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The enigma of the Persian salt dome inclusions

By AUGUSTO GANSSER [1]

ABSTRACT

Persian salt domes are particularly rich in inclusions derived from the original evaporite horizons or from older formations. Missing are debris related to the emplacement of the domes, which have broken through several kilometers of competent formations. Still enigmatic are aspects of the origin, size and transport mechanisms of salt dome inclusions that are incompatible with current theories of the formation of salt diapirs. It is particularly difficult to account for km-scale rafts of undisturbed Hormuz sediments and masses of basic volcanics still in a upright position with thermal contacts preserved at their base. Most difficult to explain are inclusions of plutonic origin. We discuss salt dome inclusions from the Persian Gulf islands, the Zagros ranges and from the Kavir basin in Central Iran.

ZUSAMMENFASSUNG

Die persischen Salzdome sind besonders reich an Einschlüssen, die aus den ursprünglichen Evaporithorizonten oder aus älteren Formationen stammen. Es fehlen Einschlüsse im Zusammenhang mit der Platznahme der Dome, die mehrere Kilometer kompetenter Formationen durchbrechen. Noch problematisch sind Ursprung, Grösse, Transport und Platznahme der Salzdom-Einschlüsse; sie sind unvereinbar mit den meisten Theorien über die Bildung von Salzdomen. Wir beobachten mehrere Kilometer lange, ungestörte Hormuz Sedimentpakete sowie basische Vulkanite, die noch thermische Kontakte an ihrer Basis erkennen lassen. Äusserst schwierig zu erklären sind Einschlüsse von Plutoniten. Wir besprechen Salzdom-Einschlüsse der persischen Golf-Inseln, aus den Zagrosketten und aus dem zentraliranischen Kavir Becken.

Introduction

General interest in the Persian salt domes was revived during a December 1990 symposium on diapirism with special reference to Iran. In spite of the latent hostilities in the Persian Gulf it was held in Bandar Abbas, the heart of the most famous salt domes in the world (Fig. 1). The many local papers and lectures and the participation of many Iranian university students showed the great interest in the still problematic theme of salt dome initiation, composition and emplacement. The discussion on the origin, size, transport and composition of the frequent inclusions was only marginal, even though the large inclusions in the Persian salt diapirs is one of their greatest problems.

The inclusions of harder basic and acid volcanics in the salt diapirs are the only rocks suitable for the very active construction underway or planned in the region. Examples are marine structures near Bandar Abbas and the major industrial development of Qeshm island (Fig. 2). We noted the results of these activities during the visit of the Gachin salt dome to the west of Bandar Abbas. This dome is now criss-crossed by roads

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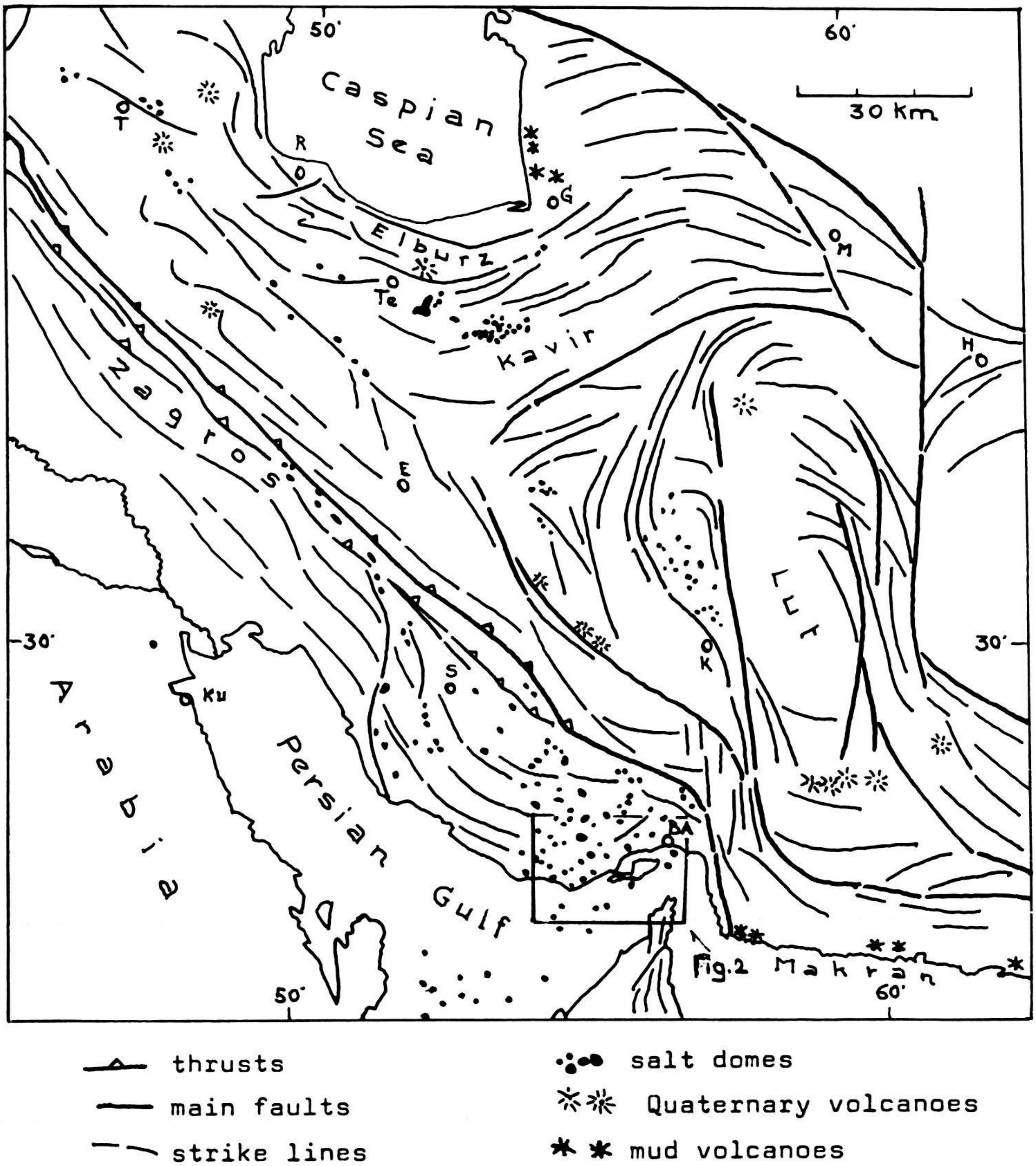


Fig. 1. Structural trends and salt dome distribution in Iran. Generalized from Stoecklin in Jackson et al. 1990 and Gansser 1960. BA Bandar Abbas, E Esfahan, G Gorgan, H Herat, K Kerman, Ku Kuwait, M Mashad, R Rasht, S Shiraz, T Tabris, Te Teheran.

and many of the rhyolitic and diabasic inclusions are being intensively quarried. The final results seem obvious; the only advantage for the geologist, apart from fresh outcrops, is their accessibility. This was quite different when over 40 years ago we had to walk over difficult terrain.

One of the most enigmatic salt domes regarding inclusions is Hengam island, near the larger Qeshm island (Fig. 2). This area was out of bounds during the 1990 meeting, and

