadrangle has limited prospects for copper, lead, and iron.

EXPLANATORY TEXT OF THE BOSHRUYEH QUADRANGLE MAP

1 : 250,000

INTRODUCTION

SITUATION AND GEOLOGY

The Boshruyeh Quadrangle lies in the Khorassan Province of eastern Iran between the towns of Tabas, Ferdows, and Khur-e-Birjand. None of these three places is situated within the quadrangle itself, but they lie very close to its western, northern, and southern limits respectively. The limits are given by longitudes 57°E and 58°30'E and latitudes 33°N and 34°N.

The area belongs to the extremely arid desert region of central-eastern Iran, but its climate is somewhat ameliorated by the influence of the high range of Kuh-e-Shotori - Kuh-e-Jamal - Kuh-e-Esfandiar ("Shotori Range"), which crosses the quadrangle in a north-south direction. Temperatures show great variations: in the plains they may exceed 50° C in summer, whereas during the winter months the crest of the Shotori Range is always clad in deep snow. The annual rainfall is less than 10 cm. Water supply, therefore, is very scanty, drawn mainly from a few small perennial rivers originating in the Shotori Range and in the Ferdows Mountains. Human life depends entirely on artificial irrigation.

The access to the region is mainly by the Yazd-Tabas-Ferdows-Mashhad highway, which crosses the central part of the quadrangle and has motorable connections with Boshruyeh in the north, Seh Qal'eh in the east, Khur-e-Birjand in the southeast, and Nayband-Kerman in the south.

Physiographically the quadrangle is divided into three major zones, which trend approximately north-south and coincide with the three main tectonic zones of this part of Iran: the western desert region or Tabas basin, the Shotori Range, and the eastern desert region, which is a northern part of the east Iranian Lut Desert.

The Tabas basin is an intermontane depression with an elevation of about 600 m a.s.l. Only the southeastern edge is covered by the quadrangle. The centre of the basin is occupied by a "kavir" (salt flat), from which the whole basin has received the name Kavir-e-Tabas. Only the gravel-covered eastern margin of the basin, which receives sufficient fresh water from the Shotori Range, is inhabited. Here lies the town of Tabas (about 8,000 inhabitants), the largest centre of population in the basin, and there are a number of smaller oases such as Espahk, Parvadeh, and Paykuh. Dates, grain, citrus fruits, and cotton are cultivated in these places. Tabas is also an important commercial and administrative centre and has a small airport. The town lies midway on the Yazd-Mashhad road, which traverses the width of the east-central Iranian desert region.

The road runs from Tabas eastwards through the Shotori Range to Dehuk and thence to Ferdows, crossing thereby the central part of the quadrangle.

The Shotori Range crosses the entire quadrangle from its northwest-corner in a south-southeast direction. It is part of a more extensive range that continues south to Nayband and north to Ozbak-Kuh. The range is narrow (10 km in the south, 30 km in the north) and sharply limited by important fault lines. The highest elevation is Kuh-e-Shotori proper, a peak east of Tabas with an elevation of 2,700 m. A number of springs, rivers, and pasture grounds permit some cattle raising, but permanent settlements are limited to a few hamlets in the larger valleys. A few larger villages, however, are situated at or near the eastern mountain foot: from north to south they are Boshruyeh, Raqqeh, Ereshk, Fathabad, Dehuk, and Esfandiar. Two motorable roads traverse the range: the Tabas-Ferdows road with the Kolukhi pass in the south, and the Shirgesht-Boshruyeh road in the north, outside the quadrangle except for a short section in the northwest corner.

The Lut Desert with its northern and southern extensions is nearly 1,000 km long and occupies as a distinct north-south-trending geographic unit the greater part of east Iran. The portion covered by the Boshruyeh Quadrangle is situated in its northern sector and is a country of low-weathering hills and several intervening large gravel plains and salt flats. Among the latter, the most extensive ones are the Kavir-e-Namak in the north and the Kavir-e-Robat in the east, both with extensive sand belts on their eastern side. The lowest point is Boshruyeh (675 m); from there the area generally rises to the east (Seh Qal'eh and Khur about 1,300 m). The highest elevations are in the northern hills near Ferdows (about 1,700 m). The only settlement of significance is Seh Qal'eh with its dependencies in the northeast, altogether about 5,000 inhabitants. Caravan trade has diminished to a fraction of what it was in former times. Most of the numerous water tanks ("howz") along the old camel paths are now ruined and dry.

The town of Ferdows on the Mashhad highway, just outside the northern quadrangle limit, equals Tabas in size. The town was nearly totally destroyed by the Khorassan earthquake in 1968, but reconstruction is underway. Khur, just outside the southern limit of the quadrangle, is the westernmost outpost of the fertile Birjand district east of the Lut Desert.

PREVIOUS STUDIES

Earlier geological information on the report area is extremely scanty. In 1906 Tabas and its surroundings were visited by Sven Hedin (1918-1927) on his expedition to India, and some rocks collected by him in the vicinity of the Boshruyeh Quadrangle were described by Asklund (1927) and Dietrich (1927). Furon (1941) was the first to report on the occurrence of Paleozoic rocks in the Shotori Range. The short-lived Amiranian Oil Company did reconnaissance work in the Tabas and Ferdows areas, and determinations of a few Paleozoic and Jurassic fossils from the northern Shotori Range were published by Clapp (1940). Further reconnaissance work in the Shotori Range and in the mountains west and south of the Tabas basin was undertaken by the National Iranian Oil Company; the results were compiled on the Geological Map of Iran, scale 1:2,500,000 (National Iranian Oil Co., 1959), and two papers by Gansser

(1955) and Stöcklin (1961) briefly treated the Paleozoic, Triassic, and Jurassic rocks of the region. No geological work had been done in the eastern desert within the Boshruyeh Quadrangle except for reconnaissances along the Dehuk-Ferdows road by the oil companies mentioned above.

QUADRANGLE MAPPING

In 1963 the Geological Survey of Iran began systematic mapping in the Shotori Range as part of an extensive mapping project to cover the entire Shotori - Shirgesht - Ozbak-Kuh Range. This work resulted in three geological maps on a scale of 1:100,000, two of which have been published together with detailed reports (Stöcklin et al., 1965; Ruttner et al., 1968). The initial field work for the Shotori map that was later incorporated in the present quadrangle map was done during the spring months of 1963 by J. Stöcklin, J. Eftekhar-nezhad, and A. Hushmand-zadeh, in close cooperation with the Shirgesht - Ozbak-Kuh team of A. Ruttner, M.H. Nabavi, J. Hajian, and M. Alavi. In the later part of 1963, J. Eftekhar-nezhad, and M. Zahedi, mapped the southern extension of the Shotori Range and the adjoining desert strip. A complementary stratigraphic study in the Shotori Range was made in early 1964 by J. Eftekhar-nezhad and Sh. Tatevossian. Finally, the eastern part of the eastern desert region was surveyed by M.H. Nabavi and Sh. Tatevossian in late 1964. The present explanatory text is based mainly on the following three reports of the Geological Survey:

Geology of Shotori Range (Tabas area, East Iran), with map 1:100,000, by J. Stöcklin, J. Eftekhar-nezhad, and A. Hushmand-zadeh: Report No. 3, 1965.

Geology of Boshruyeh area, with map 1:100,000, by J. Eftekhar-nezhad, and M. Zahedi: Geol. Note No. 17, 1965 (unpublished).

Geology of the Seh Qal'eh area (south-Ferdows, East Iran), with map 1:100,000, by M.H. Nabavi and Sh. Tatevossian: Geol. Note No. 30, 1966 (unpublished).

All mapping was originally done on aerial photographs of the Worldwide Aerial Survey Corporation on a scale of approximately 1:60,000. Those of the Shotori Range were tied in to a special field triangulation carried out by H. Taraz and A. Geranpey of the Geological Survey. Adjustment of the photos covering the eastern desert area was done with the help of Shoran control points provided by the Geographic Department of the Imperial Army.

ACKNOWLEDGMENTS

Apart from the basic field work done by the geologists mentioned above, many specialists in Iran and abroad have made valuable contributions. The petrographic studies of the volcanic rocks were carried out by S. Iwao (Tokyo, United Nations), and by A. Hushmand-zadeh and M. Sabzehei of the Geological Survey. D.L. Stepanov (Leningrad, United Nations), T.S. Winsnes (Oslo, United Nations), P. Sartenaer (Brussels), O.H. Walliser (Göttingen), and H. Flügel (Graz) investigated the Paleozoic macrofossils, and F. Allemann and F. Bozorgnia (National Iranian Oil Co.) the Paleozoic microfauna. K. Seyed-Emami (Geological Survey) identified the Mesozoic ammonoids, E. Flügel (Darmstadt) determined a collection of Jurassic corals, and M. Minato and

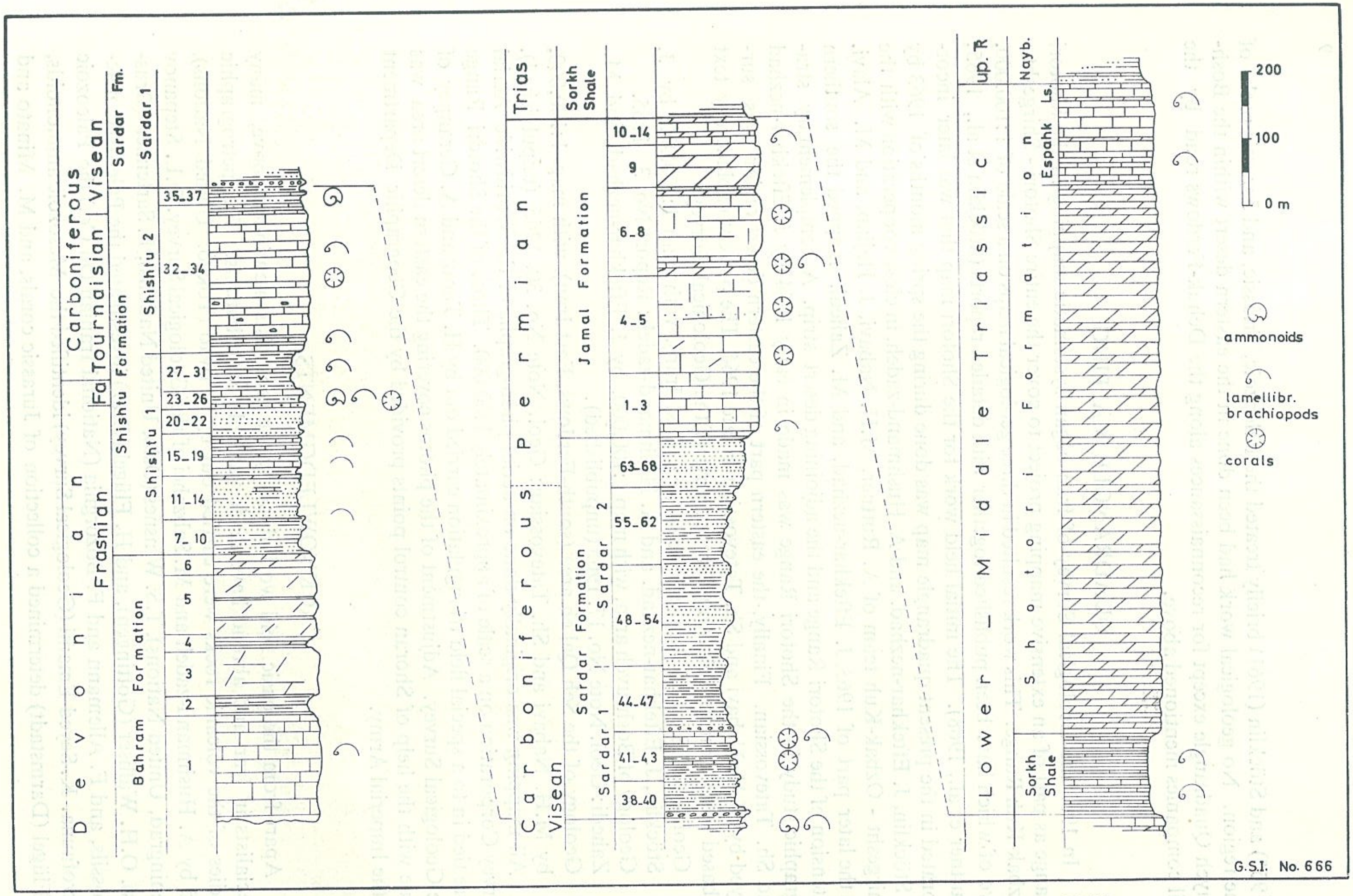

Fig. 1. The Paleozoic-Triassic rock sequence of the Shotori Range. (After Stöcklin et al., 1965.)

M. Kato (Sapporo, Japan) a number of Permian corals. Tertiary microfossils were identified by M. Mehrnush (Geological Survey). B. Kuhbanani, A. Afaghi, Mrs. P. Tahmasebi, T. Sajedi, and S.M. Salek have done the essential cartographic work for the Boshruyeh map.

STRATIGRAPHY

GENERAL REMARKS

The rock column exposed in the Boshruyeh Quadrangle is about 8 km thick and represents an incomplete sequence from Devonian to Recent.

The Paleozoic and Mesozoic formations consist exclusively of sedimentary deposits of shallow marine and, to a minor degree, continental origin, and they contain several important sedimentary gaps. These rocks are found mainly in the Shotori Range and have been fully described by Stöcklin, Eftekhar-nezhad, and Hushmand-zadeh (1965), so that a brief summary including the most recent paleontological data is considered sufficient for this report. However, some new information on the stratigraphy of the Jurassic is included, as rocks of this age reappear in a broad strip in the eastern desert region that was not covered by the 1965 report.

The Cenozoic is represented mainly by volcanic formations and unfossiliferous continental deposits covering the desert depressions west and east of the Shotori Range. A major part of the present text is devoted to the volcanic formations, which are most extensively developed in the eastern desert region and were treated only summarily in the 1965 report.

Metamorphic rocks and large intrusive bodies are absent from the Boshruyeh Quadrangle.

DEVONIAN AND CARBONIFEROUS

Bahram Formation (Db)

This unit (Fig. 1) crops out only at one place in the Boshruyeh Quadrangle, near Howz-e-Dorah at the southern foot of Kuh-e-Jamal (southern Shotori Range). Its identification at this place is based on lithological comparison with the better exposures in the Shirgesht area (Ruttner et al., 1968) and on its stratigraphic position below the Shishtu Formation. At Howz-e-Dorah the formation consists of thick-bedded dark-grey limestone in the lower part and of massive brown dolomite with minor green shale intercalations in the upper part. The exposed thickness is about 500 m. The limestone contains *Tentaculites* and poorly preserved small brachiopods, which have not been determined. From the more richly fossiliferous outcrops in the Shirgesht area, Ruttner et al. (1968) have reported a late Middle Devonian to early Late Devonian fauna.

Shishtu Formation (Ds)

At Howz-e-Dorah the predominantly carbonatic Bahram Formation is conformably overlain by a unit of complex lithology, which has been named Shishtu Formation (Fig. 1) after a locality in the Ozbak-Kuh Mountains (Ruttner et al., in preparation). Parts of the same unit reappear on the west side of the Shotori Range across the Sardar Valley, and in two small outcrops in Kuh-e-Esfandiar (southern Shotori Range), one at Kuh-e-Chengtri southwest of Godar-e-Kolukhi and the other west of the village of Esfandiar.

The most complete section, Howz-e-Dorah, has been described in detail by Stöcklin et al. (1965). Additional fossil material from this place has since been determined, and the fauna and age of the unit have been discussed by Stepanov (1967). The section can be divided into two main parts, which correspond to the Shishtu 1 and Shishtu 2 Subformations distinguished by Ruttner et al. (in preparation) in the type section of the unit.