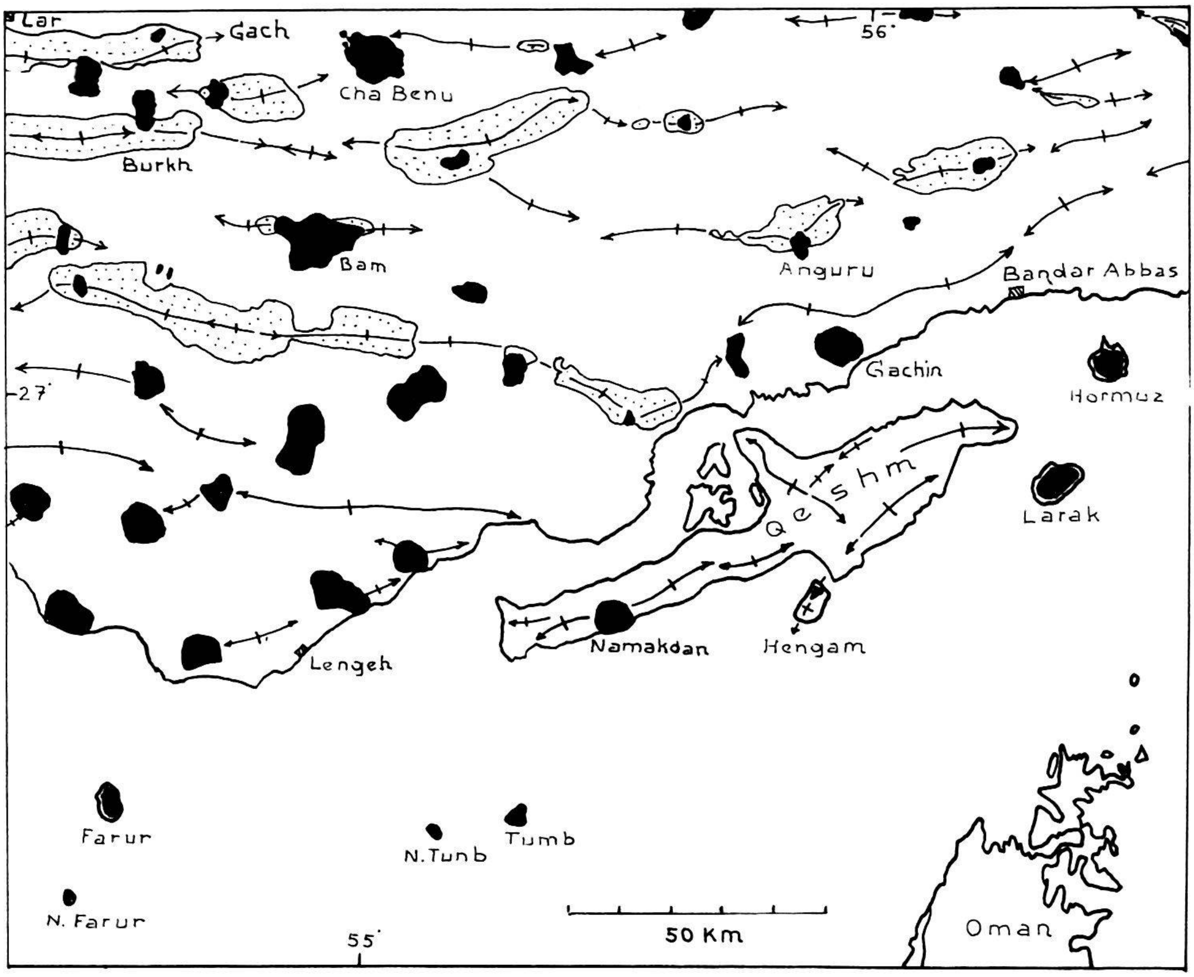


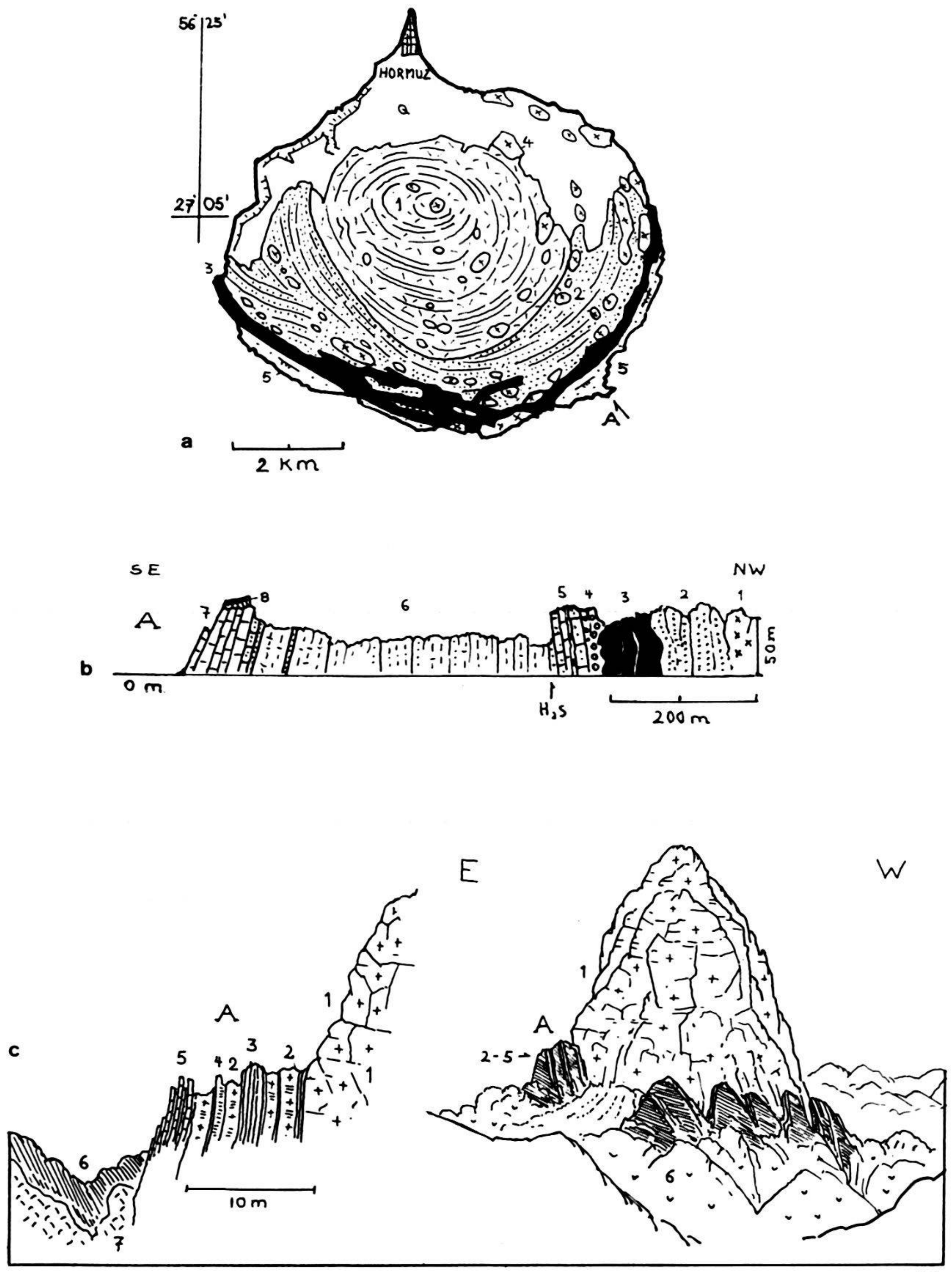
Fig. 2. The salt domes of the Bandar Abbas region, SE Zagros, black = salt domes, stippled = Eocene and older. (Based on the 1: 1000000 map of Nat. Iran Oil Co. 1977 and Kent 1979.)

it was not possible to obtain information of this island from the many Iranian geologists dealing with the Persian Gulf salt domes. It seems likely that no significant geological work has been carried out since our field investigations for Iran Oil Company in 1951. On the other hand, the unique Hengam salt dome inclusions have already, or may eventually, disappear, victims of the industrial development. Considering this situation I decided to discuss in the following old and new facts concerning some of the many inclusions in the salt domes of the Gulf area, the Zagros range (Pre-Cambrian – Lower Cambrian) and the Kavir area, Central Iran (Eocene – Miocene).

The Persian salt domes (Fig. 1) are well known and some have been investigated in detail. I therefore refrain from dealing with the general salt dome geology which has been covered mainly by Harrison (1930), Gansser (1960), Stoecklin (1968 a), Trusheim (1974), Kent (1979), Jackson et al. (1990) and recently by 2 volumes (the third one in print) on the proceedings of the symposium on diapirism (1990).

Inclusions in the Persian salt domes

Sedimentary, volcanic and even some plutonic inclusions characterize many of the Persian salt domes. Their origin, composition, size and transport mechanism poses however many problems, some incompatible with current theories of evolution of salt domes. All inclusions are related to the original salt deposits or are older. Younger country rocks displaced by the rising dome, a cylinder several kilometers in diameter and 5–10 kilometers in depth, are absent within the salt domes. The space problem related



to the intrusion of the salt domes remains (Kent 1979). Inclusions are well exposed in the salt dome islands of the Persian Gulf, some of which I will discuss first (Fig. 2).

Hormuz Island

All who know this island do not hesitate to call it the most beautiful salt dome in the world. A perfect concentric structure with the last emplaced Hormuz salt in the core rises above the shallow waters of the Gulf (Fig. 3a). Miocene marine sediments, sharply uptilted on its southern rim, suggest a post Miocene emplacement (Fig. 3b). Inclusions of white rhyolites and trachytes are frequent. Most occur as irregular masses, up to one kilometer long, while a few are more plug-like. Dominant is the famous white rhyolite plug called Qualé e Rostam on the eastern side of the island. This plug is over 50 m high and is rimmed by exposed volcano-sedimentary Hormuz layers, into which the rhyolite plug has originally intruded. Field evidence suggests that this plug is still in its original position. Considering the post Miocene emplacement of this salt dome, the rhyolite plug must have travelled 9–10 kilometers within the salt mass to its present level (Fig. 3c). The concentric structure of the dome suggests a rather complicated intrusion mechanism, hardly compatible with the "normal" position of the rhyolite plug. The Miocene sediments, sharply uptilted around the rim, indicate a very active post-Miocene phase of salt intrusion, followed by marine planation, growth of Quaternary corals, a slow rise of the whole area and a slight outward tilt (Fig. 3b).

Larak island

This island has been investigated in detail recently and a new geological map was shown to us during our visit to the island in December 1990. Larak is famous for its very well crystallized hematite ores which are locally exploited. Otherwise it is a more gentle replica of Hormuz island and to a large extent covered by local coral limestones which transgress with a basal conglomerate on the Hormuz rocks (Fig. 4a and 4b). The island is dominated by a central peak, previously considered to be a plug similar to Rostam on Hormuz (Guide to field exkursions, p. 27. Symposium on diapirism, 1990). During the

Fig. 3a. The classical Hormuz Island, a concentrically zoned salt dome in the Persian Gulf. 1. Salt, partly reddish banded 2. ferruginous gypsum and salt 3. concentrated red oxide, forming a rough hematitic and limonitic surface (locally mined) 4. rhyolitic and trachytic plugs and irregular masses, frequent in 1 and 2, together with small Hormuz limestones and basic volcanics 5. steeply dipping rim of transgressive limestones and marls (Miocene). (Redrawn from air photos and Gansser 1960)

Fig. 3b. The sharply uptilted rim of Miocene along the southern coast of Hormuz island. 1. Rhyolitic plug or mass 2. ferruginous gypsum and salt beds 3. red oxide rim 4. transgressive basal conglomerate, rich in acid volcanic pebbles 5. platy sandy limestones, with stringers of fine conglomerates at the base 6. gray green silty marls 7. limestones with shell breccia layers 8. transgressive, uplifted coral limestones (Quaternary), H_2S = sulfurous brine spring, related to outer salt dome contact, runs during the dry season.

Fig. 3c. The rhyolite plug, Qualé e Rostam, intruded into banded Hormuz pyroclastic sediments, both as inclusions in the eastern part of the Hormuz salt dome island. 1. White rhyolite 2. tuffaceous trachy-rhyolite 3. pyroclastic shales with gypsiferous bands 4. fine grained white tuff 5. dark gray, well bedded sandy limestone (Hormuz type) 6. ferruginous, gypsiferous residual cap rock 7. reddish salt. (After Gansser 1960)

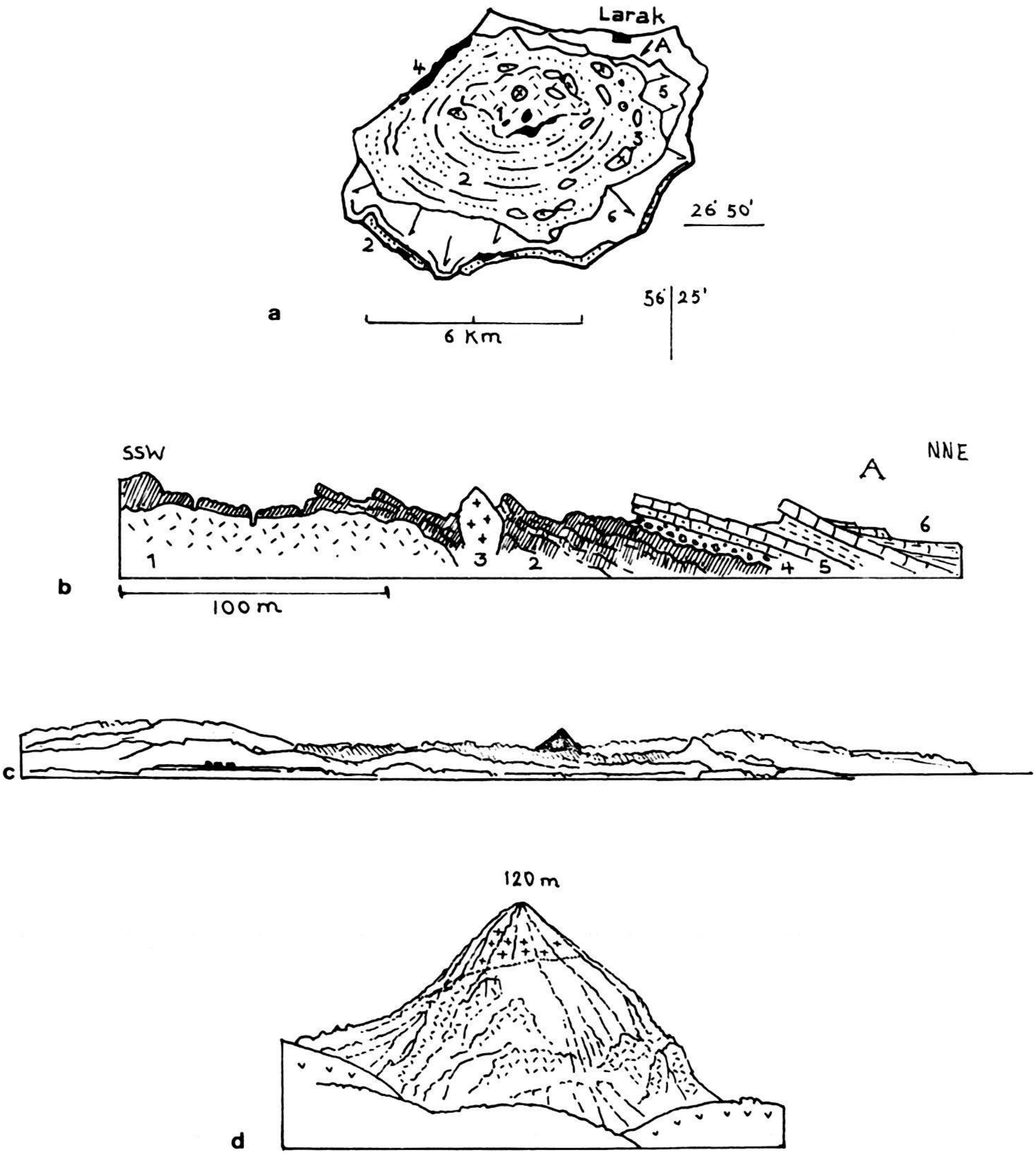


Fig. 4a. The Larak Island, salt dome in the Persian Gulf. This island, still with a concentric structure of the diapir, is a more gentle replica of the Hormuz Island (Fig. 3a). 1. Irregular salt core 2. ferruginous and gypsiferous cap-rock formation, very rich in crystallized hematite 3. rhyolitic masses; in contrast to Hormuz, plugs seem rare 4. concentrated red oxide (hematite and limonite) locally mined 5. sandy marls and thin limestones, Miocene 6. Plio-Pleistocene coral beds.

Fig. 4b. The northern contact of the Larak salt dome. 1. Salt 2. ferruginous, gypsiferous cap-rock 3. rhyolitic plug or block 4. basal conglomerate rich in rhyolite and hematite pebbles 5. sandy limestones with marls and large pecten (Mio/Pliocene) 6. transgressive coral limestones (Pleistocene to recent).

Fig. 4c. The Larak island with its marked central peak, seen when approaching from the north (sketched 1990).

Fig. 4d. The central peak of Larak island, always regarded as a rhylotic plug, similar to Hormuz island plugs, was found, during a 1990 visit, to consist of salt capped by a greenish rhyolite.

1990 visit it turned out to be a mass of greenish rhyolite capping and protecting the salt, which crystallized with large clear crystals (Fig. 4c and d).

Larak and Hormuz are the easternmost salt dome islands in the Persian Gulf, where the original evaporite deposits end towards the Oman trend (Oman line of Furon 1941, Gansser 1955). Salt domes are unknown to the east of this line where they are replaced by the diapiric mud volcanoes of the Makran region. The numerous rhyolitic inclusions may have some relations to the eastern end of the Hormuz salt basin. Such large masses of acid volcanics are rare in the Hormuz type sections in the wider Kerman area where smaller basic intrusions prevail (Stoecklin 1968a). Igneous intrusions are completely absent in the many thousands of meters of the Phanerozoic sediments of the Zagros range.

Hengam island

The northern crest of the small domal island of Hengam (Fig. 2) is pierced by a salt dome of which only the uppermost part is exposed (Fig. 5). The residual inclusions on Hengam make this the most enigmatic salt dome of the Gulf area. Salt is only visible in sink holes amongst an intensely folded mass of ferruginous gypsum layers covered by Mio-Pliocene limestones. Gypsum and salt are "intruded" by a plug-like mass of quartz and muscovite rich rhyolite. Both are transgressed by over 5 m thick, dense Miocene

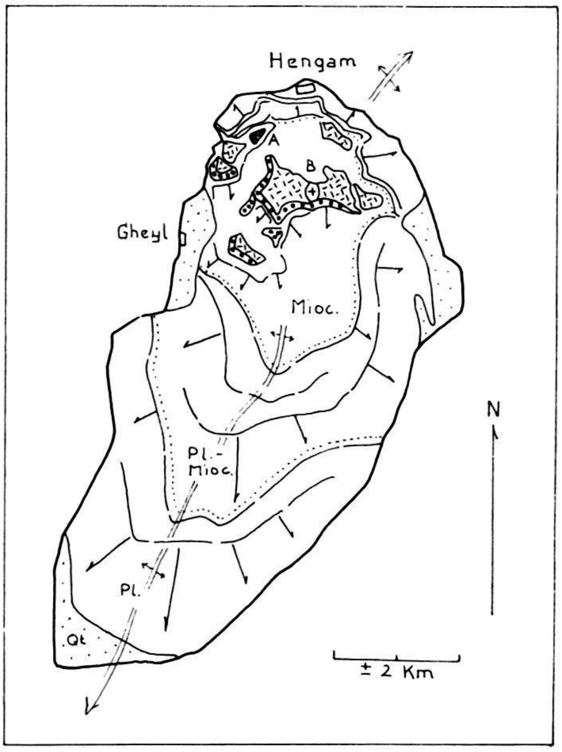


Fig. 5. The Island of Hengam, Persian Gulf. Mio-Pliocene limestones and marls form a domal anticline, broken at the northern crest by the Hengam salt diapir. The gypsiferous cap rock is transgressed by 5 m of Miocene limestone containing blocks of tonalite (black dots). At A the residual 3000 m^3 block of hornblende granite gneis (partly migmatitic). At B the view of Fig. 6.

limestones rich in irregular inclusions of angular to semirounded tonalites, some mesuring 12 m^3. The same limestones contain homogenous hornblende gabbros on the northern rim. These plutonic rocks must have been brought up as inclusions by the salt dome (Fig. 6). A large block of over 3000 m^3 of a gneissic granite sits on the northwestern rim of the outcropping dome (Fig. 5 at A). The main mass consists of hornblende granite to granosyenite with variable proportions of plagioclase, orthoclase and microline. Aplitic veins criss-cross the main rock without sharp contacts. The tonalites, gabbros and the gneissic granite are certainly pre Hormuz basement, unknown in the other salt domes of this area. They must originally have been deeply burried by thick sections of evaporitic Hormuz and pre-Hormuz sediments. No similar rocks are known in the wider Gulf area. The closest equivalents in-situ are in the shield of Arabia. Have they been torn off from a thrusted basement block, a structure however unknown in the subsurface of the Gulf? The enigma of the Hengam inclusions remains. It is hoped these unique vestiges will not disappear into marine constructions.