Shishtu 1 (beds No. 7-31 of the 1965 report, pp. 11-12) is 326 m thick and consists of dark-grey to dark-green shale and sandstone with intercalations of quartzite, dolomite, and dark-grey brachiopod limestone. From the lower part (bed No. 10) Sartenaer (1966) has described the new rhynchonellid subspecies *Cyphoterorhynchus koraghensis interpositus*, a form which he assigned to the Frasnian. From about the middle of Shishtu 1 (bed No. 18) the same author identified *Hypothyridina* cf. *cuboides* (Sow.), *Schizophoria* cf. *striatula* (Schloth.), *Strophonella* sp., *St.* cf. *productoides* (Murchison), *Atrypa* cf. *reticularis* (Linné), *Cyrtospirifer* ex gr. *verneuili* (Murchison), *Athyris* cf. *communis* (Gosselet), and the new genus and species *Coeloterorhynchus tabasensis* Sartenaer, 1966. This fauna also indicates Frasnian (probably Late Frasnian) age. A richly fossiliferous zone, 28 m thick, consisting of sandy oolitic limestone, iron oolite, and shale (beds No. 23-26) appears near the top of Shishtu 1. This zone, which is an excellent marker in the Shotori Range and the Shirgesht area, has been called "Cephalopod Beds" or "Goniatite Horizon 1". In addition to bryozoans, crinoids, and an undetermined trilobite, this zone has yielded the following fossils: *Receptaculites neptuni* Defr. (det. H. Flügel, 1961); corals (det. H. Flügel): *Tabulophyllum* sp., *Favosites* cf. *styriacus* Penecke, and *Disphyllum lazutkini;* brachiopods (det. P. Sartenaer): *Hypothyridina* cf. *cuboides* (Sow.), *Athyris* cf. *communis* (Gosselet), *A.* cf. *davidsoni* (Rigaux), *Strophalosia* cf. *productoides* (Murchison), *Schizophoria* cf. *striatula* (Schloth.), *Cyrtospirifer* ex gr. *verneuili* (Murchison), *Adolfia* sp., *Strophonella* sp., *Aulacella* cf. *eifeliensis* (de Verneuil), *Cariniferella* cf. *dumontiana* (de Verneuil), *Atrypa* cf. *reticularis* (Linné), and *Coeloterorhynchus tabasensis* Sartenaer; cephalopods (det. O.H. Walliser, 1966): orthoceratids, *Manticoceras ammon* (Keyserling), *Platyclymenia Platyclymenia) quenstedti* Wedekind, *P.* (*P.*) *intracostata* Frech, *P.* (*P.*) div. sp., *Prionoceras* (*Imitoceras*) *sulcatum* (Münster), *Sporadoceras* (*Sporadoceras*) ex gr. *biferum* (Phillips), *S.* (*S.*) ex gr. *sedgwicki* (Wedekind), *S.* (*S.*) ex gr. *descendens* Schmidt, and the new subgenus *Sporadoceras* (*Iranoceras*) Walliser, 1966, with the species *S.* (*I.*) *pachydiscus* Walliser, *S.* (*I.*) *pingue* Walliser, and *S.* (*I.*) *sphaericum* Walliser. Most of the brachiopods and the goniatite *Manticoceras ammon* (which seem to have been derived from the lower part of the "Cephalopod Beds") indicate Frasnian age, whereas the remainder of the goniatites are definitely Famennian (including the *Platyclymenia* Zone or Upper Devonian IV of Wedekind's classification).

The top of Shishtu 1 (beds 27-31, 58 m) is mainly dark shale containing an intercalation of strongly gypsiferous pink shale and a thin layer of brachiopod limestone, fossils from which have not been determined. These beds probably correlate with the

"Mush Horizon" on top of Shishtu 1 in the type area (Ruttner et al., in preparation), which is believed to be lowermost Carboniferous; at Howz-e-Dorah, the immediately overlying beds (base of Shishtu 2) are Upper Tournaisian.

The Shishtu 1 Subformation is thus largely Upper Devonian (Frasnian-Famennian), but with the top beds reaches probably into the Lower Carboniferous. The Devonian-Carboniferous boundary may tentatively be drawn at the gypsiferous horizon (bed No. 28), which seems to indicate a short period of marine regression.

Subformation *Shishtu* 2 at Howz-e-Dorah (beds No. 32-37) is 217 m thick and consists mainly of dark, well-bedded limestone with some dark shale at the base and on top. The basal beds (No. 32) contain corals, crinoids, and the brachiopods *Marginatia vaughani* M. -Word, *Spirifer attenuatus* Sow., and *Sp. logani* Hall (det. D.L. Stepanov), indicating Late Tournaisian age. The same age is indicated for the main limestone (No. 33), which has yielded the corals *Syphonophyllia* sp. and *Caninia* ex gr. *cornucopiae* (det. H. Flügel) and poorly preserved spiriferids reminiscent of the *Fusella tornacensis* Kon. group (det. D.L. Stepanov). From near the top of the unit (bed No. 36) D.L. Stepanov identified the brachiopod *Pugilis subscoticus* Sar., and a fragment of a goniatite attributable to *Merocanites* sp., both characteristic forms of the Lower Visean. *Merocanites* is also a characteristic form of "Goniatite Horizon 2" distinguished by Ruttner et al. (in preparation) in the Ozbak-Kuh Mountains.

The Shishtu Formation as a whole thus ranges in age from Late Frasnian to Early Visean. In the northern outcrop area (west side of Shotori Range) the "Cephalopod Beds" of Shishtu 1 are particularly well developed and reach a thickness of 50 m, whereas the main limestone of Shishtu 2 is much thinner than at Howz-e-Dorah. Only Shishtu 2 is exposed in the outcrop of Kuh-e-Chengtri. The southernmost occurrence near Esfandiar has not been studied in detail, and its identification as Shishtu is tentative, based on lithology and the general character of the fauna (corals, brachiopods, orthoceratids, trilobite fragments).

Sardar Formation (Cs)

This unit (Fig. 1) has received its name from the Sardar Valley on the west flank of the Shotori Range. The type section, which was measured south of the Sardar River, and a reference section at Howz-e-Dorah have been described and illustrated by Stöcklin et al. (1965, p. 16-21 and Fig.8). As in the case of the Shishtu Formation, some precision in the dating of the unit has since been reached with the help of paleontological studies, mainly by Stepanov (1967).

The Sardar Formation consists predominantly of light-green shale with intercalations of sandstone and quartzite and with a few beds of highly fossiliferous limestone. This facies, however, shows considerable lateral changes. The fossiliferous limestone intercalations are most numerous in the type area south of the Sardar River but farther south are increasingly replaced by sandy limestone and unfossiliferous sandstone. At Howz-e-Dorah, only a few limestone beds remain in the lower part of the section, which here is much more sandy than in the type area. The thickness of the type section, which is incomplete at the base, is 660 m; at Howz-e-Dorah the beds are 570 m thick. The lower limit is marked by a conglomerate bed which is 30 m thick in the Sardar Valley but thins to 4 m at Howz-e-Dorah. This conglomerate overlaps different horizons of the Shishtu Formation; in an outcrop east of Niaz (Sardar Valley) it rests directly on the "Cephalopod Beds" of Shishtu 1. Although no clear angularity of contact could be observed in individual outcrops, a disconformity or slight unconformity at the base of the Sardar Formation must be deduced from these contact relations.

The lower part of the type Sardar (beds 6-8 and 17-19 in Stöcklin et al., 1965, p. 17) has yielded large brachiopods, among which D.L. Stepanov identified *Orthotetes keokuk* Hall, *Antiquatonia* ex gr. *hindi* M. -Wood, *Pustula pustulosa* Phill., and *Spirifer* ex gr. *striatus* Mart. Based on these determinations, a Middle Visean to early Late Visean age can be assigned to the lower part of the Sardar. The corals *Cyathaxonia cornu cornu* Mich., *Fasciculophyllum omalusi omalusi* Mich., and *Plerophyllum* (*Ufimia*) *infracarbonicum* (Schindewolf), confirming generally an Early Carboniferous age, have been determined by H. Flügel from the lower part of the Sardar Formation at Howz-e-Dorah; and D.L. Stepanov identified brachiopods close to *Rotaia subtrigona* Meek. and Worth. from the same beds (No. 43 in Stöcklin et at al., 1965, p. 20). A slightly younger, Late Visean - Early Namurian fauna is known from the lower Sardar in the Shirgesht area (Ruttner et al., 1968).

From higher parts of the Sardar type section (beds No. 31-35) the following fossils have been obtained: *Meekella* sp., *Antiquatonia* (?) cf. *coloradoensis* Girty, *Ovatia* ex gr. *tenuistriata* Vern., *Kozlowskia* aff. *haydenensis* Girty, *Brachythyrina* aff. *kleini* Fisch., *Anthracospirifer* (?) sp., *Composita* ex gr. *subtilita* Shep., *Dielasma* sp. (det. D.L. Stepanov), and the goniatite *Gastrioceras* (*Branneroceras*) cf. *branneri* Smith (det. O.H. Walliser (1966). Stepanov (1967) commented on this fauna: "According to O.H. Walliser (1966) the occurrence of *Gastrioceras* (*Branneroceras*) cf. *branneri* can be interpreted as an indication of lower Pennsylvanian age, and in terms of European stratigraphy the unit may be attributed to an "upper Namurian to lower Westfalian" or to a Bashkirian Stage as understood in Russian; on the other hand, O.H. Walliser emphasized the close resemblance of this goniatite with *Gastrioceras yohi* Yin from the Wanchapia Limestone of China, which has been attributed to the Uralian. From the brachiopods a valid age determination cannot be made, the assemblage being most probably Upper Carboniferous (in a broad sense) - an Early Permian age cannot be completely dismissed; but a Bashkirian (Morrow) or Early Moscovian (Sendian or Atocan) age seems most probable for the host rocks."

Unfortunately, the highest part of the Sardar Formation in the Shotori Range, above the horizon with *Gastrioceras* cf. *branneri*, has not yielded any determinable fossils. A fauna considered by Stepanov (1967) to be indisputably Early Permian has been obtained by Ruttner et al. (1968) from the top beds of the Sardar Formation in the Shirgesht area immediately northwest of the Boshruyeh Quadrangle. In the southern Shotori Range (Kuh-e-Jamal) the uppermost part of the formation is characterized by a persistent purplish-white quartz sandstone about 70 m thick, passing into a 2 m shale bed which includes a thin coal layer and marks the top of the formation. Stepanov has compared these beds with the predominantly sandy and locally coal-bearing Early Permian (Asselian) Dorud Formation of the Alborz Mountains, and also with the "Carboniferous" sandstone unit containing *Sigillaria persica* Seward in the Bakhtyari Mountains of the Zagros. Concerning this plant fossil, Stepanov (1967) wrote: "According to A.C. Seward *Sigillaria persica* belongs to the group of ribless representatives of the genus, which are characteristic of highest Upper Carboniferous and Lower Permian beds. The Iranian species shows a very close relation to *Sigillaria* from the Lower Permian strata of Blanzy and from the Stephanian of Germany (Seward, 1932, p. 382)".

The Sardar Formation thus ranges from Early Carboniferous (Middle - Late Visean) to most probably Early Permian, and it is one of the very rare formations in Iran that seems to include marine Upper Carboniferous, although the evidence, in the opinion of Stepanov, is not entirely conclusive.

In addition to the two continuous sections of the Sardar Formation discussed above (Sardar Valley, Kuh-e-Jamal - Howz-e-Dorah), isolated outcrops of the Formation have been found east of Neysan and in the Godar-e-Kolukhi - Kuh-e-Chengtri area of the southern Shotori (Kuh-e-Esfandiar) Range. At Godar-e-Kolukhi, limestone beds intercalated in green shale have yielded corals of the *Ufimia-Cyathaxonia* group and the brachiopods *Rhipidomella* sp. and *Athyris* cf. *lamellosa,* all indicating Early Carboniferous. Moreover, the formation seems to crop out in the Hormuk - Khorow-bala area of the northern Shotori Range, but there a clear separation from the Shishtu Formation could not be made, and the two units have been mapped together as part of the Ozbak-Kuh Group.

PERMIAN

The Sardar Formation is overlain by a complex of limestone and dolomite, about 2,000 m thick, which has been called the Tabas Group and is composed of three formations: the Permian Jamal Formation, and the Triassic Sorkh Shale and Shotori Formations. The Tabas Group forms most of the high walls and crests of the Shotori Range facing the Tabas plain in the east, and also a number of conspicuous ridges in the mountains bordering this plain to the west. The carbonatic, mountain-forming Tabas Group contrasts sharply with the soft-weathering, mainly shaly and sandy rocks constituting the underlying Shishtu and Sardar Formations and the overlying Nayband, Shemshak, and Baghamshah Formations.

Jamal Formation (Pj)

As stated above, the sandy and coal-bearing highest beds of the Sardar Formation in the Shotori Range may be Early Permian in age, as are the highest beds of the formation in the Shirgesht area. The position of the Carboniferous-Permian boundary in the rock sequence of the Boshruyeh Quadrangle is not accurately known. The main representative of the Permian System, however, is the Jamal Formation (Fig. 1), named after Kuh-e-Jamal in the southern Shotori Range. The steep, south wall of the southern promontory (locally called Kuh-e-Mehdi) of this mountain represents the type section, which has been described and illustrated *in* Stöcklin et al. (1965, pp. 21-26 and Fig. 11).

At the type locality the unit is 473 m thick and consists mainly of massive, dark-grey, brown-weathered reef limestone. The limestone is partly dolomitized and in the upper part contains a distinct yellow dolomite band that persists throughout the southern and central Shotori Range. The top beds are thick - to thin-bedded limestone and dolomite having white, yellow, blue, and red colours and approaching in lithology the overlying red calcareous Sorkh Shale. The total thickness is greater in some other sections, e.g., about 600 m in Kuh-e-Shotori, and more than that farther north, where a greater portion of the limestone is replaced by dolomite.

Only few fossils have been obtained from the type section. The basal limestone beds contain crinoids, fenestellids, and poorly preserved gastropods, productids and spiriferids, which have not been determined. Corals are abundant in the middle part and include *Liangshanophyllum parachihsiaensis, L. tabellatum, Ipsiphyllum subtimoricum, Yatsengia kiangsuensis kiangsuensis* (det. H. Flügel), and two new species described by Minato and Kato (1965) as *Wentzelophyllum* (?) *tabasense* and *Pseudohuangia stoecklini*. These corals indicate generally Permian, probably "Middle" Permian, age. The coloured top beds contain indeterminable algae, gastropods, and bivalve fragments.

Other sections of the Jamal Formation in the wider type area (Shotori Range) contain abundant Foraminifera and other microfossils. Some of them have been illustrated by Bozorgnia (1964) and determined by him as follows: Lower Permian, *Agathammina pusilla* (Geinitz); Middle Permian, *Verbeekina verbeeki* Geinitz and *V.* cf. *parvula* Douglas; probably Upper Permian, *Globivalvulina biserialis* Cushman and Waters, *G. bulloides* (Brady), *Hemigordiopsis* sp., and *Glomospira* sp. Other microfossils identified by Bozorgnia include *Schwagerina* sp.,? *Pseudofusulina* sp., *Climacammina* sp., *Biserammina* sp., *Palaeotextularia* sp., *Cribrogenerina sumatrana, Geinitzina* sp., *Pseudovermiporella* sp., *Colaniella* sp., *Tetrataxis* sp., and *Mizzia* sp.

From a section south of Niaz T.S. Winsnes identified the trilobite species *Neoproetus* cf. *indicus*, which occurs together with *Schwagerina* sp. in the middle part of the Jamal Formation. From the upper part of the unit, in the same area, H. Flügel determined *Wannerophyllum* sp., *Favosites* sp., and *Verbeekiella* (?) *australis*.

An accurate dating of the Jamal Formation is not yet possible. In the Shirgesht area (Ruttner et al., 1968) the lower part of the formation has yielded corals, brachiopods, and ammonoids suggesting a late Early Permian to early Late ("Middle") Permian age. This and the few data from the Shotori Range discussed above suggest a "Middle" to early Late Permian age for the greater part of the Jamal Formation. More accurate data are expected from systematic studies of the fusulinids, which are very abundant in several sections.

TRIASSIC

Sorkh Shale Formation (Tsr)

The Sorkh Shale Formation (Fig. 1) is an easily recognizable, red-coloured marker, which splits the thick, carbonatic Tabas Group into a lower part (Jamal Formation, Permian) and an upper part (Shotori Fomation, Triassic). The unit has received its name from Godar-e-Sorkh ("red pass") in Kuh-e-Jamal, which is the type locality. The type section, described and illustrated in Stöcklin et al. (1965, pp. 26-29 and Figs. 12, 13), consists of 122 m of calcareous and argillaceous shales having a very characteristic tile-red colour and containing a few very thin intercalations of yellow limestone and dolomite. The contacts with both the underlying Jamal Formation and the overlying Shotori Formation are conformable and seemingly transitional. Except for the predominant red colour, the Sorkh Shale is a perfect lithological equivalent of the "calcaires vermiculés" in the lower part of the Elikah Formation in the Alborz Mountains and of the "Claraia Beds" in the Lower Triassic of Julfa (Stepanov et al., 1969). Like the latter it contains numerous thin layers of edgewise conglomerate, and many bedding planes are covered with *Serpula*-like worm tracks giving the rock the typical "calcaires vermiculés" appearance.

The only other fossils are poorly preserved small gastropods and scarce lamellibranchs. The latter have previously been referred to as *Pseudomonotis* and *Aviculopecten,* but it is now believed that most of them are representatives of the genus *Claraia.* Apart from this, an Early Triassic age is inferred from the stratigraphic position above the dated Permian rocks of the Jamal Formation and from the very close similarity in stratigraphic position and lithology to the dated Early Triassic *Claraia* Beds and "calcaires vermiculés" of North Iran.

The Sorkh Shale Formation has been mapped throughout the central and southern Shotori Range, but in its northern part, between Kuh-e-Shotori and Malvand, the formation is missing because of pre-Rhaetic erosion; here, the Rhaeto-Liassic Shemshak Formation rests unconformably on the Jamal Formation. However, the Sorkh Shale reappears north of Malvand in the northwestern corner of the Boshruyeh Quadrangle, and it keeps its character as a lithological marker farther north in the Shirgesht area, as well as south of the Boshruyeh Quadrangle in the Nayband-Darband area.

Shotori Formation (Tsh)

A thick, uniform sequence of dolomite, the Shotori Formation (Fig. 1), follows conformably on the Sorkh Shale and forms several of the highest peaks in the Shotori Range, including the central "Kuh-e-Shotori" peak, after which the unit has been named. Limestone appears as a distinct unit in the upper part of the formation and has been distinguished as Espahk Limestone Member (Te), a name derived from the village of Espahk at the western foot of Kuh-e-Jamal.

The type section has been measured in two parts, one for the main dolomite member at Tang-e-Kuri ton the west-side of Kuh-e-Jamal, the other for the Espahk Limestone at Kamar-e-Machekuh southeast of Espahk. The two complementary sections have been described and illustrated by Stöcklin et al. (1965, pp. 29-31 and Fig. 13). The main (lower) dolomitic part is 972 m thick and consists of thick- to thin-bedded, dense to finely crystalline yellow dolomite, which is practically barren. The Espahk Limestone at Kamar-e-Machekuh is 152 m thick and made up of massive to thick-bedded, whitish, creamy, and blue-grey limestone containing rare thin dolomite bands. The only fossils observed in the limestone are algae and recrystallized sections of big lamellibranchs believed to be megalodonts. Two isolated outcrops of well-bedded dark-grey limestone, discovered in the desert plain about 30 km southeast of Boshruyeh (Eftekhar-nezhad et al.,1965), have been tentatively mapped as Espahk Limestone because they also contain abundant fragments of such shells.

In the southern extension of the Shotori Range, immediately south of the quadrangle, the dolomites of the Shotori Formation show a slightly gypsiferous facies, which does not persist for a great distance, as farther south at Kuh-e-Nayband the dolomites show their normal development. Gypsum reappears still farther south, however, at Kuh-e-Darband, in the transitional interval between Sorkh Shale and Shotori Formation (Stöcklin, 1961). Northeast of Malvand in the northwest corner of the Boshruyeh Quadrangle, most of the dolomite section is replaced by thin-bedded, grey, slightly marly limestone, a local facies that disappears farther north in the Ferdows Quadrangle.

The Shotori Formation in most outcrops is truncated to a variable degree by pre-Rhaetic erosion and unconformably overlain by the Rhaeto-Liassic Shemshak Formation; but at Kamar-e-Machekuh the Noric-Rhaetic Nayband Formation overlies the Espahk Member of the Shotori Formation without visible unconformity, though with sharp lithologic break. A Middle Triassic age is inferred for the Shotori Formation from its stratigraphic position between the Lower Triassic Sorkh Shale and the Noric-Rhaetic Nayband Formation. In lithology and stratigraphic position the Shotori Formation is closely comparable to the dolomitic upper part of the Elikah Formation in North Iran.

Nayband Formation (Tn)

At Kamar-e-Machekuh and a few other places the dolomites and limestones of the Shotori Formation are overlain by a unit of richly fossiliferous shales, sandstones, and limestones, which has been mapped as Nayband Formation. The type locality of this formation, Nayband, is outside the Boshruyeh Quadrangle, in the approximate southern continuation of the Shotori Range. At Nayband the unit is about 2,800 m thick and contains the classical Upper Triassic marine fauna described by Douglas (1929). Douglas believed that a part of the fossiliferous sequence (his "Hauz-i-Sheikh Series") represented possibly the Ladinic Stage of the Middle Triassic, the rest being of Noric-Rhaetic age. The fauna described by Douglas has never been revised, and the question of the lower age limit is still open. However, from later stratigraphic studies (Stöcklin, 1961) it appears that Douglas's "Hauz-i-Sheikh Series" occupies a rather high position in the fossiliferous sequence of Nayband and is very unlikely to be older than the beds containing the characteristic Noric fauna. Therefore, the whole fossiliferous sequence at Nayband, now called "Nayband Formation", is at present believed to be exclusively Upper Triassic, all the more as 1,000 m of "Middle" Triassic dolomites of the Shotori Formation were also found to be present at Nayband, below the fossiliferous beds described by Douglas.

From Nayband Village the fossiliferous beds extend northward in almost uninterrupted outcrop into the Boshruyeh Quadrangle. West of Parvadeh in the extreme southwest corner of the quadrangle, the beds are still of the lithology characterizing the formation at the type locality, i.e., thick green-grey shales similar to those of the overlying Shemshak Formation but distinguished from them by numerous intercalations of fossiliferous limestone, sandstone, and calcarenite. The thick coral limestone (Howz-e-Khan Member) that marks the top of the formation at Nayband is, however, missing at this place and farther north. The outcrops west of Parvadeh also contain the characteristic fauna described by Douglas, including abundant representatives of the most typical genera *Heterastridium* and *Indopecten*. At Kamar-e-Machekuh, where the disconformable contact with the underlying Espahk Limestone Member of the Shotori Formation is well exposed, the thickness of the Nayband Formation has decreased to 780 m and the fauna is less abundant. In the Shotori Range proper, typical Nayband Formation is missing and the Shemshak Formation or younger Jurassic beds overlap with clear unconformity the Shotori Formation and various older units. However, typical Nayband Formation beds with limestone intercalations containing abundant specimens of *Heterastridium, Indopecten, Pinna,* etc., reappear in the eastern desert region at Borjak, southwest of Ferdows (northern quadrangle margin). The exposed thickness of the fossiliferous beds is here about 500 m. The beds occupy the core of an anticline and, as at Nayband and elsewhere, underlie conformably the Shemshak Formation.

The stratigraphic relations between Nayband and Shemshak Formations are not clearly defined. The two formations are lithologically similar and distinguished mainly by the presence or absence of fossiliferous beds containing typical Nayband forms. Where such beds are present, the limit between the two formations is conventionally drawn on top of the uppermost marine fossil layer, which at Kamar-e-Machekuh is a thin coral blanket. Where the fossils were poorly preserved and atypical, or the fossil beds entirely missing, the whole shale-sandstone sequence has been mapped as Shemshak Formation, although it may still include, in the lower part, time equivalents of the Nayband.

JURASSIC

Shemshak Formation (Js)

The name Shemshak Formation, originally defined in the Alborz Mountains (Assereto, 1966), is applied in the Boshruyeh Quadrangle to a rock unit which in lithology and approximately in stratigraphic position is closely comparable to the type Shemshak. In the report area the unit consists of rather monotonous argillaceous, silty, and sandy shales of dark green-grey colour containing numerous intercalations of grey to brown-grey sandstone. The sandstones are predominantly quartzitic and in places show distinct ripple marks. The shales are locally carbonaceous and contain coal seams, but these are insignificant in comparison with the type Shemshak or its equivalents in the Kerman area. Plant remains have been frequently observed and in the Machekuh area include well-preserved tree stems. These plant fossils have not yet been determined. Calcareous beds containing marine fossils are extremely rare except in the area of Malvand - Ghor-e-Neyzar in the northern Shotori Range, where several intercalations of oolitic limestone, coral limestone, and calcareous shell beds have been found. The latter contain corals, *Pentacrinus,* fragments of ostreids and pectinids, *Trigonia* sp., gastropods, and belemnites, none of which could be specifically determined. According to Flügel (in Ruttner et al., 1968, p. 76), corals obtained from corresponding beds a short distance north of the quadrangle have a definite Liassic habitus.

Extensive outcrops of the Shemshak Formation have been discovered by Nabavi and Tatevossian (1966) in the Kavir-e-Robat area of the eastern desert region. The grain size of the rocks is here distinctly finer than usual, with shales greatly predominating and sandstones much less common than in the western outcrops. Shales of the Shemshak Formation reappear east of Feyzabad in the extreme northeast corner of the quadrangle, where J. Eftekhar-nezhad found them to be slightly phyllitized.

The thickness of the Shemshak Formation varies widely within the Boshruyeh Quadrangle. About 1,200 m are preserved in a syncline northeast of Kamar-e-Mache-kuh, and about 1,500 m at Borjak southwest of Ferdows; in both these places the Shemshak overlies conformably the Nayband Formation. At least 2,000 m have been estimated for the outcrops in the Kavir-e-Robat area, where the base of the formation is not exposed. East of Malvand in the northern Shotori Range the thickness is less than 1,000 m, and it is generally less than 200 m and locally zero in the central Shotori Range and in the Kuh-e-Jamal area. These greatly reduced thicknesses in the Shotori Range are coupled with a more conglomeratic facies, a distinct angular unconformity at the base of the formation, and absence of the Nayband Formation below the unconformity. A strongly conglomeratic facies also characterizes the Shemshak Formation in the core of the anticline northwest of Abbasabad, west of the Shotori Range.

As discussed above, the lower limit of the Shemshak Formation is either a conformable contact with the Nayband Formation or a markedly unconformable overlap on to older formations. The upper limit is given by the base of the Badamu Limestone marker; in the eastern desert region where the Badamu is poorly developed or missing, upward passage from the dark shales of the Shemshak Formation into the lighter-coloured shales and marls of the Baghamshah Formation has been observed.

In his definition and comprehensive description of the Shemshak Formation Assereto (1966) has clearly demonstrated that the rock unit so-designated by Stöcklin et al. (1965) in the Shotori Range corresponds only to the lower half of the type Shemshak in the Alborz; the upper half of the type Shemshak has its time equivalents in the Badamu Limestone and, partly at least, in the Baghamshah Formation of the Shotori Range. Considering this and certain lithological features common to the Nayband, "Shemshak", and Baghamshah Formations, Assereto proposed to extend the name Shemshak so as to comprise all of these units of eastern Iran, either as "Shemshak Formation" including several local members or as "Shemshak Group" comprising several local formations. One can agree with Assereto that a grouping of the Nayband-Baghamshah interval into a stratigraphic unit of higher order would be justified and useful. In no way, however, can the name Shemshak be used to designate such a comprehensive rock unit of higher rank, because the greater part of this unit would lack the characteristic features of the type Shemshak. Thus: (a) the Nayband Formation in its typical develoment is essentially a marine deposit with a high proportion of carbonatic sediments, without plant fossils or coal but with an exceptionally rich marine fauna, well distinguished from the overlying plant beds, which alone compare sufficiently with the type Shemshak to deserve this name; (b) the Badamu Limestone, which would also have to be included in the proposed group, is a pure calcareous deposit, as much as 200 m thick, such as does not exist in the type Shemshak; (c) the Baghamshah Formation in its typical development is a kind of transitional facies between Shemshak-like shales and undoubtedly marine carbonate deposits, sufficiently different from the type Shemshak to deserve its own name.

In the Boshruyeh and Ferdows Quadrangles the name Shemshak Formation has therefore been limited to that part of the rock sequence which is a true lithological counterpart of the type Shemshak; the fact that it is only a partial time equivalent is not in contradiction with accepted rules of nomenclature.

Badamu Limestone (Jbd)

An easily recognizable limestone marker, the Badamu Limestone, conformably overlies the Shemshak Formation in the Shotori Range. The unit is 20-40 m thick and consists of dark greenish-grey to dark-grey, medium-to thin-bedded, partly nodular and oolitic limestone rich in belemnites, ammonites, lamellibranchs, brachiopods, and other marine fossils. In most sections the fossils were found to be most abundant in the uppermost few metres of the limestone.

According to Seyed-Emami (1967, p. 17), the ammonites collected from this unit at several localities in the Shotori Range indicate Upper Bajocian to Bathonian age. The original determinations, listed in Stöcklin et al. (1965, pp. 36-37), were preliminary only; more-detailed study of the fossils has resulted in the following list (Seyed-Emami, pers. comm.): *Phylloceras* sp., *Holcophylloceras* sp., *Bullatimorphites bullatus* (Orbigny), *Procerites* cf. *schloenbachi* Grossouvre, *Morphoceras replictum* (Buckman), *Parkinsonia* sp., and *Cadomites* sp. Other fossils include *Cidaris* spines, *Collyrites* sp., rhynchonellids, terebratulids, *Trigonia* sp., and *Posidonia* sp. From the ammonites, the age must be considered as Late Bajocian to Bathonian. The limestone is thus somewhat younger in the Shotori Range than the type Badamu at Kerman, which is dated as Toarcian - Middle Bajocian, although both occupy very similar positions in the general rock sequence and are lithologically almost identical.

South of Kuh-e-Shotori and on the east side of Kuh-e-Jamal, the limestone gives way to sandy limestone and sandstone which directly overlie Triassic or various Paleozoic formations with sharp angular unconformity. In the southern extension of the Shotori Range (Kuh-e-Esfandiar) the Badamu Limestone has not been recognized, but it is again well developed farther south in the Nayband-Darband area (Stöcklin, 1961) and from there extends to Ravar and Kerman (Huckriede et al., 1962; Seyed-Emami, 1967), where it attains locally thicknesses of more than 200 m.

A probable equivalent of the Badamu Limestone has been found by Nabavi and Tatevossian (1966) in the eastern desert region in the form of a thin band of black, partly oolitic limestone separating the Shemshak Formation from Baghamshah-type shales. This limestone is only about 10 m thick, contains only poor belemnite fragments, and occurs only at Kuh-e-Birg and as a discontinuous lenticular layer north of Galeh Chah. Apart from this the Badamu Limestone seems to be missing in this eastern region. Northwards the limestone has been traced as far as Neygenan in the Ferdows Quadrangle (Ruttner et al., 1968), so that the total known south-north extension of the unit (Kerman to Neygenan) is about 400 km.

Baghamshah Formation (Jbg)

The Badamu Limestone is followed everywhere by a soft-weathering unit of pale-green marly and silty shale, called Baghamshah Formation after Lasht-e-Baghamshah in the northern Shotori Range. The shales contain fine streaks of harder siltstone and fine- grained sandstone, and some layers have a slight gypsum and salt content. The very characteristic pale-green colour shows in places variations into pinkish shades due to haematitic clay concretions. A few streaks of coal, not exceeding a few centimetres in thickness, have been noticed at one place near Sorond, south of Kuh-e-Shotori. A zone of yellow fossiliferous marl usually forms the base of the unit and shows a sharp but conformable contact with the underlying Badamu Limestone. The contact with the overlying Esfandiar Limestone in the southern Shotori Range (Kuh-e-Jamal, Kuh-e-Esfandiar) is conformable but marked by a sharp lithological break; in the Kuh-e-Shotori area and farther north the Baghamshah is overlain either by the Esfandiar Limestone or by the Qal'eh Dokhtar Formation and the contacts are more transitional. The type section of the Baghamshah Formation at Lasht-e-Baghamshah has been described and illustrated by Stöcklin et al. (1965, p. 38 and Fig. 19). At this place the unit is 476 m thick. It reaches its greatest thickness of more than 1,500 m south of the Boshruyeh Quadrangle, in the area east and south of Nayband (Stöcklin, 1961).

The formation was recognized by Nabavi and Tatevossian (1966) in its typical development of pale-green shales in the eastern desert region. At Galeh Chah, west of Kavir-e-Robat, the unit is 400 m thick and indistinguishable lithologically from the type Baghamshah. At Kuh-e-Birg the thickness has increased to 610 m, and a more sandy facies appears in the lower part and a more calcareous facies in the middle part. However, the typical pale-green marly shales predominate here too.

Fossils collected from the Baghamshah Formation at various places within the Boshruyeh Quadrangle include corals, crinoids ("*Pentacrinus*"), *Cidaris* spines, rhynchonellid and terebratulid brachiopods, *Trigonia* sp. and other lamellibranchs, gastropods, belemnites, and ammonites. Ammonite genera identified by K. Seyed-Emami are *Holcophylloceras, Lilloetia, Kamptocephalites, Dolikephalites, Phylloceras, Kellwaysites, Erymnoceras, Nequeniceras, Kheraiceras,* and *Polyplectites*. These ammonites indicate a Callovian age. Some of them have been obtained from the transitional beds between the Baghamshah Formation and the Esfandiar Limestone and may be attributed to either of these two units. Although no fossils definitely attributable to the Bathonian have been found, it is possible that the Baghamshah Formation represents Bathonian in its lower part as it does farther north in the Shirgesht area (Ruttner et al., 1968).