In a structurally similar dome, the *Namakdan* of Qeshm island, about 30 km west of Hengam (Fig. 2), the well exposed salt is free of large inclusions and the transgressive

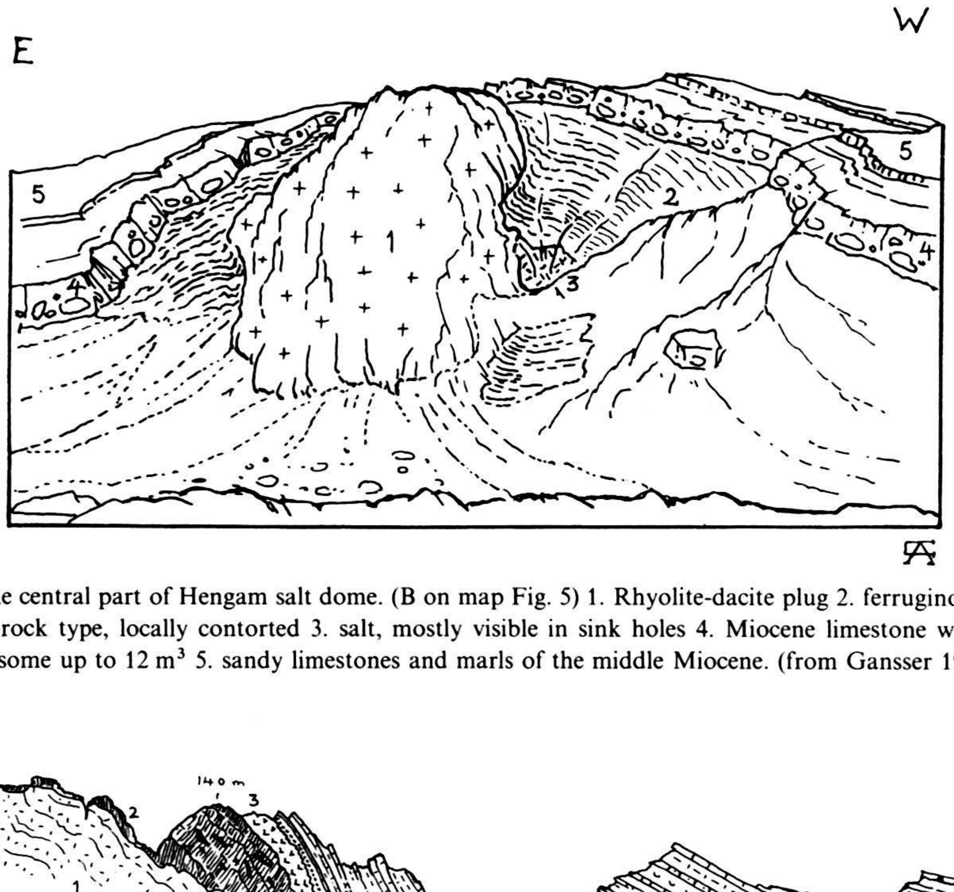


Fig. 6. The central part of Hengam salt dome. (B on map Fig. 5) 1. Rhyolite-dacite plug 2. ferruginous gypsum beds, cap-rock type, locally contorted 3. salt, mostly visible in sink holes 4. Miocene limestone with tonalite boulders, some up to 12 m^3 5. sandy limestones and marls of the middle Miocene. (from Gansser 1960)

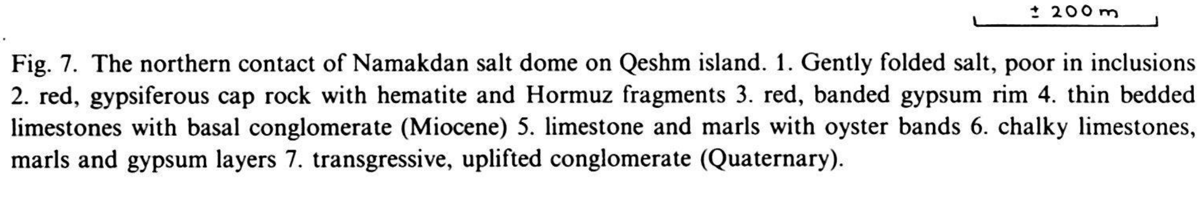


Fig. 7. The northern contact of Namakdan salt dome on Qeshm island. 1. Gently folded salt, poor in inclusions 2. red, gypsiferous cap rock with hematite and Hormuz fragments 3. red, banded gypsum rim 4. thin bedded limestones with basal conglomerate (Miocene) 5. limestone and marls with oyster bands 6. chalky limestones, marls and gypsum layers 7. transgressive, uplifted conglomerate (Quaternary).

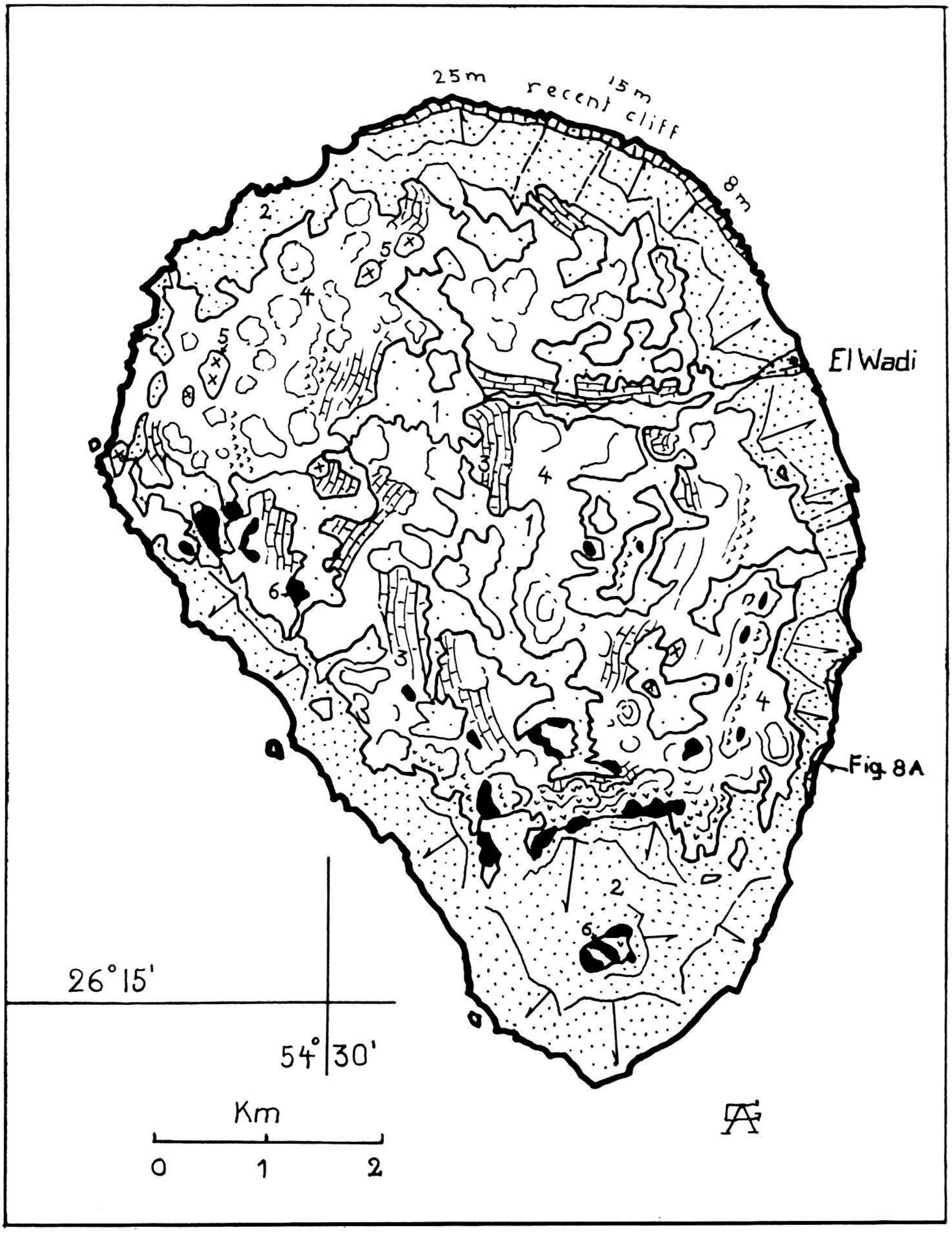


Fig. 8. Farur island, Persian Gulf salt dome. 1. Pleistocene coral limestones, partly detritic 2. Pliocene coral limestones, tilted dome-like 3. dark gray, banded, partly dolomitic fetid limestones (Hormuz); some 2 km long inclusions show an undisturbed, primary bedding 4. folded ferruginous shales and gypsum (Hormuz) 5. hornblende diabase 6. masses of hematite crystals (completed from Gansser 1960).