Qal'eh Dokhtar Formation (Jd, Jds, Jdl)

The Qal'eh Dokhtar Formation (Fig. 2) is a complex unit of well-bedded limestone, marly shale, and sandstone, typically developed in the northeastern foothills of the Shotori Range and reappearing in the central part of the eastern desert area, west of the Kavir-e-Robat.

In the type section near the Qal'eh Dokhtar fortress west of Boshruyeh (Stöcklin et al., 1965, pp. 40-46 and Figs. 20-23) the unit is 974 m thick and divided into three distinct members: a lower, sandy member (194 m), a middle, shaly member (458 m), and an upper, calcareous member (322 m).

The sandy lower member (Jds) consists of alternating, well-bedded, grey quartzitic and brown calcareous sandstone conformably overlying the Baghamshah Formation, with rather sharp contact. Only few, indeterminable fragments of corals and lamellibranchs, probably reworked, have been seen. This member passes southwards into the sandstone and sandy limestone beds at the base of the Esfandiar Limestone.

The shaly middle member is made up of thin-bedded shale, sandy shale, and sandstone, containing an increasing amount of marl beds in the upper part and a 15 m thick intercalation of dark-grey coral limestone in the middle part. Corals obtained from this bed have been identified by Flügel (1966) as *Cyatophora kobyi* Krasnov, *Stylina kachensis* Gregory, *Epistreptophyllum* cf. *oldhami* (Gregory), *Metethmos griesbachi* Gregory, *Sematethmos* sp., *Actinastraea pentagonalis* (Goldfuss), *Chomatoseris iranense* Flügel, *Microsolena subturbinata* (Gregory), *M. variolata* Gregory, *Dimorpharea* cf. *lineata* (Eichwald), *D.* sp., *Comoseris jumarense irregularis* (Gregory), *Montlivaultia* sp., *Isastrea explanata* (Münster), and *Axosmilia* sp. Other fossils from the middle member include spines of *Cidaris*, shells of "*Pecten*" and "*Rhynchonella*", and a fragment of a perisphinctid ammonite. The coral fauna, in the opinion of Flügel (1966) shows close affinities with the corals described by Gregory (1900) from the Bathonian-Callovian Upper Puchum Series of Cutch in India.

The calcareous upper member (Jdl) of the Qal'eh Dokhtar Formation is composed of light blue-grey to brown limestone. The limestone is medium- to thin-bedded, in part strongly sandy-detritic or oolitic, and in part rather marly and very dense. Fossils include crinoids (*Cidaris* sp.), *Ostrea* and *Pecten* fragments, *Alectryonia, Aptychi,* belemnites, and a few ammonites, determined by K. Seyed-Emami as *Peltoceras* sp. (cf. *Peltomorphites*), *Perisphinctes* cf. *plicatilis*, and *Idoceras* sp., suggesting a Late Oxfordian to possibly Early Kimmeridgian age.

South of the type area, in Kuh-e-Neygu and Ezhdarkuh, the Qal'eh Dokhtar Formation gives way laterally to the massive, mountain-building Esfandiar reef limestone. In the area of transition the well bedded aspect of the Qal'eh Dokhtar persists in the lower part of the common stratigraphic interval, whereas massive algal limestone of Esfandiar type develops more and more in the upper part.

In the eastern desert region (Nabavi and Tatevossian, 1966) typical Qal'eh Dokhtar Formation forms a north-south-trending range of hills extending more than 50 km from Kuh-e-Takherg in the north to Shekasteh Kasuri in the south. The unit reaches in places a thickness of as much as 1,600 m and is composed of sandstones, shales, marls, and well bedded limestone similar to those characterizing the formation at its type locality. The contact with the underlying Baghamshah Formation is sharp. Upwards the unit grades into massive limestone of Esfandiar type.

A strongly sandy facies, apparently representing the lower part of the unit, prevails throughout the section of Kuh-e-Shisui (Fig. 2). The sandstones contain layers of brown sandy limestone crowded with corals. Such coral limestones form outstanding biohermal reefs, up to 100 m thick, at Kuh-e-Shisui, Galeh Chah, and Kuh-e-Faqih (Fig. 3); on the map they have been distinguished with the colour and symbol of the Esfandiar Limestone. The facies of bedded limestones representing the higher parts of the Qal'eh Dokhtar Formation (Fig. 2) is best developed south of Kuh-e-Shisui in the Kuh-e-Faqih area. Here, oolitic limestone becomes more and more important towards the top of the unit.

In the west flank of Kuh-e-Birg syncline the Qal'eh Dokhtar Formation is represented by 355 m of alternating marl and bedded limestone passing upwards into massive

Esfandiar-type limestone; eastwards the marl-limestone alternation decreases sharply in thickness and gives way very rapidly to massive limestone, so that in the east flank of the syncline 500 m of massive limestone - mapped as Esfandiar Limestone - represents the higher Jurassic above the Baghamshah shales.

Fossils obtained from the Qal'eh Dokhtar Formation in the eastern desert region comprise algae, bryozoa, corals, crinoids, lamellibranchs, and belemnites. Only the corals *Thamnasteria* sp. from Kuh-e-Birg and *Montlivaultia* spp. and *Trocharea tenuilamellosa* (Gregory) from the Takherg-Kasuri ridge (det. E. Flügel, 1966) have been determined so far, though an additional collection of corals is presently under investigation. *Trocharea tenuilamellosa* suggests late Middle Jurassic age.

The age limits of the Qal'eh Dokhtar Formation are not yet clearly determined and seem not to be the same everywhere. The coral fauna of the middle part of the type section, as has been mentioned above, suggests Bathonian-Callovian, but Bathonian is unlikely at this place because the ammonites found nearby in the underlying Baghamshah Formation, according to K. Seyed-Emami (1967) reach as high as Callovian. Whereas in the northern Shotori Range, and also in the eastern desert region, the Baghamshah clearly *underlies* the Qal'eh Dokhtar Formation, a partial interfingering between the two formations has been observed farther north in the Shirgesht area (Ruttner et al., 1968). From all available evidence, which is admittedly still insufficient and in part controversial, it may be concluded that within the Boshruyeh Quadrangle the Qal'eh Dokhtar Formation ranges from Callovian to at least Kimmeridgian, whereas farther north older stages (Bathonian) may be equally developed in Qal'eh Dokhtar facies.

Esfandiar Limestone (Je)

Most of the high ridges and crests in the eastern part of the Shotori Range are composed of a light-coloured unit of massive reef limestone, called Esfandiar Limestone after Kuh-e-Esfandiar in the southern part of the Range. Little can be added to the observations on this formation by Stöcklin et al. (1965). The thickness is 690 m in the type section at Kuh-e-Esfandiar but seems to be more than 1,000 m farther north. In addition to massive limestone, well bedded sandy limestone and sandstone are commonly found in the lowermost part of the unit. As explained above, the Esfandiar Limestone and the Qal'eh Dokhtar Formation interfinger in the northern part of the Shotori Range. Reef limestones closely comparable in lithology to the Esfandiar Limestone, and shown on the quadrangle map with the same colour and symbol, appear also in the Jurassic outcrops in the eastern desert region but here play a much less important role.

Reef-building algae are the main organic remains, besides which only scarce Foraminifera, corals, crinoids, echinids, lamellibranchs, and ammonites have been found. *Dolikephalites* sp., indicating Callovian age, was found in beds transitional between the Baghamshah Formation and the Esfandiar Limestone. Clapp (1940) reported *Virgatosphinctes* sp., suggesting latest Jurassic (Tithonian) age, from a limestone in the northwestern spurs of the Shotori Range belonging to the upper part of the Esfandiar formation. A late Middle Jurassic to Late Jurassic age is thus sufficiently established

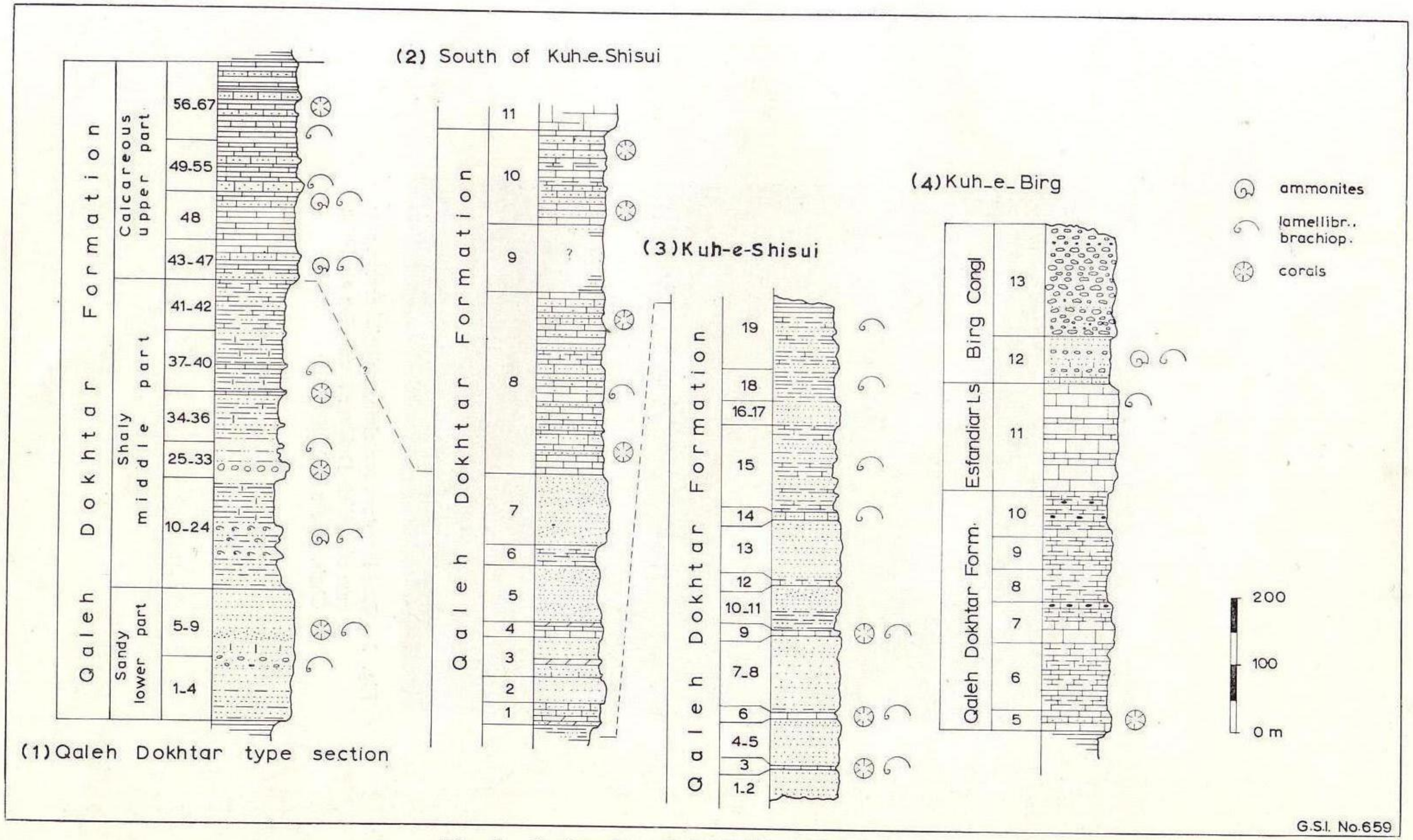

Fig. 2. Sections through the Qal'eh Dokhtar Formation.
(1) After Stöcklin et al 1965.
(2) (3) (4) After Tatevossian 1966.

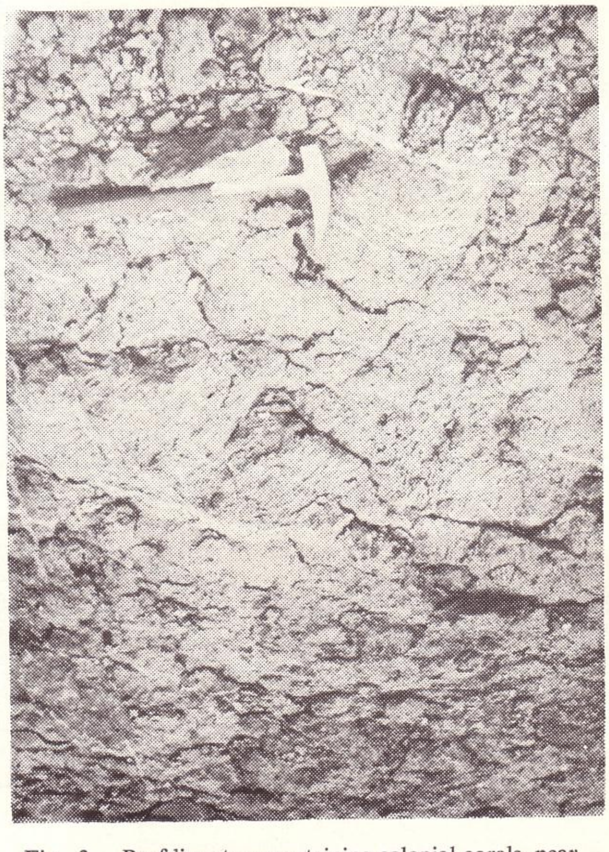

Fig. 3. Reef limestone containing colonial corals, near base of Qal'eh Dokhtar Formation at Galeh Chah. (Photo M.H.Nabavi.)

and confirms the approximate stratigraphic equivalence of the Esfandiar and Qal'eh Dokhtar formations as suggested by field evidence.

In the Shotori Range the Esfandiar Limestone is everywhere truncated and unconformably overlain by Cretaceous or Paleogene rocks. At Kuh-e-Birg in the eastern desert region, however, the limestone grades upwards into a conglomerate that seems to be Jurassic in age.

Conglomerate of Kuh-e-Birg (Jec)

In the syncline of Kuh-e-Birg, Nabavi and Tatevossian (1966) found an unusual conglomerate formation overlying the Esfandiar Limestone and having a transitional contact with it. The unit is 230 m thick. The lower 65 m consist of alternating sandy to pebbly limestone and conglomerate, the limestone beds containing a few badly preserved fragments of cephalopods and lamellibranchs. The upper 165 m are poorly bedded, coarse conglomerate with a red sandy-calcareous matrix. The components are well rounded, reach fist size, and consist mainly of Esfandiar Limestone.

This conglomerate, which has been seen only at Kuh-e-Birg, can be compared in stratigraphic position and partly also in lithology to the Upper Jurassic (Kimmeridgian-Tithonian) Garedu Red Beds described by Ruttner et al. (1968) from the Shirgesht area. The conglomerate of Kuh-e-Birg is truncated and unconformably overlain by the much younger (Late Cretaceous or Paleogene) Kerman Conglomerate.

CRETACEOUS

Cretaceous rocks (K) are poorly developed in the Boshruyeh Quadrangle. They are limited to rudimentary occurrences in some narrow synclines and fault zones on the east side of the Shotori Range and a few isolated outcrops at Kuh-e-Chavosh in the eastern desert region near the northern quadrangle margin.

The Chavosh occurrences (Fig. 4) are massive, pale-red rudist limestone with some marl in the lower part, totalling about 200 m in exposed thickness. Their base is not exposed and they are unconformably overlain by Tertiary andesite.

The Shotori exposures consist of marl, sandstone, sandy limestone, and conglomerate, not exceeding 300 m in thickness. They contain *Orbitolina* cf. *concava* and *Choffatella decipiens* (det. F. Bozorgnia), and the following macrofossils identified by K. Seyed-Emami: *Schloenbachia* sp., *Acanthoceras* (cf. *Buchiceras*) sp., *Actaeonella* sp., *Polinices* sp., *Exogyra* sp., *Cyprina* sp., *Ostrea* sp., and *Hemiaster* cf. *minimus* Agassiz. The age of the fossiliferous beds is Albian-Cenomanian. No undisturbed contacts with older rocks have been observed except at Kuh-e-Khani (northern Shotori Range), where a red conglomerate of supposed Cretaceous age overlies with clear unconformity the Jurassic Esfandiar Limestone. At Khoda Aferid (east of Kuh-e-Khani) the fossiliferous beds grade into conglomerates that alternate with basaltic tuffs; these rocks are likely to be Late Cretaceous in age. In other places the fossiliferous beds are overlain by the Kerman Conglomerate with marked discordance.

CENOZOIC

General Remarks

The post-Cretaceous formations of the Boshruyeh Quadrangle, which are extensively developed in the desert regions west and east of the Shotori Range, are all non-marine and unfossiliferous and in great part of volcanic origin. Their stratigraphy had to be based on lithology, degree of deformation, and comparison with dated formations in other parts of Iran. This problem was particularly difficult in the eastern desert region, where volcanic formations play a dominant role.

This region has been studied by J. Eftekhar-nezhad and M. Zahedi (in 1965, area west of the 58th meridian) and by M. Nabavi and S. Tatevossian (in 1966, area east of the 58th meridian), with temporary participation of J. Stöcklin in the field work of both teams. The studies of the latter team have been extended to the Khur area, a short distance beyond the southeast corner of the Boshruyeh Quadrangle, where marine deposits of Early Tertiary age provide a key for the better understanding of the stratigraphy of the volcanic formations. The results of the studies at Khur are summarised here.

The Tertiary sequence of the Boshruyeh Quadrangle has been divided into a "Paleogene" and a "Neogene" part, the two parts being separated by a major unconformity. However, the identification of this unconformity with the Paleogene-Neogene boundary is purely conventional and with future studies will certainly need adjustment.

Kerman Conglomerate (Pgk)

The name Kerman Conglomerate, defined by Huckriede et al. (1962) in the Kerman area, has been extended to various conglomerate deposits in the Boshruyeh Quadrangle, the common characteristic of which is their conformable position below the Tertiary volcanic sequence. They are thus regarded as "basal conglomerates" of the Tertiary, although some of them may actually be of Late Cretaceous age; evidence for this is found in the exposures of Khoda Aferid in the northern Shotori Range, where fossiliferous Cenomanian beds pass gradually into conglomeratic beds and these into an alternation of conglomerate and basaltic tuff that initiated the volcanic sequence in this area (see Stöcklin et al., 1965, p. 51 and Fig. 26). In other outcrops, however, the "basal conglomerate" rests with distinct unconformity on truncated Cretaceous and older rocks. This is also the case at Jastekuh in the Khur area, southeast of the Boshruyeh Quadrangle; here, a Kerman-type Tertiary basal conglomerate overlies unconformably Mesozoic and Paleozoic rocks and grades upwards into fossiliferous limestone of Middle Eocene age (see p.32).

The conglomerates are often monomict, the components being derived from the immediately underlying formation. In the Shotori Range this is usually light-coloured limestone of the Esfandiar Formation. The pebbles are well-rounded, reach as much as half a metre in diameter and are embedded in a reddish sandy-argillaceous matrix. The thickness varies from a few metres to more than 100 m, being about 250 m in the Khur area. Over large stretches, particularly in the eastern desert region, the Kerman Conglomerate is missing and the volcanic rocks rest directly on various Mesozoic sedimentary formations.

Paleogene Volcanic Group

The distinctions made on the Boshruyeh map in the Tertiary volcanic and pyroclastic formations are mainly petrographic and lithologic. The various colours and symbols used do thus not necessarily indicate a definite stratigraphic sequence, although such a sequence could be worked out in at least gross outlines. The main stratigraphic division is that between a lower ("Paleogene") and an upper ("Neogene-Quaternary") group. The total thickness is not known; it may be of the order of 1 km at the eastern foot of the Shotori Range and twice as much or more in the eastern part of the quadrangle. Of this, only a few hundred metres are referable to the younger group.

The lower or "Paleogene" volcanic group consists of effusive and pyroclastic rocks of predominantly dacitic composition. Basalts, andesites, quartz keratophyres, and rhyolites are associated but subordinate. The group occupies most of the eastern foothills of the Shotori Range and the greater part of the desert region in the central and eastern sectors of the Boshruyeh Quadrangle. Rudimentary outcrops occur also within the Shotori Range and west of it.

Arguments in favour of the supposed Paleogene age are: (a) In the neighbouring Khur area the volcanic complex overlies conformably the dated Middle Eocene sedimentary rocks and is stratigraphically closely associated with it (p. 32). (b) The few exposures of these volcanic rocks to the west of the Shotori Range, northwest and southeast of Espahk, are unconformably overlain by a thick red-bed formation, the age of which can be safely assumed to be Neogene; the same holds true for the northern extensions of the lower volcanic complex in the adjoining Ferdows Quadrangle. (c) Though little affected by tectonic deformation in the central part of the Boshruyeh Quadrangle (a fact that might suggest a very young, post-orogenic age), these rocks are still considerably folded in the Shotori Range and in the eastern part of the Quadrangle. (d) The broad volcanic zone of the Boshruyeh Quadrangle seems to be a direct northwestern extension of the Zahedan-Birjand zone of easternmost Iran, in which a major part of the volcanic formations is dated as Lower Tertiary (Paleocene-Eocene) from association with fossiliferous marine deposits (Clapp, 1940; National Iranian Oil Co., 1959). The lower volcanic group of the quadrangle seems thus to be just another product of the powerful Early Tertiary volcanism, which has played such an important role in northern, central, and eastern Iran. However, the very beginning of volcanic activity may well date back to the Late Cretaceous, as will be explained below.

The following distinctions have been made within the lower volcanic group:

Earliest Basaltic and Andesitic Products (Pga)

The fossiliferous Cenomanian beds at Khoda Aferid in the northern Shotori Range (see p. 28) grade upwards into conglomerate and this in turn is overlain conformably by some 250 m of black tuff with several repetitions of conglomerate beds and intercalations of greenish-black amygdaloid lava, ash beds, and volcanic bombs.* The dark volcanic rocks are of olivine-basaltic composition and as such are a unique occurrence

* In error this small outcrop of volcanic rocks and underlying Cretaceous sediments was left blank on the quadrangle sheet. It is shown on the coloured 1:100,000 geological map and on Fig. 26 in Stöcklin et al. (1965).

in the Boshruyeh Quadrangle. Microscopically they are characterized by the association of basic plagioclase (labradorite-bytownite), titanaugite, olivine, and accessory iron oxides. The seemingly transitional contact relations of these volcanic rocks with Cenomanian sedimentary deposits suggest that they also may be of Cretaceous age. A very few pebbles of similar basic rocks have been found in the Kerman Conglomerate at Khur, which further supports a pre-Tertiary age for the initial volcanic activity.

Apart from this isolated occurrence of basaltic rocks at Khoda Aferid, the volcanic sequence in the Shotori Range starts either with dark-coloured andesites or directly with the main mass of the dacites. The andesites are limited to the eastern foothill sector between Dekuh and Fathabad. They are mostly augite andesites, which are poorly bedded and form large, irregular bodies. In thin section they show a hypocrystalline-porphyritic texture. Zoned plagioclase (andesine to labradorite) and monoclinic pyroxene constitute the phenocrysts. The groundmass consists of fine plagioclase laths, glass, celadonitic clay minerals, and felsitic and chalcedonic material. More acidic varieties transitional to the younger dacites contain in addition minor amounts of quartz, biotite, and alkali feldspar (? albite).* South-east of Talkhuk the andesites overlie the Kerman Conglomerate, which here rests unconformably on Upper Cretaceous marls or on the Jurassic Esfandiar Limestone. In the easternmost foothills of Onj Pain, the andesites pass into more massive, coarser-grained rocks which may be described as diorite-porphyrites. These are intrusive rather than extrusive, for they have irregularly invaded, altered, and partly absorbed the Jurassic and Cretaceous sedimentary rocks. They are characterized by a higher amount of biotite and quartz.

Dacites (*Pgd*)

Dacites together with their tuffs form the main part of the Paleogene volcanic group. In the Dehuk-Fathabad region they clearly overlie the andesites just described, but elsewhere in the Shotori Range as well as in the eastern desert region they rest directly, with or without a basal "Kerman Conglomerate", on the eroded Mesozoic basement.

The dacites are massive to distinctly bedded rocks of mostly black-red to purple colour, more rarely pink, ash grey, and whitish grey, forming conspicuous landforms. They have a distinctly porphyritic texture with phenocrysts of more or less idiomorphic quartz visible in hand specimen. Under the microscope they reveal a hemicrystalline texture with quartz, feldspar, and a variable, sometimes considerable, amount of biotite in an aphanitic groundmass. The feldspars are almost exclusively plagioclase, mostly andesine, more rarely oligoclase or labradorite, often with zonal structure. K-feldspar is exceptional. The biotite appears in tabular, euhedral crystals and frequently shows alteration to chlorite. Hornblende is a major constituent in samples from the Shikasteh Divar area (southeast corner of the quadrangle), where dacite flows form a few thin layers in an otherwise mainly tuffaceous sequence. Devitrified glass, fine plagioclase laths, and felsic crystals usually make up the groundmass of the dacites; apatite, monoclinic pyroxene, iron oxides, and other opaque minerals are common accessories.

In places such as Kuh-e-Chinga and Kuh-e-Shurab the dacites form extensive,

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* These and all other petrographic data on the following pages are based on microscope studies by S. Iwao, A. Hushmand-zadeh, and M. Sabzehei, Geological Survey of Iran.

elongated, homogeneous bodies up to 20 km long, thought to represent extrusion cupolas composed of true effusive material. More frequently, however, the dacites show distinct bedding and alternation with pyroclastic material. These are hardly distinguishable petrographically from the more massive ones, but their bedding and the great lateral persistence of individual beds indicate that they are welded tuffs, perhaps of the ignimbrite type, rather than true lava. This assumption is supported by thin section studies, the groundmass of the bedded dacites sometimes showing fluidal texture, abundant vitric fragments, and aggregates of pumiceous tuff. The interbedded pyroclastics consist of agglomerates, tuff breccias, whitish-grey crystal tuffs rich in biotite, and above all of fine-grained, well bedded dacitic crystal tuffs of predominantly pale-green colour.

Rhyolite (Pgr) and Quartz Keratophyre (q)

Rhyolitic rocks closely associated with the dacites occur in the eastern desert region southwest of Robat-e-Chah Gombad, at Chah-e-Hoseyn, and in the area of the Ghaleh Chah and Shurab mines. In the field the rhyolites are hardly distinguishable from the dacites, and their distinction on the map has been based largely on thin section studies and is therefore rather arbitrary. Even under the microscope the rhyolites show close affinities with the main mass of the dacites, differing from them mainly by the presence of appreciable amounts of K-feldspars, which are missing from the dacites or are markedly subordinate. The quartz is often bipyramidal. The rhyolites also show a greater tendency to kaolinization and sericitization of the feldspars than do the dacites.

The lead mineralizations of the Ghaleh Chah and Shurab mines are apparently related to such rhyolites, which at these places form several small sub-volcanic intrusive stocks.

Kuh-e-Robat-e-Shur in the northern central part of the quadrangle is a nearly circular, perfectly dome-shaped mountain of quartz keratophyre, 3-4 km in diameter. It is the best example of an extrusion cupola in the report area.

Green Tuffs (Pgt) and Related Sedimentary Rocks (Pgs, Pgc)

A thick sequence of well bedded, fine-grained tuffs of a characteristic pale-green colour is widely distributed in the eastern desert region, being typically developed in the area west and south of Kuh-e-Chinga - Kuh-e-Shurab, where the tuffs clearly *overlie* the massive dacite-lava composing these two mountains. In this southern area, only a few thin dacite "flows" (? ignimbrites) are found within the tuff sequence, but farther north, along the Dehuk-Ferdows road, the tuffs and bedded dacites show intimate alternation and interfingering. Under the microscope the tuffs reveal a mineral composition similar to that of the dacites, crystal fragments of oligoclase-andesine, quartz, and biotite, and more or less devitrified glass being the main constituents.

In some respects the green tuffs recall the Eocene "Green Series" (Karaj Formation of the Alborz Mountains), but in contrast to them they do not contain any organic remains that would indicate a submarine depositional environment. They pass locally into slightly gypsiferous green and pink tuffaceous mudstones, siltstones, and sandstones, suggesting deposition in a "kavir"- (playa-) like environment.

The dacitic green tuffs and tuffaceous sediments extend eastwards into the area of Kavir-e-Birg and from there southeast beyond the quadrangle limit into the Khur area, where their stratigraphic relation with Eocene marine deposits can be studied.

In the stratigraphic sequence of this southeastern area a unit of slightly tuffaceous red sandstone and marl (Pgs) is particularly significant. According to Nabavi and Tatevossian (1966) 600 m of these red beds are exposed south of Borj-e-Sargilu (southeast of Kavir-e-Birg) and underlie with transitional contact the green dacitic tuffs, which in this area are estimated to reach a thickness of 1,000 m. The red beds reappear with a thickness of about 1,000 m farther south, at Jastekuh southeast of Khur (just outside the quadrangle), where the following section has been recorded (top to bottom):

	Metres
Green tuffs (exposed farther north) .... about	1,000
Red sandstone and marl, partly gypsiferous, with layers of gritstone and conglomerate, few indeterminable *Nummulites*....about	1,000
Marl, grey, soft, weathering yellow	100
Limestone, yellow-grey, thick-bedded, partly marly, containing *Nummulites globulus, Alveolina* aff. *levantina, Rotalia trochiformis, Fasciolites* sp., and *Eponides* sp. (Age: Lutetian)	250
"Kerman Conglomerate", composed mainly of sedimentary material but containing also a very few pebbles of dark-green basic volcanic rock	250
——— Unconformity ———	
Marl, soft, silty, green-grey, barren (?Mesozoic)	

The succession — Kerman Conglomerate, nummulitic beds, green tuffs — is very like that in the Alborz Mountains Fajan Formation (conglomerates), Ziarat Formation (nummulitic limestone and marl), Karaj Formation (green tuffs). The green tuffs of the Boshruyeh Quadrangle thus occupy a stratigraphic position very similar to that of the Karaj Formation of the Alborz, which is Middle to Upper Eocene in age.

The red sandstones exposed south of Borj-e-Sargelu dip westwards below the green tuffs and seem to pinch out in this direction, as they do not reappear farther west. At Kuh-e-Birg the green tuffs overlie directly the Kerman Conglomerate and in their lower part contain a lenticular layer of conglomerate up to 30 m thick (Pgc). The latter differs from the underlying Kerman Conglomerate in having a tuffaceous matrix and abundant dacitic material among the components. This shows that not only the red sandstone unit but also the lower parts of the dacitic sequence are missing at Kuh-e-Birg. In the Kavir-e-Robat area the green tuffs rest with pronounced unconformity on Jurassic rocks.

The dacitic tuffs, which are predominantly pale-green in colour, include locally also red varieties in the higher parts, notably a conspicuous, persistent brick-red layer, about 3 m thick, near the top of the dacitic sequence in the southeastern part of the quadrangle (Chang-e-Habitu, Cheshmeh Khuri, etc.).

Biotite-andesite (*Pgab*) *and Related Tuffs* (*Pgat, Pgtb*)

Andesites, mainly biotite andesite, appear in the highest parts of the Paleogene volcanic sequence in the south-central and southeastern parts of the Boshruyeh Quadrangle. Petrographically they differ little from the dacites, the main difference being a smaller amount or total absence of quartz. The plagioclase ranges from oligoclase to labradorite. Biotite and iron oxides are the most important dark minerals; pyroxene occurs occasionally.

The andesites overlie the green tuffs and in places interfinger with the higher parts of them. Dacitic tuffs with many intercalations of andesitic lava (Pgat) occur extensively in the Borj-e-Sargilu - Shekasteh Divar area in the southeastern part of the quadrangle; they seem to indicate interfingering of dacitic material from western sources with andesitic material from eastern sources and a general increase of the latter to the east. Some of the interbedded lava flows show pillow structure, suggesting transition into a submarine volcanic environment towards the east. Intermingling of dacitic and andesitic material is evident also in a unit of tuff breccia (Pgtb), up to 80 m thick, south of Shekasteh Mir-e-Khash. In this breccia, blocks of black andesite up to 2 m in diameter are embedded in fine-grained green dacitic tuff.

The biotite andesites, which occur only in the southern parts of the quadrangle, are the youngest member of the "Paleogene" volcanic group.

"Neogene-Quaternary" Volcanic Group

Pyroxene andesites (ap)

The older, "Paleogene", mainly dacitic group of volcanic rocks is unconformably overlain by a younger group that consists mainly of pyroxene andesites (Fig. 5). The younger andesites are very dark, almost black, and form extensive subhorizontal flow sheets reminiscent of basalt plateaus in the northern and southern parts of the eastern desert region. The flow sheets are practically unfolded but are disrupted by a complicated system of faults into angular slabs gently tilted in different directions. The unconformable contact with the older volcanic group is particularly clear in the area west of Kuh-e-Chinga and south of Kuh-e-Shurab, where the pyroxene-andesites rest in subhorizontal position on the gently folded green tuffs. It is more difficult to distinguish further to the southwest, in those places where the young pyroxene-andesites overlie the lithologically similar biotite andesites which, in this southern area, appear in the upper part of the older volcanic group. However, numerous dark feeder dikes of the younger andesites, cutting through the somewhat lighter-coloured older andesites, could be distinguished and mapped in this southern area too. At Kuh-e-Takherg, Kuh-e-Shisui, and elsewhere, the young flows overlap steep sedimentary beds of the Jurassic.