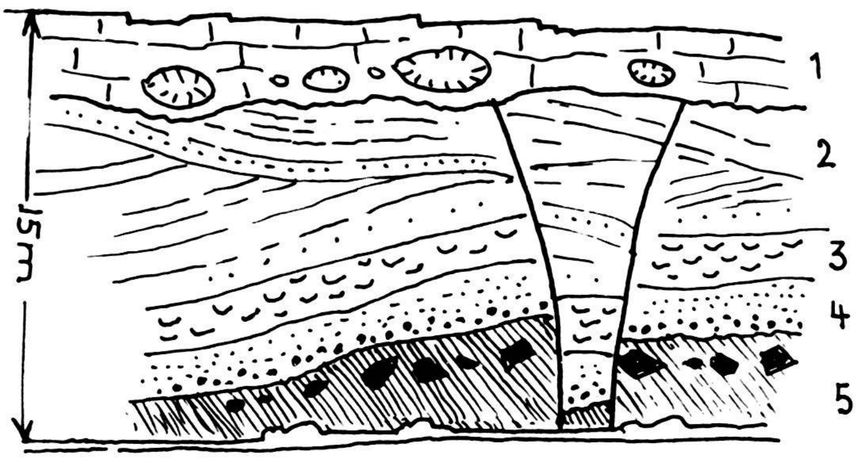


Fig. 8 A. Cliff section of eastern Farur island, locally faulted. 1. Coral limestone cover, sub-recent 2. banded sandy marls with sandstone layers, locally cross-bedded 3. oyster layer in sandy marls 4. silty marls with transgressive conglomerates 5. Hormuz beds with hematite blocks. A pre coral layer covers graben like fault-block, frequent along the peripheral part of the dome, may be related to extension during the rising of the diapir.

basal Miocene limestone contains only small pebbles of hematite, rhyolite and Hormuz fragments (Fig. 7).

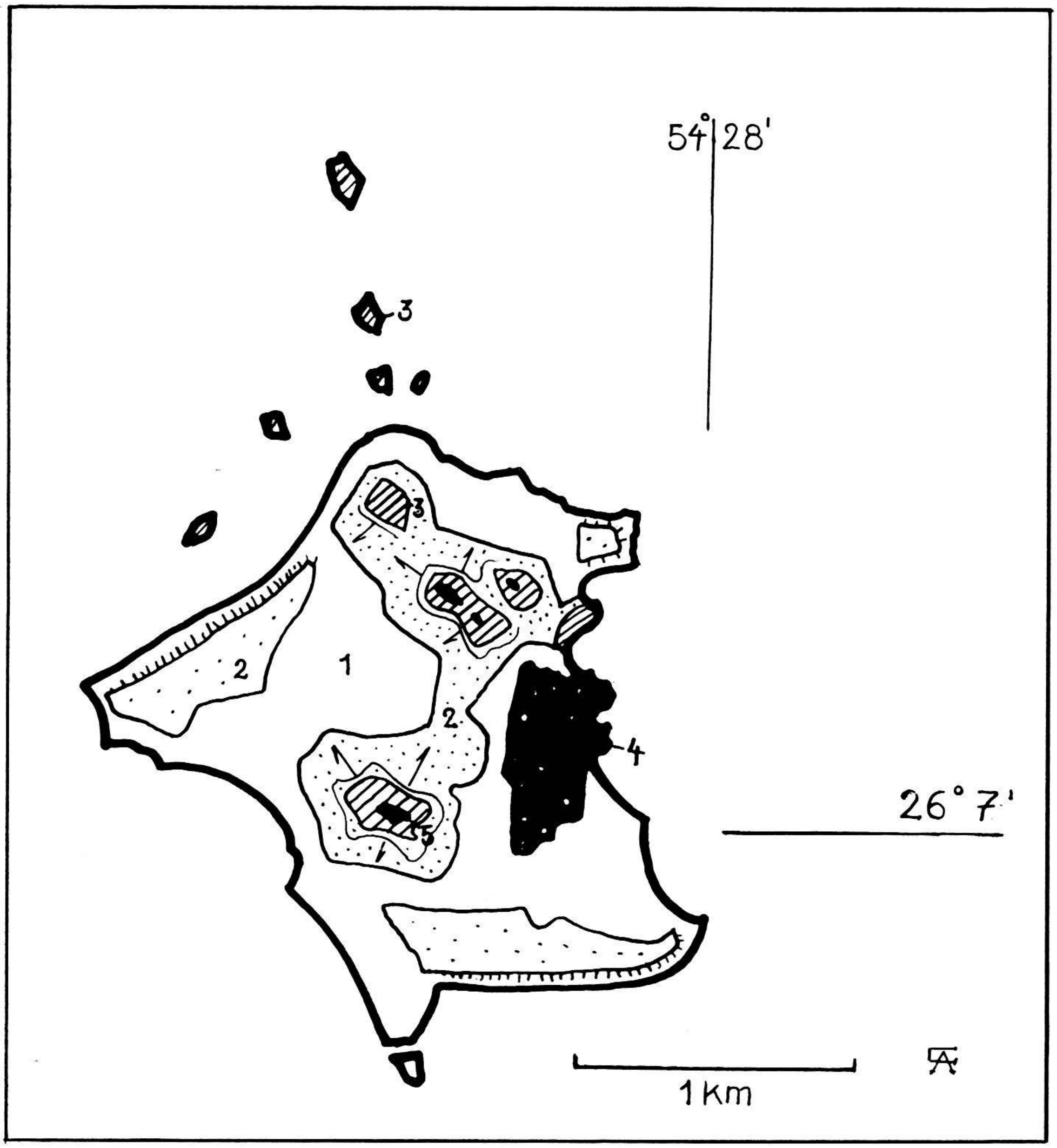
Farur island

This salt dome island (for location see Fig. 2) is a perfect dome, intruded into Pliocene coral limestones (Fig. 8). Large rafts of well bedded dolomitic Hormuz limestones are striking among smaller blocks of ferruginous shales and gypsum, hornblende-diabase and hematite. Some of the rafts are over 2 km long, with primary bedding practically undisturbed, striking EW in the central part and NS further S. Zoisite-hornblende diabases intruded locally the Hormuz limestones. How did these large sedimentary rafts rise through over 8000 m of post Hormuz sediments, undisturbed within the salt?

Recent coastal cliffs suggest that the Farur dome is still rising at present. The contact between the salt dome cap rock and its cover of Mio-Pliocene fossiliferous sediments is cut by graben like fault blocks in a local cliff section (Fig. 8 A). These faults are frequent along the exposed cliffs and suggest an extensional phase during late emplacement of the salt dome. The recent to subrecent coral limestones have been uplifted up to 25 m above mean sea level since the faulting.

Nabiyu Farur island

This "small" Farur emerges 20 km SSW of Farur, shown on Fig. 2 and forms the eroded part of a larger salt dome. The eastern side of this island is dominated by a 700 m long, high hill of hornblende diabases, which may be considerably larger at depth. Intrusions of such a large volume are normally unknown in the Hormuz sections. This enigmatic mountain strikes the observer when approaching the island from the southeast (Fig. 9).



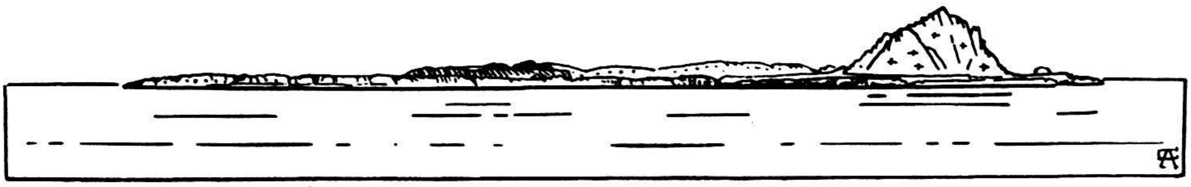
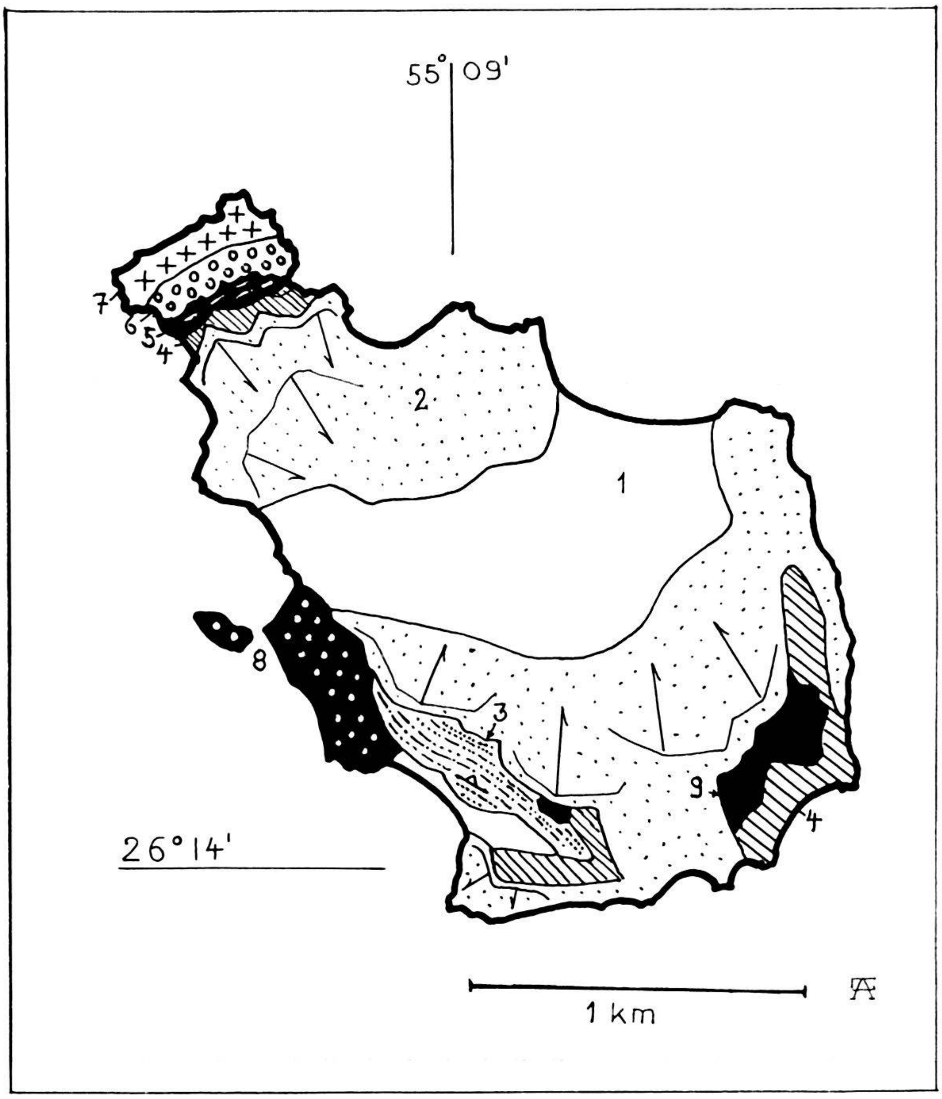