The young andesitic flows and dikes are connected to numerous small but well preserved volcanic cones. More than 40 such features have been mapped in the eastern desert region. They are particularly abundant south of Kuh-e-Shurab, in the Kavir-e-Robat area (Fig. 6), and around Kuh-e-Shisui and Kuh-e-Takherg. Most of them are only a few hundred metres, and some only a few tens of metres, in diameter. A remnant of a larger eruptive centre is the prominent hill, pt. 1370, west of Shurab. The largest cone, which has a well preserved central crater, is northeast of Robat-e-Shur in the northern part of the quadrangle. Dikes radiating in a spider-web pattern from several small cones north of Kuh-e-Shisui extend for as much as 10 km, standing as rigid black walls above the low-weathering green tuffs through which they cut. Several small ring dikes are also present, one example being shown on the map, viz at Chang-e-Habitu in the southern part of the quadrangle.

The andesites have a porphyritic texture with pyroxene and plagioclase as the main phenocrysts. The plagioclase is andesine to labradorite, and the pyroxenes are of both the monoclinic and orthorhombic (hypersthene) varieties. Green hornblende and biotite are found occasionally. The matrix consists of fine plagioclase laths with interstitial pyroxene, and glass. Apatite, zircon, iron oxides, and other opaque minerals occur as accessories. The rocks are distinctly less altered than the older dacites and andesites.

At Kuh-e-Haji Heydar, in the extensive andesite mass in the northern part of the quadrangle, a lower and an upper part could be clearly distinguished. The lower part is a fine-grained, dark-red rock with pyroxenes as the only phenocrysts visible to the naked eye. The upper part is a very dark, nearly black vesicular rock of basalt-like appearance. The vesicles are filled with quartz and milky chalcedony reaching in places head size. The pyroxene phenocrysts are smaller and fewer than in the lower part. The matrix is very rich in opaque minerals as well as fine needles of pyroxene and plagioclase. Chlorite and some serpentine appear as alteration products.

Hornblende andesite (ah)

A local, hornblende-rich variety of the young andesites is found in a few small outcrops in the southeastern part of the Boshruyeh Quadrangle. The best example is the plug-like hill called Mikh-e-Khur ("nail of Khur") near the southern quadrangle margin, an outstanding landmark for all travellers in this region (Fig.7). The rock displays distinct columnar structure. Under the microscope it reveals phenocrysts of plagioclase (andesine-labradorite) and green hornblende floating in a holocrystalline to pilotaxitic groundmass of the same minerals. K-feldspar, biotite, some quartz, apatite, and opaque minerals are present as accessories.

Biotite dacite (d)

At Kuh-e-Chah near the northern quadrangle limit, a dacitic formation very similar to the "Paleogene" dacites reappears above the young pyroxene andesites. It has been followed by J. Eftekhar-nezhad far north into the adjoining Ferdows Quadrangle. This young dacite is poorly bedded and characterized by abundant crystals of brown biotite, which along with plagioclase (andesine-labradorite) and quartz is the main constituent. The formation reaches about 300 m in thickness.

Age of the Volcanic Rocks

As already stated, the dating of the two major volcanic groups as "Paleogene" and "Neogene-Quaternary" is rather arbitrary, and it may be useful to summarize here the criteria bearing on the question of the age of the rocks.

From the stratigraphic relations with the dated Eocene sedimentary rocks in the Khur area it is evident that the bulk of the *lower* volcanic group (with the possible exception of its basaltic predecessors in the Shotori Range, which may be as old as Late Cretaceous) cannot be older than Middle Eocene. The upper limit of the lower group is given by the unconformable overlap, at the western foot of the Shotori Range, of the "Neogene Red Beds"; these are very likely an extension of the "Neogene" red beds of Central Iran, which are essentially Miocene in age but in places include Oligocene. This leaves little doubt that the lower volcanic group is at least pre-Miocene. Its pro-

Fig. 4. Kuh-e-Chavosh from south. Cretaceous limestone surrounded by Tertiary andesite. (Photo J.Stöcklin.)

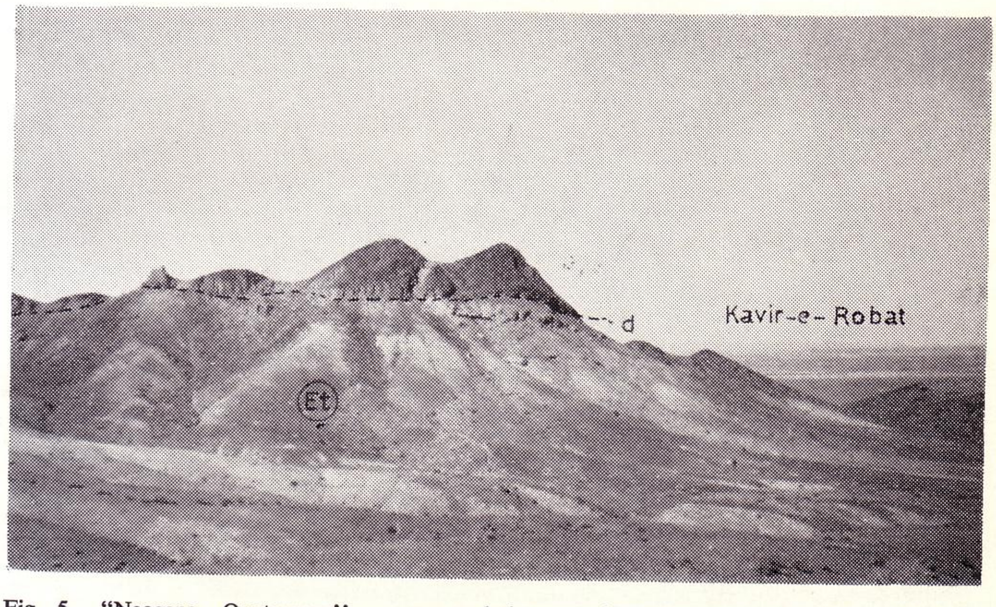

Fig. 5. "Neogene - Quaternary" pyroxene andesite unconformably overlying dacitic tuff of the Paleogene volcanic group, south of Kavir-e-Robat. (Photo M.H.Nabavi.)

Fig. 6. Miniature volcano in Kavir-e-Robat, northeast of Chah-e-Yazdani. (Photo J. Stöcklin)

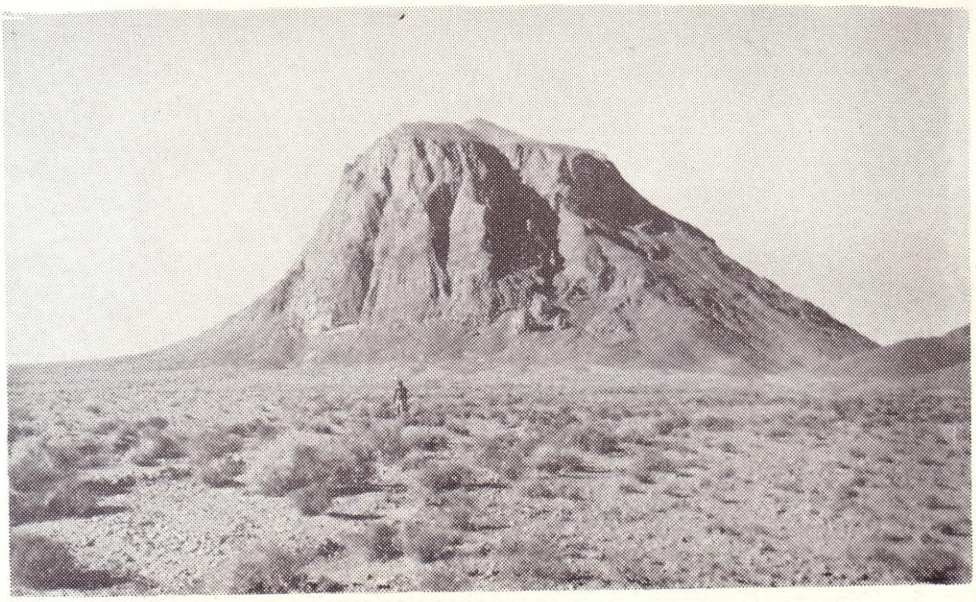

Fig. 7. Mikh-e-Khur, pyroxene andesite. (Photo M.H.Nabavi.)

bable age from comparison with the Karaj Formation of North Iran is late Middle Eocene to Late Eocene; Oligocene cannot be excluded as a possibility.

From what has been said, a post-Eocene age can be safely assumed for the *upper* volcanic group, all the more as the two groups are separated by a regional unconformity indicating a phase of deformation and thus a time break. Unfortunately, the "Neogene Red Beds", which are so extensively developed west of the Shotori Range, are missing from the desert depression east of the range, so that their stratigraphic relation with the younger volcanic group remains unknown. A very young (Quaternary) age is suggested by the generally youthful aspect of many of the dikes, necks, cones, and craters. In particular, some of the very small conelets in the Kavir-e-Robat area are perfectly preserved miniature volcanoes (Fig. 6). The fresh aspect of the rocks in thin sections strengthens this impression. A third argument in favour of a very young, post-orogenic age is the small degree of tectonic deformation, as indicated by the subhorizontal position of the young flows especially in the central sector of the eastern desert region. This feature may be misleading, however, as this part of the Lut Desert seems to belong to a tectonic element of unusually high rigidity ("Lut Block"), in which not only these young volcanic formation but also the older volcanic group and the Mesozoic substratum have been remarkably little affected by tectonic deformation. An invalid argument is the similarity to subhorizontal flows of undoubtedly Quaternary age occurring not far to the south in the Nayband area: these flow rocks are of a quite different (olivine-basaltic) type unknown among the young volcanic rocks of the Boshruyeh Quadrangle. What speaks more directly against a very young, post-orogenic age of at least part of the upper volcanic group is that the small degree of deformation does not obtain over the whole area of distribution of this group: the bedded pyroxene-andesites of Kuh-e-Haji Heydar near the northern quadrangle margin were found to be tilted at angles of 15° to 50°, and similar observations were made in the young dacites in the northern extensions of Kuh-e-Chah.

These somewhat controversial observations tend to the conclusion that the upper volcanic group comprises formations of very similar composition but belonging probably to two or more phases of volcanic activity, covering a considerable time span and including, indeed, rocks of both Neogene *and* Quaternary age. The solution of this problem lies in more refined stratigraphic and petrographic studies of the volcanic formations.

Neogene Red Beds (Ngr) and Conglomerates (Ngc)

A gypsiferous red-bed formation makes up most of the low hill country west of the Shotori Range. This formation has been studied on the ground only cursorily, and its representation on the map has been based largely on photogeology. The rocks are soft, gypsiferous, more or less saline, mudstones, siltstones, and sandstones of pink, buff, and yellow-grey colour. The formation is warped into gentle folds and, with a basal conglomerate, overlies with pronounced unconformity various older rocks. In the exposures northwest of Espakh it encroaches northwestwards successively on the Paleogene dacites, the Kerman Conglomerate, and the Jurassic Shemshak Formation. The thickness here is only a few hundred metres, but it increases towards the Tabas basin. An estimated 1,000 m are exposed in the anticline southwest of Abbasabad.

The red beds pass upwards as well as laterally (towards northwest) into grey conglomerates. The conglomerates clearly interfinger with higher parts of the red beds and replace them entirely towards the Shotori Range. The components are rounded and reach cobble and boulder size, and are derived mainly from the Paleozoic and Mesozoic limestones and dolomites of the Shotori Range; pebbles of Tertiary volcanic rocks are subordinate but not missing. In some places the cement shows a high salt content.

The assignment of these rocks to the Neogene is based on their close lithologic similarity to the Mio-Pliocene red beds and conglomerates which fill all the major depressions of Central Iran. Paleontological evidence to support this correlation was not found and could hardly be expected, as fossils in these continental deposits are in general extremely scarce.

Similar red beds and conglomerates reappear in the extreme northeast corner of the Boshruyeh Quadrangle, where they similarly overlie Paleogene tuffs and Jurassic shales with marked unconformity. Apart from this, such Neogene sedimentary deposits are conspicuously missing throughout the desert area east of the Shotori Range.

QUATERNARY DEPOSITS

Continental deposits of Quaternary age are extensively developed in the desert depressions west and east of the Shotori Range.

Gravel fans spread from the foot of the mountains and hills to form extensive sheets of unconsolidated clastic material that cover the greater part of the desert plains, notably their marginal areas. Near the foot of the Shotori Range they are dissected by numerous dry river beds ("kal") into a system of *terraces* - older high terraces (Qtl and younger low terraces (Qt2). Both can be followed upvalley along the main rivers from elevations of 1,200-1,300 m at the western and eastern mountain fronts to more than 2,000 m in the interior of the range. The older terraces are to be found mainly in the broad, consequent (longitudinal) valleys of the range, whereas the younger (lower) terraces are best developed in the narrow subsequent (transverse) valleys such as the Sardar Valley; here, the young terraces reach elevations of 30-40 m above the present valley floor. With increasing distance from the mountains both terrace systems gradually converge, become less and less pronounced, and fade out towards the interior of the basins. The terraces thus testify to strong uplift of the Shotori Range in Quaternary time. In the eastern desert region the terraces are very weakly developed, but here too they are clearly related to young tectonic uplift along fault lines, as can be seen on the map in the Hoseynabad area east of Dehuk.

Kavirs (salt flats) have formed in the central parts of the main desert depressions. These are the Tabas Kavir in the southwest, the Kavir-e-Namak in the north, and in the east the Kavir-e-Robat and the smaller Kavir-e-Birg and Dagh-e-Kajband. The kavirs are isolated terminal basins, in which the run-off waters from the surrounding mountains collect and evaporate. The kavir deposits consist of highly saline, silty, and clayey mud of yellow, pink, or brown colour in the marginal parts of the depressions, and of a solid, white salt crust in their interior parts. The salt displays the familiar polygonal crack pattern. Smaller basins may not reach the stage of salt formation but be covered merely by a hardened mud crust, which forms smooth surfaces called "dagh" (e.g., Dagh-e-Kajband) and develops a crack pattern similar to that of the salt crusts. The boundary between the kavir deposits and the surrounding gravel fans ("dasht") is everywhere conspicuously sharp; Bobek (1959) has drawn attention to this phenomenon, which can be observed in most salt deserts of Iran and seems to be the result of overlap of the kavir deposits on the adjoining gravel fans.

Sand dunes are found mainly in the southeastern parts of the depressions, where they have accumulated to form large, impenetrable belts of high hills (southeast corner of Tabas basin and of Kavir-e-Namak depression, east and southeast side of Kavir-e-Robat). The position of the sand belts indicates the prevalence of northwesterly winds, which conforms with the northwest-southeast direction of the spectacular wind-erosion channels and ridges ("kalut") in the southern Lut Desert (outside the quadrangle).

Recent alluvium fills the numerous, mostly dry, river beds. It is practically inseparable from the terrace-forming gravel fans in the lower reaches of the rivers, where the terraces disappear and the rivers start to fan out into the nearly horizontal plains.

TECTONICS

The region covered by the Boshruyeh Quadrangle is divided into four structural zones: (1) the western desert depression, or Tabas basin; (2) the Shotori Range; (3) and (4) the western and eastern parts, respectively, of the eastern desert depression, which itself is a northern extension of the Lut Desert.

TABAS BASIN

The Tabas basin as a whole is a typical intermontane depression. It has a triangular outline and is bounded by the Pirhajat-Kalmorz mountains in the west, the Shotori Range in the east and northeast, and low hill country without official name (the "west Nayband desert") in the south. The central part of the basin is occupied by a salt flat (the Kavir-e-Tabas); the outer parts consist mainly of gravel fans and, particularly on the east side, of low hills formed by the Neogene red beds. The Boshruyeh Quadrangle covers only the southeastern edge of the basin, where the red beds form a number of gentle folds that plunge northwest below the young alluvium and salt deposits of the basin centre.

Some idea of the subsurface structure of the Tabas basin can be got from a study of the surrounding mountains, particularly those in the south, west, and north (all outside the quadrangle).

The hill country south of the Tabas plain, made up mostly of Jurassic shales and sandstones, has a type of structure quite unusual for the Mesozoic formations of Iran (Stöcklin, 1961). The beds are practically unfolded but are dissected by numerous faults, among which a series of east-west faults clearly predominates. Along the east-west faults, downthrow is usually to the north. From each fault the beds rise gently to the north (a few degrees to a maximum of 10 degrees) to within a short distance of the next east-west fault, where they suddenly show a steep, flexure-like downdrag towards the fault line. This succession of extensive dip slopes and sharp, steep northward flexures imparts a step-like structure to an area that extends about 100 km from the southern border of the Tabas basin to the south. The straight southern border of the basin is itself such a flexure-like "step" related to an east-west fault, and it may be assumed that this pattern of gentle tilting and faulting continues northwards in the Mesozoic substratum of the basin.

A similar type of structure is found in the outcrops that form the converging western and eastern borders of the northern edge of the Tabas basin. The eastern boundary here is formed by a northwestern branch of the Shotori Range (hills around Ezmaigu - see map in Stöcklin et al. 1965), composed of Jurassic limestone with a core of Paleozoic rocks. The Jurassic limestone (Esfandiar Limestone) is gently tilted in various directions; it displays scarcely any folding, but is dissected by many faults. The fault strike is mostly northwest with a few east-west branches. Similarly, the first outcrops west of the Tabas basin on the Tabas-Yazd road are Jurassic shales, sandstones, and limestones having a conspicuously subhorizontal position at the basin margin but becoming narrowly folded a short distance farther west; a strip of such subhorizontal Jurassic beds can be followed all along the western basin margin and merges with the area of gentle tilting and step-like structure south of the basin.

Thus, uniform structure, dominated by gentle tilting and faulting, characterizes the rocks immediately bordering the basin, true, but very gentle, folding appearing only in the Neogene red beds on the east side, in front of the Shotori Range. The same structure must therefore be assumed for the Mesozoic substratum of the Tabas basin. The basin appears, then, to be an integral part of a rigid block - "Tabas Block" - which extends more than 200 km in a north-south direction from north of Tabas to near Darband in the south, between the narrow folds of the Pirhajat - Kalmorz - Bahabad ranges in the west and the intricate fold and schuppen structures of the Shotori Nayband Range in the east. The Tabas basin is emplaced on the submerged northern half of this block.

SHOTORI RANGE

The Shotori Range with its markedly straight trend is the most conspicuous structural element of the Boshruyeh Quadrangle. It crosses the quadrangle in a north-northwest direction and continues northward into Kuh-e-Bam and Kuh-e-Neveng in the Ferdows Quadrangle, where its general direction changes to south-southwest - north-northeast. Southwards the range becomes gradually narrower and extends for another 200 km beyond the quadrangle in a narrow, morphologically less conspicuous zone of north-trending folds that pass through Nayband and end at the southern tip of Kuh-e-Morghab, east of Darband.

Structurally, the Shotori Range (Fig.8) is clearly dominated by a set of longitudinal faults and thrusts, which farther south merge into a single, major fault line - the Nayband Fault. The latter is one of the main deep fractures in the overall structure of Iran; it borders the Lut Desert depression for a distance of 500 km against the Tabas-Kerman

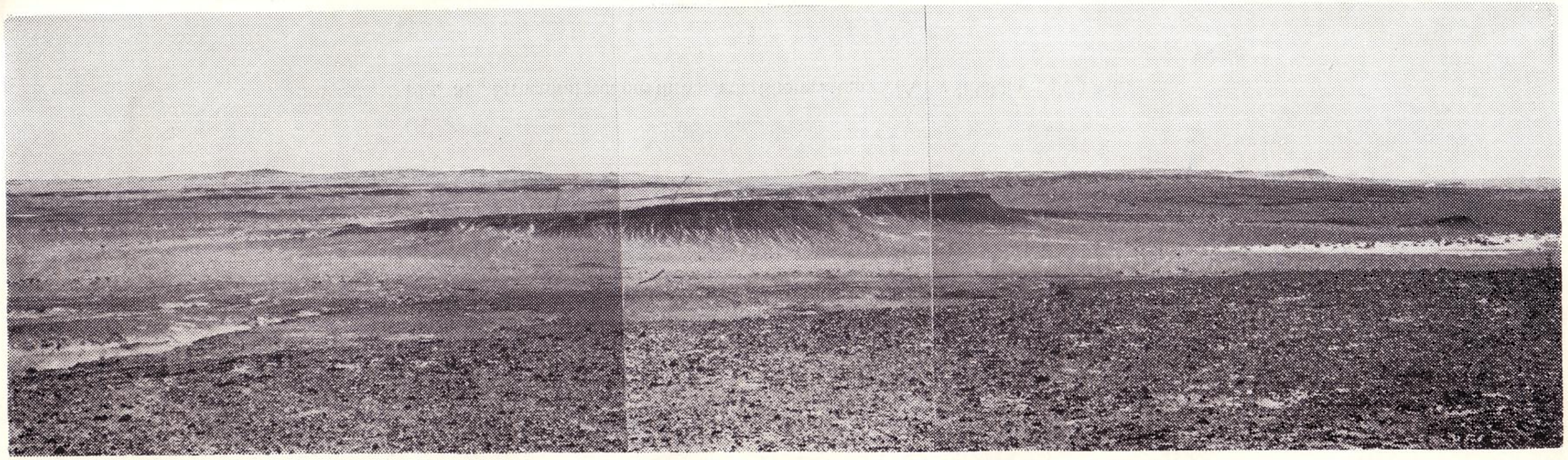

Fig. 9. Subhorizontal Paleogene volcanic rocks in northern Lut Desert. (Photo J. Stöcklin.)

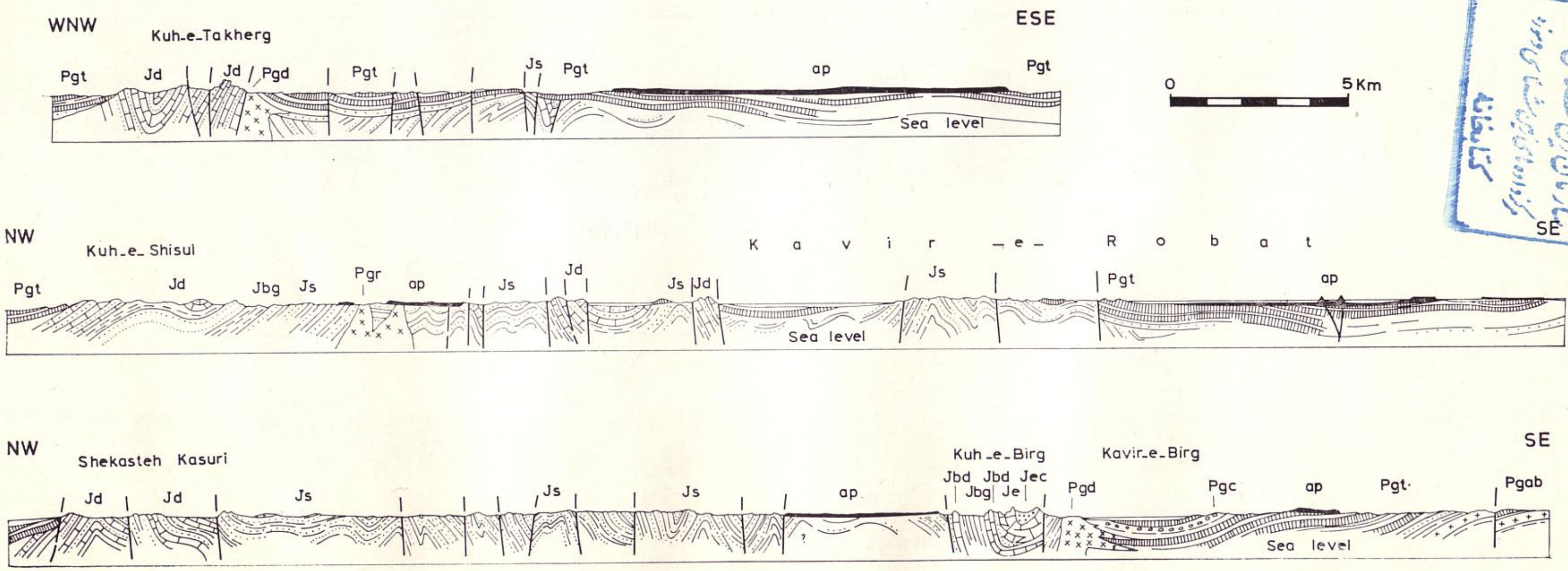

Fig. 10. Structural sections through Seh Qal'eh area, eastern part of the northern Lut Desert. By M.H.Nabavi and Sh. Tatevossian.

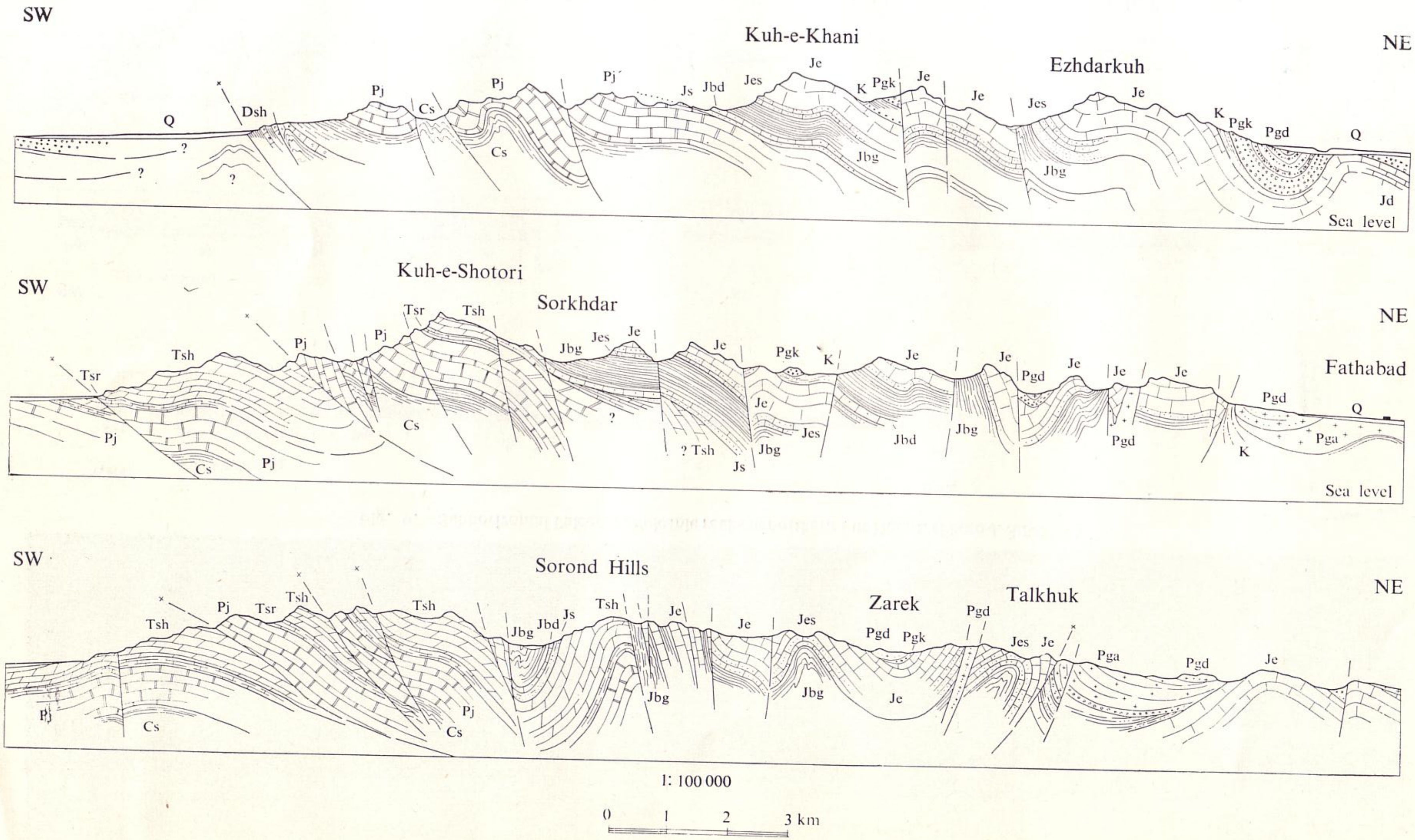

Fig. 8. Structural sections through the Shotori Range. (After Stöcklin et al., 1965.)

Ranges to the west and runs into the Bazman group of Quaternary volcanoes. East of Ravar two small volcanic cones are situated on the same fault line, and at Nayband the fault has caused considerable vertical displacements of Quaternary terrace deposits and even of subrecent alluvium and Kavir deposits. All this indicates very young fault movements. However, evidence in the Boshruyeh Quadrangle suggests an origin of this important fault system in at least Early Mesozoic time.

Within the Boshruyeh Quadrangle, the main branch of the Nayband fault system seems to be the longitudinal fault that passes more or less along the axis of the Shotori Range, through the Kolukhi Pass, and along the eastern foot of the Kuh-e-Jamal - Kuh-e-Shotori central ridge. This axial fault is accompanied by many small sub-volcanic dacite intrusions and marks the approximate western limit of the dacitic formations that are so extensively developed in the eastern foothills and in the adjoining eastern desert area. An important branch fault is the one on the eastern side of the Shotori Range, which separates the Mesozoic formations of this range from the main mass of the Paleogene volcanic rocks in the eastern foothills and farther east. South of Fathabad it is a reverse fault with steep eastward up-thrusting of Jurassic limestone against the volcanic formations. The distribution of the volcanic formations thus shows clearly the close relationship between Early Tertiary volcanism and these longitudinal faults.

A distinct western set of branch faults, west of the axial fault, has a more northwesterly direction. These are in places low-angle thrusts, with thrusting to the southwest. Their age is pre-Neogene, as they are overlapped by the Neogene conglomerates and red beds at the western foot of the Shotori Range. The thrust faults are also clearly dissected by the subvertical longitudinal faults and, therefore, must be older than these.

The Shotori Range appears thus to be split by an axial fault into two structurally different halves. The western side of the range, west of the axial fault, is a pile of schuppen which are separated from each other by low-angle thrusts that strike obliquely (northwest) to the main trend (north-northwest) of the range as a whole. Strong compressional forces must be assumed to have produced this structural pattern in the western part of the range. East of the axial fault, subvertical longitudinal faulting predominates; the fault blocks show relatively gentle folding and step-like sagging towards the east, i.e., towards the Lut depression. Some of these longitudinal faults seem to be tension faults; this is also suggested by the sudden appearance of abundant volcanic material on the east-side of the range.

These observations point to two distinct phases in the structural development of the Shotori Range: an older phase of compression and thrusting, and a younger phase of tensional faulting accompanied by powerful volcanism. The younger phase apparently started with the Paleogene (Middle - Late Eocene) volcanism and persisted, or repeated itself, till subrecent time. The older, compressional phase must be older than the Paleogene volcanism, most probably pre-Middle Eocene. As it has affected almost exclusively the Paleozoic-Triassic rocks on the western side of the range, it is thought to be partly identifiable with the Late Triassic phase of deformation (see below).

In addition to the faults which follow, or nearly follow, the trend of the Shotori Range, many cross faults of different directions are observed. They seem to be younger than the thrust faults and may be of the same age or younger than the longitudinal faults. A preferred direction is southwest-northeast and conforms with a major fault trend in the eastern desert region and with the general direction of the northern continuation of the Shotori Range in the Ferdows Quadrangle. The best example of this type of fault is in Kuh-e-Jamal, where the structure is that of a bowl-shaped syncline, thrust as a whole to the southwest and dissected by two northeast-striking cross faults into three blocks. The downthrow along the cross faults is to the southeast and is probably combined with some right-lateral displacement.

The intricate, predominantly longitudinal thrust and fault structure of the Shotori Range contrasts sharply with the much simpler structural picture of the adjoining desert depressions to the west and east, which are affected mainly by gentle warping and fracturing in a mosaic-like pattern. The Shotori Range appears thus as a cicatrice-like, fault-bounded, strongly tectonized and uplifted feature between two regions of considerable rigidity, the Tabas Block in the west and the Lut Block in the east. The facies distribution of the Jurassic deposits shows that this general structural disposition was already in existence in Jurassic time. An early swell, or horst, a predecessor of the present Shotori Range, is indicated by the strongly reduced thickness of the Upper Triassic - Lower Jurassic section and by the predominance of reef limestone (Esfandiar Limestone) in the Upper Jurassic section. The horst separated two areas with much greater thicknesses and more basinal facies (shales, sandstones, detritic limestones, evaporites) of the Upper Triassic - Lower Jurassic sequence to the west and east. This early "Shotori horst" was evidently created by strong Late Triassic faulting and folding movements, as witness the pronounced angular unconformity at the base of the Jurassic sequence throughout the Shotori Range. There is reason to believe that the important fault trend along which the Shotori Range is aligned is of still older, Precambrian, origin: this has been discussed in earlier publications (Stöcklin et al., 1965; Stöcklin, 1968).