Fig. 9. (top) Nabiyu Farur, the "small" Farur island, Persian Gulf diapir. 1. Quaternary, with recently uplifted coral flats 2. tilted Plio-Pleistocene coral limestones 3. ferruginous and gypsiferous Hormuz group 4. hornblende diabase 5. well crystallized hematite masses (from Gansser 1960). (bottom) Nabiyu Farur island, seen from SE. Note the high hornblende diabase hill (from Gansser 1960).



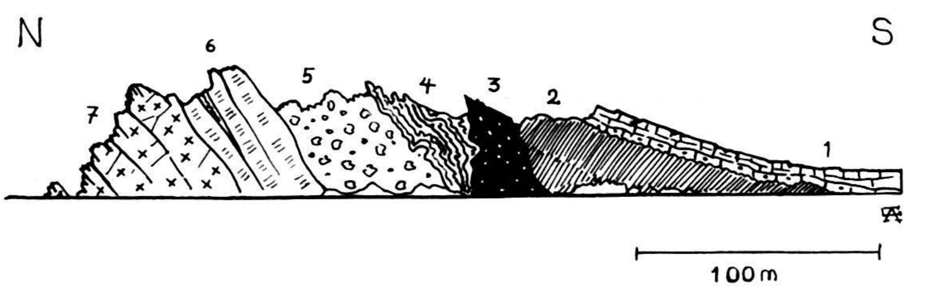


Fig. 10. (top) Nabiyu Tunb island, Persian Gulf salt dome. 1. Quaternary, including some recently uplifted coral flats 2. Plio-Pleistocene coral limestones, partly detrital 3. ferruginous sandstones, siltstones and dark gray, fetid limestones (Hormuz group) 4. red hematitic silty shales 5. diabasic pillow lavas 6. agglomerates with diabase layers and gypsum 7. rhyolite 8. doleritic basalt 9. ironoxide with concentration of hematite (from Gansser 1960). (bottom) The NW end of the Nabiyu Tunb island. 1. Plio-Pleistocene coral limestone, tilted 2. hematitic silty shales 3. pillow lava 4. intensely folded ferruginous shales and gypsum 5. agglomerate 6. rhyolitic tuff 7. rhyolite

Nabiyu Tunb island

This peculiar salt dome island also represents the top of a larger dome and is situated to the west of the larger Tunb island, a salt dome mostly covered by coral limestones (Fig. 2). Nabiyu Tunb exposes a wide gentle syncline of Plio-Pleistocene coral limestones. Along its SW shore, an outcrop of doleritic basalt, visible over 500 m, forms a prominent hill which borders a nearly one kilometer long section of well bedded arenaceous and calcareous Hormuz rocks (Fig. 10 top). Of special interest is the rough NW end of the island exposing a steeply NE dipping section of hematitic shales, pillow lavas, gypsum, rhyolite tuffs and a cliff of white rhyolite (Fig. 10 bottom). Does this 300 m thick section represent an original, though highly complicated volcanic sequence? Here, as in most of the islands of the Persian Gulf, salt is not visible at the surface.

Some special salt domes of the Zagro range

A very active, well exposed salt dome in the southwestern Zagros is *Kuh e Anguru*, which I revisited during the 1990 diapir symposium. The salt dome emerges from a competent domal anticline without any structural interference (Fig. 11). This fact is a further proof that during their final emplacement, most of the salt domes of the Zagro ranges intruded into already existing structures (Fig. 2). Only when emerging in incompetent Tertiary formations do we note a sharply uptilted rim along the contacts. The Anguru salt dome pierced a competent section of over 5000 m Lower Cambrian to Cretaceous. However no trace of these rocks are visible as inclusions, a most characteristic fact for all the Persian salt domes and well known to the relevant investigators. The salt from the active Anguru dome overflows to the south with a salt glacier covering Quaternary terraces (Fig. 11).

In contrast to the lack of any substantial Hormuz inclusions in Kuh e Anguru, the *Cha Benu* salt dome (Fig. 2) is famous for the largest included rafts of sediments known in the Persian salt domes. Cha Benu dome emerges between two plunging anticlines and an uptilted rim of Miocene sediments is visible on its southern border. Large inclusions of well bedded Hormuz rocks are recognizable even on air photos (Fig. 12). Outstanding is a raft of well bedded, dark Hormuz dolomites nearly 5 km long. To transport such a large section of undisturbed sediments for nearly 8 km from its base to the present position, defies all theories on the flow mechanism of a salt dome. "The Cha Benu plug thus demonstrates a minimum age of Middle Miocene for extrusion; it includes undamaged exotic masses so large as to require much more than causal transport of accidentally entrained rock for their survival and emplacement" (Kent 1979, p. 135). The only other salt plug with similar large rafts of sediments is *Kuhe Bam*, one of the largest saltdomes, to the south of Cha Benu (Fig. 2). Known by aerial reconnaissance (Kent 1979), its periphery was described by Harrison (1930), who commented on its difficult access.

This still enigmatic transport of large inclusions rising for thousands of meters depends to some extent on the mobility of salt. Little is known of the temperatures in salt beds 6–10 kilometers deep. The many volcanic inclusions, some with preserved thermal contacts, suggest that volcanic activity may have affected the temperature. On *Kuh e Chaha*, an elongated dome along the Zagros thrust (E of Hajiabad) we were shown during a visit in connection with the diapir symposium 1990, veins of a sky blue magne-

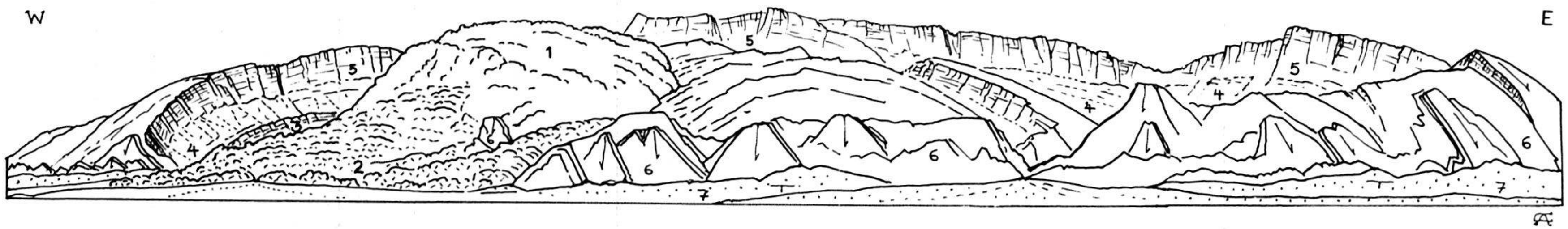


Fig. 11. The Kuh e Anguru (Angohran acc. spelling 1990) a competent domal anticline intruded by an active salt dome forming a large salt glacier. This dome contains only minor conclusions. 1. Salt dome 2. salt glacier, on its SW side flowing over recent terraces 3. Upper Cretaceous limestones 4. Upper Cretaceous marls 5. Eocene limestones 6. Asmari limestone (Oligo-Miocene) 7. tilted Quaternary (not related to salt dome intrusion).

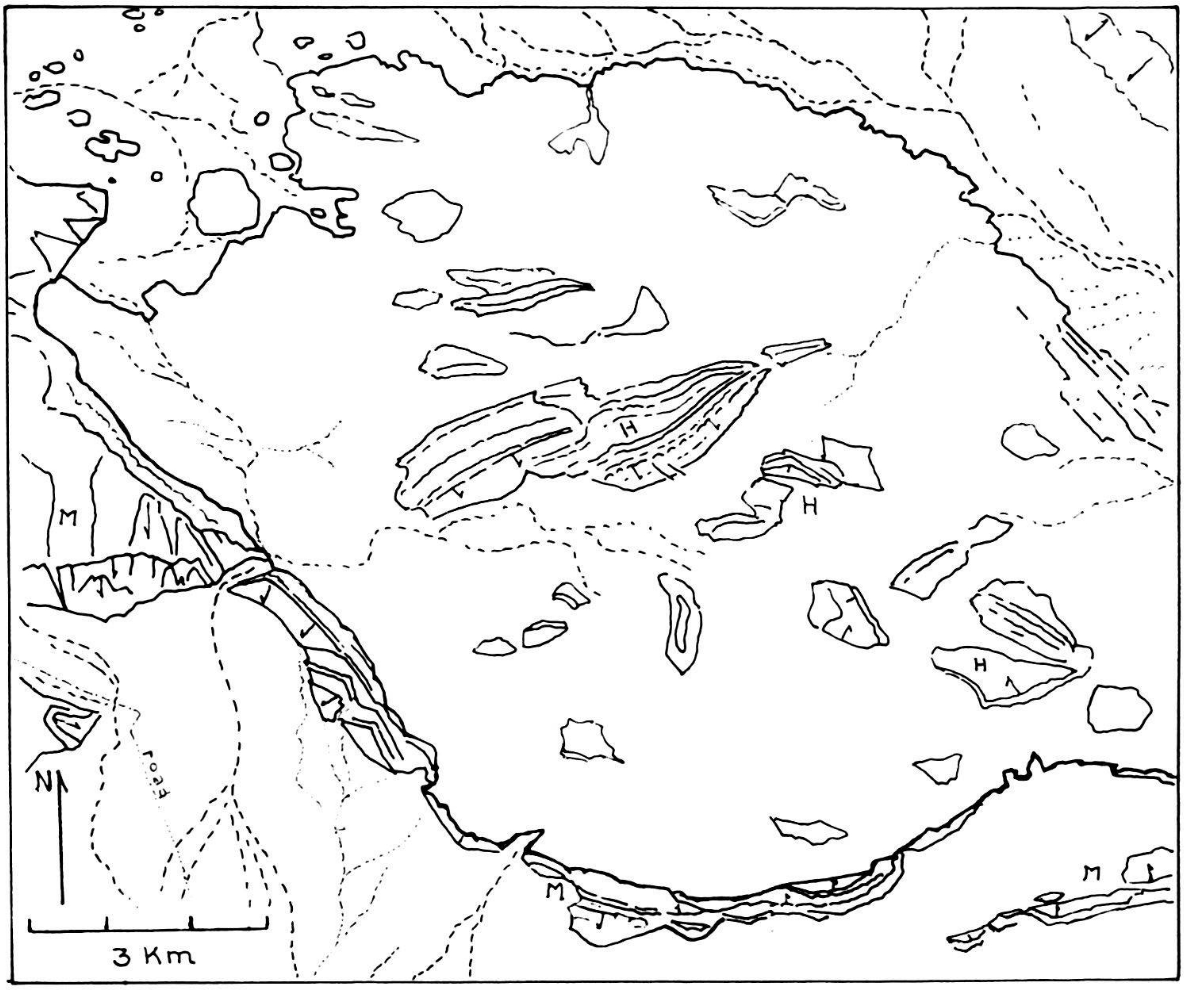


Fig. 12. Cha Benu salt dome, E of Lar, famous for the largest (nearly 5 km long) rafts of undisturbed Hormuz sediments (H). The rest of the dome consists mainly of a jumbled mass of gypsum, wine-red shales and some diabase masses. The south side of the dome is bordered by steeply dipping beds of Miocene (M). On the northwestern part irregular blocks suggest remnants of an eroded, glacial-like overflow. (Sketch from air foto by Gansser, geology from Kent 1979).

sium riebeckite along the contact of salt with Hormuz inclusions. The metasomatic reaction needs temperatures exceeding 300 °C. (For the confirmation of the mineralogy I am grateful to Volkmar Trommsdorff, Zürich.) According to Davoudzadeh (1990), temperature is critical for the formation of salt diapirism. Above 205 °C salt become plastic. Intrusion would have been facilitated by thermal expansion at 300–400 °C suggested for salt buried by 7000 m of sediments.

In the writer's opinion connate water is at least as important for salt mobility. Actually in many salt domes peripheral brine springs flow even during very dry seasons. It is well known how drilling into salt horizons in the Persian oil fields produced surprising large volumes of salt water with very high pressures. Peripheral water may reduce friction during the rise of a salt dome. The main movements of a rising dome could be concentrated in the peripheral zone, while leaving the more central part to rise in a more competent manner. A more competent core may actually allow the transport of larger inclusions. During a visit of some salt mines in Texas salt domes in 1961, I was

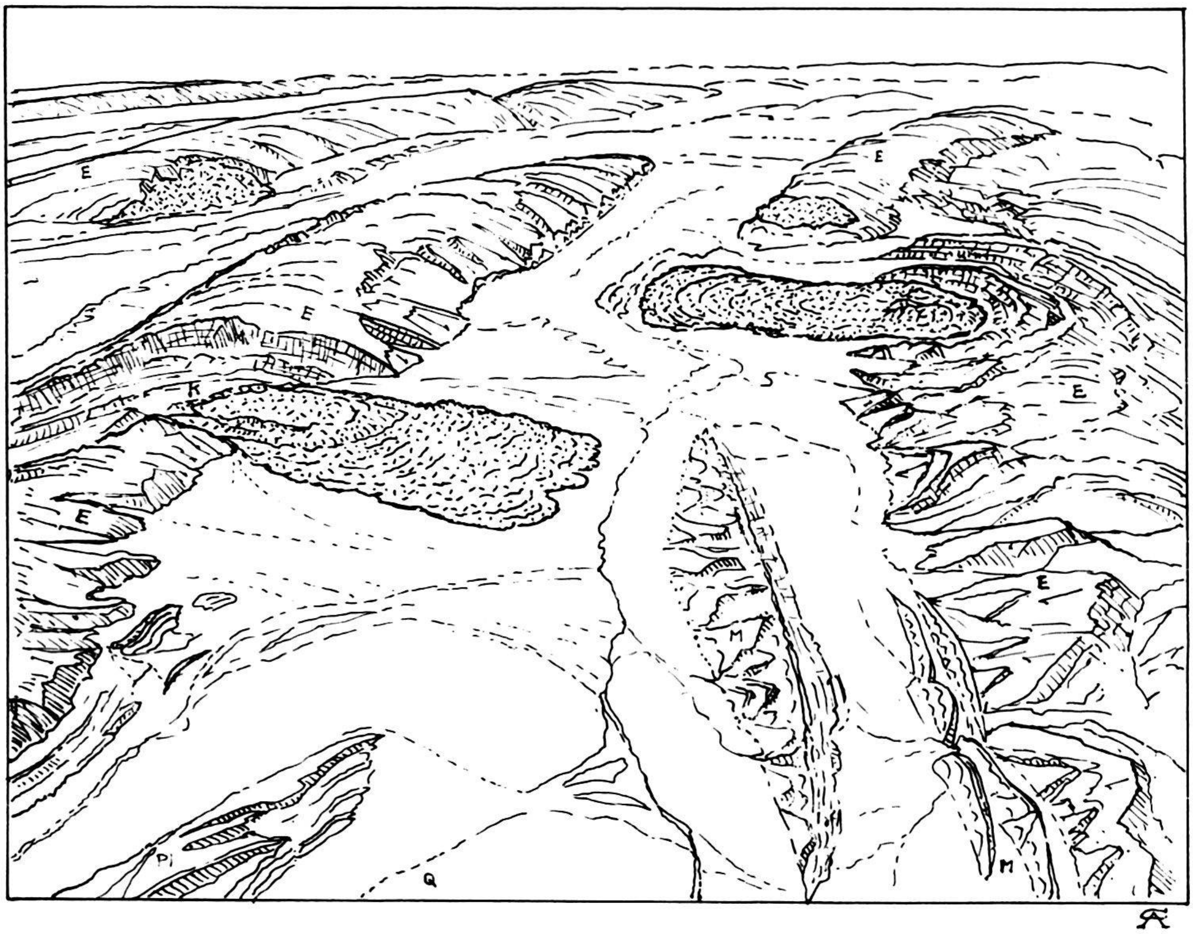


Fig. 13. The most spectacular salt glaciers known, the left one issuing from Kuh e Gach, the right one from Kuh e Burkh, Zagros, iran. The domes pierce large anticlines of Eocene (E) with some Cretaceous (C) in the core. Miocene (M) is exposed along the synclinal depression. From the domes, the salt flows for 7–8 km over Quaternary fans with a dip of only a few degrees. Sketched from trimetrogon oblique air photos. View towards E.

struck by the fact how water mobilized the peripheral steeply dipping part while large artificial caverns with gentle salt layering kept their shape for a considerable time (years) in the central part of the dome.

No higher temperature is needed in order to mobilize salt when water is present. The proof are the extraordinary *salt glaciers* produced by some active salt domes to the SE of Lar (Figs. 2 and 13). They are the largest salt glaciers known and flow for 7–8 kilometers over Alluvial fans with an inclination of a few degrees. Both salt domes emerge from competent Eocene anticlines with Cretaceous cores. Both domes extruded after the formation of the remarkable anticlines.