LUT DEPRESSION: WESTERN PART

The greater (central and eastern) part of the Boshruyeh Quadrangle is occupied by a northern (relatively small) portion of the Lut depression, whose centre lies some 300 km farther south.

This part of the depression within the quadrangle exposes mainly Tertiary volcanic rocks and a large north-trending central ridge of Jurassic sedimentary rocks. The Neogene red beds of the Tabas basin are conspicuously missing, whereas subrecent and recent alluvial, aeolian, and playa deposits occupy vast stretches between the outcrops of Mesozoic and Tertiary rocks.

The western part of the desert depression, which occupies the centre of the Boshruyeh Quadrangle between the ridge of Jurassic sediments in the east and the Shotori Range in the west, stands apart as a distinct structural entity. Here, the well bedded Paleogene dacites and tuffs and the Neogene-Quaternary andesites show conspicuously little deformation (Fig.9) and have a structural pattern very similar to that of the Jurassic formations exposed in the immediate neighbourhood of the Tabas basin (see p. 39) The volcanic and tuffaceous rocks are crisscrossed by a great number of faults. The faults are subvertical and strike in various directions, but mainly northeast. The individual fault blocks are gently tilted in various directions. Tilts rarely exceed 10° and are usually a few degrees only. Dips of up to 50° are found exceptionally at a few places close to some of the more important faults, e.g. in the tuffs adjoining the fault that borders the dacite mass of Kuh-e-Chinga in the west. Warping of the Paleogene dacites and tuffs into very gentle anticlines and synclines has also been observed, particularly in the southern part of the zone (where the fold axes are approximately north-south) and in the area east of the Dehuk-Ferdows road (where the axes strike northeast).

As the same Tertiary volcanic rocks overlie, with marked angular unconformity, the older formations, in both the Shotori Range and the eastern part of the Boshruyeh Quadrangle, the question arises as to whether the extremely low degree of folding in the central part of the quadrangle is limited to the Tertiary formations or has affected also the pre-Tertiary substratum. In the two major outcrop areas of pre-Tertiary rocks, the Shotori Range to the west and the Jurassic ridge to the east, these older rocks are disturbed to a considerable degree. Three facts, however, suggest much weaker deformation of at least the Mesozoic rocks in the substratum of the zone under consideration: (1) Two small exposures, viz the Cretaceous limestone ridge of Kuh-e-Chavosh in the northern part and near the eastern margin of the zone, and a hill of Triassic limestone north of Robat-e-Gonbad, have low angles of dip - the former about 10° to the west, the latter 10° to 20° to east-southeast. (2) Similar small "inselbergs" have been discovered in the southern continuation of this zone of subhorizontal Tertiary beds in the area west and northwest of Deh Salm in the central Lut; here again, the Jurassic and Cretaceous beds show very low angles of dip, and in at least one outcrop of Cretaceous limestone (about 60 km west of Deh Salm) are practically horizontal. (3) The Tertiary volcanic rocks themselves are closely folded in their extensions to the west and east (Shotori Range, Seh Qal'eh - Khur area, etc.); the sharp decrease in the intensity of folding of the Tertiary rocks towards the central zone must be matched by a similar decrease in the pre-Tertiary substratum.

These observations lead to the conclusion that the central zone of the Boshruyeh Quadrangle (western sector of northern Lut) is an area of high rigidity (expressed by an unusually low degree of tectonic deformation of all rocks down to at least the Jurassic) similar to the Tabas Block described above. This zone and its southern extension in the central Lut has been named the "Lut Block".

The particular structural conditions in the deeper subsurface, to which the Lut Block owes its rigidity, are not known but can partly be guessed from regional considerations. It must be assumed that the pre-Jurassic formations, in particular the Precambrian basement, have been more strongly consolidated here than elsewhere. From recent structural studies by several Geological Survey and other teams in the Kerman-Tabas ranges and in the Bafq - Posht-e-Badam area adjoining the Lut Desert on the west it is now known that, in fact, the Late Triassic folding movements as well as the Late Precambrian ("Assyntic") diastrophism were much stronger in this eastern part of Iran than in the central and western parts. Evidence for this lies in the unusually large angular unconformities at the base of the Rhaeto-Liassic Shemshak Formation and the base of the Infracambrian group in the eastern region. The appearance of scattered outcrops of strongly metamorphosed pre-Jurassic (? Precambrian) sedimentary rocks in the central Lut (Garmab, Deh Salm) may further support this view. Much remains to be done, however, to clarify this problem.

LUT DEPRESSION: EASTERN PART

The north-trending strip of Jurassic rocks, which extends from Ferdows in the north to Shekasteh Kasuri in the south, forms the eastern border of the area of high rigidity. The rocks are closely folded and steeply inclined, in places vertical to slightly overturned. They are also the site of numerous small subvolcanic dacite and rhyolite intrusions and related lead-zinc mineralizations in the Shurab - Galeh-Chah area. Steep longitudinal and transverse faults both play an important role. The main direction of the folds is north-south. Scattered outcrops of the same Jurassic rocks in the Seh Qal'eh area indicate a northeast-trending branch of the main ridge.

In the easternmost part of the quadrangle, east of the main Jurassic ridge, the dacitic and andesitic Tertiary rocks that constitute the rigid central area reappear, but are much more strongly deformed, both by folding and faulting (Fig.10). The ridges of volcanic rocks in this part of the quadrangle represent the northwestern terminations of several low ranges which penetrate from the southeast into what seems to have originally been an eastern part of the Lut Block disrupted and folded by the Late Tertiary orogenic movements. The ridges branch off from the north-trending main system of the East Iranian Ranges that follow the Iranian-Afghanistan border and consist of strongly folded, very thick, flysch-type and partly volcanic Upper Cretaceous - Tertiary deposits. The easternmost part of the Boshruyeh Quadrangle can thus be regarded as a transitional zone between the extremely stable Lut Block in the west and the extremely mobile East Iranian Ranges in the east. The transitional character is evident not only in the intensity of deformation but also in the composition of the volcanic formations, which in this area show a gradual change from the predominantly dacitic types of the western Lut to the predominantly andesitic types of the East Iranian Ranges.

TECTONIC HISTORY

A Late Precambrian diastrophism, inferred from observations in adjoining areas to the north, west, and south, was responsible for the consolidation of the Precambrian basement and, most probably, for a prevailing north-south trend in the basement configuration - a trend that has persisted throughout the later history of this part of Iran.

The entire Paleozoic is believed to have been a time of relative tectonic calm. This conclusion has been drawn in recent years for the greater part of Iran to the west and north of the report area on the basis of a great lateral persistence in the facies of the Paleozoic formations and the absence of significant unconformities in the Paleozoic sequence. It must be stated, however, that this conclusion is not necessarily valid for the eastern part of Iran, east of the Kerman-Tabas (Shotori) Ranges, because outcrops of Paleozoic, in particular pre-Permian, rocks in this eastern region are scarce and so far insufficiently studied.

With more certainty it can be affirmed that Late Triassic faulting and folding movements have played an important role in the report area, more important than farther west. They created an early "Shotori horst" along an important north-trending fracture zone. The horst persisted as a swell and a facies divider during Jurassic time, whereas the areas west and east of it became further consolidated by Late Triassic movements into highly rigid blocks (Tabas and Lut Blocks) and during the Jurassic were subjected to strong subsidence. At the end of the Jurassic or in Early Cretaceous, general uplift and possibly some folding affected the whole area. The meagre development of Cretaceous deposits does not permit any definition of the tectonic events during the Cretaceous; probably it was a period of relative tectonic calm till near the end, when a local basaltic volcanism announced the beginning of the main Alpine diastrophism. The latter can be dated in this region as Early Tertiary, pre - Middle Eocene, and was characterized by strong compression and thrusting in the Shotori horst. At least two subsequent phases of gentle folding and strong faulting and fracturing were accompanied by powerful volcanism in the eastern desert area. The Tertiary movements on the whole accentuated the pre-existing situation: faulting, thrusting, and further uplift converted the Late Triassic - Jurassic Shotori horst into the present Shotori Range, whereas the adjoining Tabas and Lut Blocks persisted as relatively rigid elements and as areas of subsidence to become the Tabas and Lut depressions of to-day.

MINERAL DEPOSITS

The Boshruyeh Quadrangle has limited prospects in copper, lead, and iron. Traces of coal are numerous but do not indicate deposits of economic significance. All known deposits and traces of these minerals have been described by Stöcklin et al. (1965), and the more important lead and copper deposits also by Burnol (1968) and Bazin and Hübner (1969). The following summary is based on these reports.

COPPER

Gazu

Location 1.5 km west of Gazu village in the southern part of the Shotori Range (Kuh-e-Esfandiar). More than 100 small old workings exist in a mineralized area of about 1 square km. The visible ore is of the disseminated type and consists mainly of chrysocolla, malachite, and some magnetite. Chalcopyrite and chalcocite are said to occur at greater depth. The mineralization is related to the intrusion of granodiorite porphyry forming dikes and stocks in Triassic dolomite and Jurassic sandstone and shale. Twenty samples from depths of 20 m and less indicated copper contents up to 2.5%. One sample had in addition 5.25% zinc.

Kol-e-Firuzeh

Location east side of Shotori Range, south of Raqqeh, about 45 km north-northwest of Dehuk. Spotty impregnation of malachite in the sandy-calcareous matrix in the fractured basal part of a limestone conglomerate (Kerman Conglomerate). Extent and content very limited.

Mir-e-Khash

Southeastern part of quadrangle, 25 km northwest of Khur. Poor indications of malachite in brecciated andesite.

Shikasteh-e-Sabz

Southeast corner of quadrangle, 11 km northwest of Khur. Poor, widely scattered traces of copper carbonate in andesitic lava and tuff.

LEAD

Shurab and Galeh Chah

Eastern desert region, about 50 km south of Ferdows. Vein deposits in Jurassic shales and sandstones near contacts with small quartz porphyry ("rhyolitic") intrusions. The ore is mainly galena with accessory zinc and copper minerals and rare stibnite. On the whole, the deposits are small, discontinuous, and of low grade. Recent mining has been discontinued.

Boghuz

East flank of Kuh-e-Shotori, at an altitude of 1930 m; very difficult access. Calcite-barite veins with traces of galena in sandy limestone and sandstone within an area 80 by 20 m.

Raqqeh

3 km south-southwest of Raqqeh village. Faint traces of galena in crushed limestone.

Chiruk

Close to Chiruk village at western foot of Kuh-e-Jamal. Small pockets and spots of galeniferous barite in crushed limestone.

Godar-e-Sorkh

On Godar-e-Sorkh pass at 2,100 m altitude; difficult access. Irregular pockets of galena in calcite veins cutting through dolomitic limestone, near contact with thick basalt dike. Surface extension of mineralized area not more than 50 m.

Paykuh

Western foot of Kuh-e-Esfandiar, immediately south of quadrangle. Traces of galena in calcite filling of crushed dolomite.

IRON

A rather persistent zone of iron oolite occurs in the upper part of the Shishtu Formation ("Goniatite Horizon 1", Upper Devonian) and is exposed at the western foot of the Shotori Range north of the Sardar River and in the southern flank of Kuh-e-Jamal. The ore is haematite and limonite. Analysis of a single sample showed 42% iron. The amount of ore easily recoverable from quarries is estimated as about 3 million tons.

COAL

Thin lenses and seams of coal occur in the Jurassic Shemshak and Baghamshah Formations at several places, and at one place (Kuh-e-Jamal) on top of the Sardar Formation (Lower Permian). However, these indications are such that the Boshruyeh Quadrangle must be disqualified for coal production.

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نهشته های آواری (حداکثر ۳۰۰ متر) نمایشگر کرتاسه است . مقطع دوران سوم در خیلی از جاها با کنگلومراها (کنگلومرای کرمان) دارای ضخامت متغیر شروع میشود که با ناجوری بارزی روی یک سطح فرسایشی که در تشکیلات چین‌خورده کهن‌تر بوجود آمده قرار میگیرد . سوای این کنگلومراها، بطور عمده، ردیفی ضخیم از سنگهای آتشفشانی داسیتی و اندزیتی (بیش از ۲۰۰۰ متر ؟) در ناحیه شرقی صحرا ، جائیکه این سنگها بطور کلی به «پالئوژن» و «نئوژن-دوران چهارم» تقسیم شده‌اند ، و همچنین در حوضهٔ طبس ، لایه‌های قاره‌ای قرمز به سن نئوژن نمایشگر دوران سوم هستند . نهشته‌های آبرفتی و نهشته‌های Playa متعلق به دوران چهارم و نیز تلماسه‌ها در دشتهای کویر ، نواحی وسیعی را میپوشانند .

رشته‌کوه شتری یک گسل مشخص و نمایان بامتداد « شمال - جنوب » را که موروث ساختمان پرکامبرین است دنبال میکند . یک سلف این رشته‌یعنی-HORST شتری در اواخر تریاس بوجود آمده و از آن پس عمل مهم مقسم رخساره را بعهده داشته است . این رشته یک ساختمان پیچیدهٔ گسل دار و راندگی دار را مینمایاند که با کوهزائی آلپی به سن دوران سوم ، بوجود آمده است در حالیکه نواحی کویری مجاور آن متعلقند به قطعه‌های طبس و لوت که از نظر تکتونیکی استحکام و پایداری زیادی داشته در طول کوهزائی آلپ فقط در معرض تشکیل گسل و پیچ و تاب ملایم قرار گرفته‌اند .

در چهارگوش بشرویه آثار سطحی محدودی از مس ، سرب و آهن وجود دارد .

خلاصه

چهار گوش بشرویه قسمتی از استان خراسان واقع در شرق ایران را شامل میشود . این چهار گوش بخشی از حوضهٔ طبس ، رشته کوه شتری که روند یا امتداد « شمال ـ جنوب » دارد و قسمتی از شمال کویر لوت را دربرمیگیرد .

ردیف سنگهائیکه در معرض دید قراردارند با سنگ‌آهکها و دولومیتهای دونین (تشکیلات بهرام بضخامت، ٥٠٠ متر) شروع میشود. متعاقب آنها ، بطور عمده ، لایه‌های ماسه‌ای و شیلی که بین خود و با اهمیت کمتری لایه‌های آهک دارند یافت میگردد . سن ازدونین بالائی تا پرمین زیرین تغییر میکند (تشکیلات شیشتو و سردر ، ضخامت تقریباً ١٢٠٠ متر). تشکیلات سردر تا کنون تنها تشکیلات شناخته شده در ایران است که طبقاتی را که به گمان قوی میتوان به کربونیفر بالائی نسبت داد شامل میگردد . روی این تشکیلات را گروه‌طبس (تشکیلات جمال ، سرخ شیل و تشکیلات شتری ، ٢٠٠٠ متر) که به تقریب منحصراً از نوع کربناتی و بقدمت پرمین تاتریاس‌میانی است و بلندترین قله‌های رشته کوه شتری را میسازد پوشانده است . تشکیلات نای بند (٠-٨٠٠متر) که به‌سن تریاس بالائی و سرشار از فسیل است در شرق و غرب رشته شتری محدود است به نواحی حوضه‌ها . در این رشته ، ماسه‌ها و شیل‌های فسیل گیاهی‌دار متعلق به‌تشکیلات‌شمشک‌به‌سن‌لیاس (٠-٢٠٠٠ متر) با ناجوری (Unconformity) قاطع و مشخصی روی سنگهای گوناگون کهن‌تر قرار میگیرند . متعاقب آنها یک سنگ آهک مشخص (لایه‌نشانه) به سن باژوسین ـ باتونین که سرشار از آمونیت‌هاست (سنگ‌آهک بادامو ، ٤٠ متر) و سپس شیل‌مارنی متعلق به بالاترین قسمت ژوراسیک میانی (تشکیلات بغمشاه ، ٥٠٠ متر) قرار دارند . ژوراسیک بالائی بطور عمده متشکل است از سنگ آهک رسیفی (سنگ آهک ـ اسفندیار) که در پهلو به تشکیلات قلعه دختر که سنگهای متنوع دارد منجر میشود (هریک تقریباً ١٠٠٠ متر) . تنها یک ردیف ناقص ازسنگ‌آهک‌و

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