The salt domes of the Great Kavir, North-Central Iran

The age, type and history of the Kavir salt domes (see Fig. 1 and 14) are very different from the salt domes of the Zagros, although they share the problems related to their inclusions. A very comprehensive investigation of the Kavir domes, based on air photos,

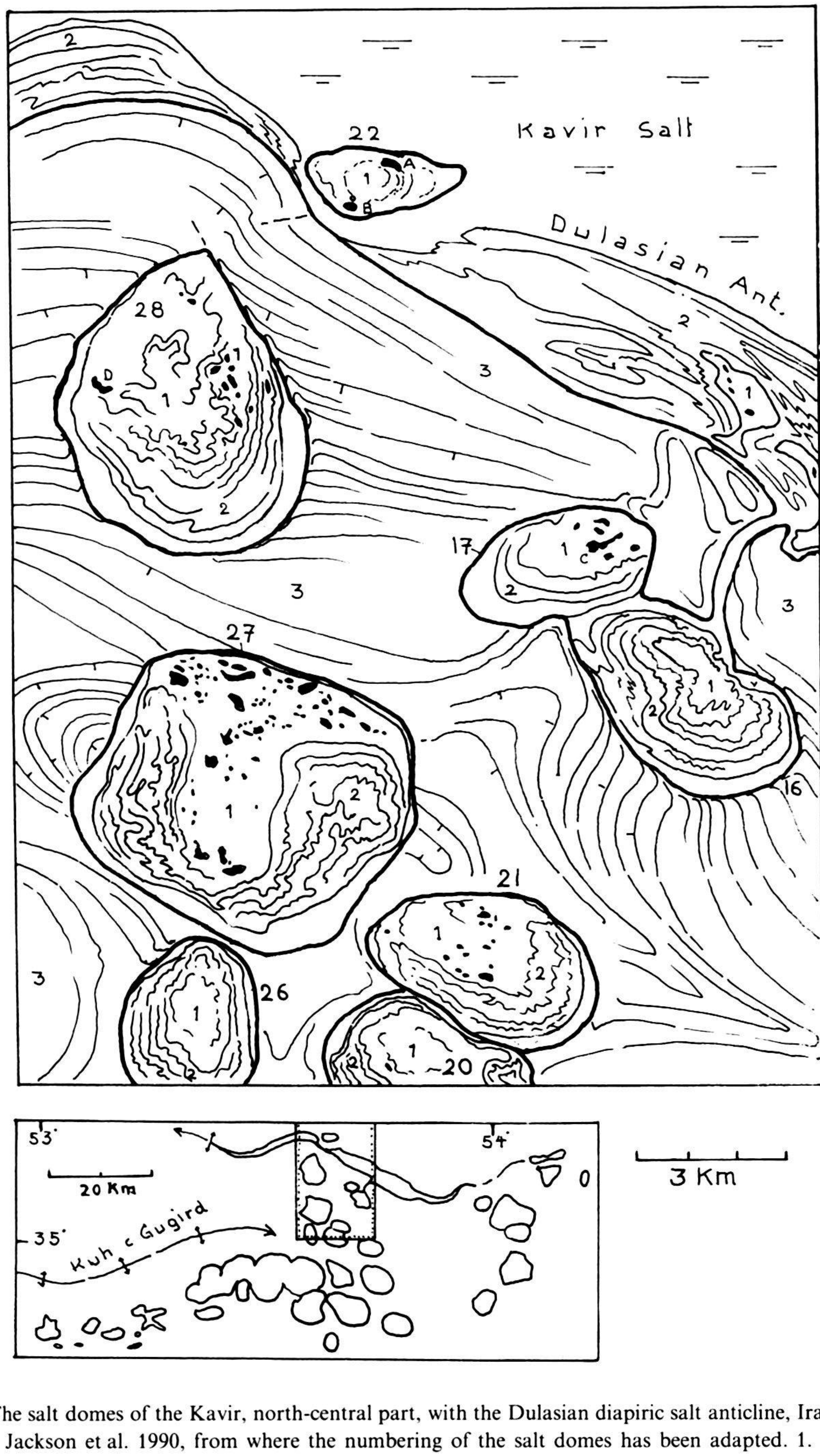


Fig. 14. The salt domes of the Kavir, north-central part, with the Dulasian diapiric salt anticline, Iran. Generalized from Jackson et al. 1990, from where the numbering of the salt domes has been adapted. 1. Eocene salt with basic volcanic inclusions (black) 2. Miocene salt, banded with gypsum and red and green saline mudstones 3. the Upper Red Beds, Miocene, incompetent, partly evaporitic well banded mud and siltstones with increasing sandstones in the upper part. Total thickness about 5000 m.

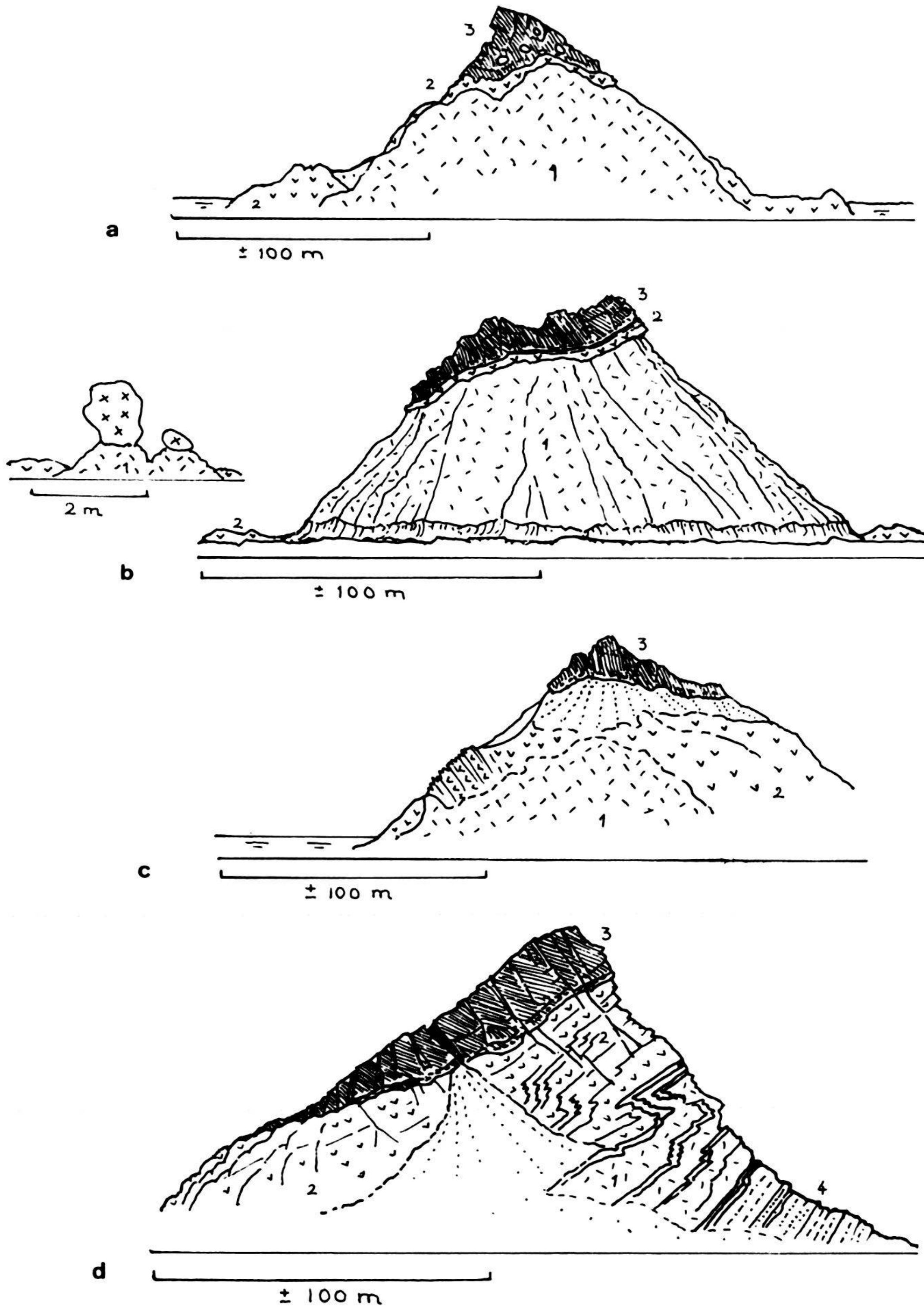


Fig. 15. Basic volcanics exposing thermal contacts with the underlying salt, preserved like glacial tables, in some Kavir salt domes, north central Iran. (Ref. also to Fig. 14). The Eocene salt (1) of the central part of the domes is capped by coarse to fine grained augite dolerites (3), locally altered to diabase. All show a chilled margin at their base with dense, often vesicular layers in direct contact with thin gypsum layers (2) hill d exposes some saline, colored sediments (4) below the folded salt (1). Well rounded xenoliths of diorites and white amphibol pegmatite occur within the dolerite inclusion (a) in dome 22. Hill b exposes along its base an erosive scarp, suggesting a recent rise. Just to the N of the basic hill b a most peculiar xenolith of pink grano-syenite sitting on salt was discovered by the writer in 1990 (5). (Figures redrawn from Gansser in Jackson et al. 1990 and Gansser 1960.)

intensive experimental work and field data gathered by Jovan Stoecklin and the writer, has been published as a special volume of the GSA memoirs (Jackson et al. 1990).

The incompetent Kavir domes expose a core of Middle to Upper Eocene, massive white salt, conformably covered by Miocene evaporites consisting of repeated cycles of salt, gypsum, green gypsiferous marls and purple saliferous mudstones. These complex, very colorful domes intruded Mio-Pliocene "Upper Red Formation," an incompetent section of over 5000 m of gypsiferous mud and siltstones with sand content increasing upwards. The salt domes intruded into already existing structures, and since the competence of the Upper Red Formation is nearly the same as the Miocene part of the salt domes, they are surrounded by a sharply uptilted rim. Along this belt the sediments abut against a vertical gypsum rim, a most characteristic feature of the Kavir diapirs, which separates the highly complex domes from more gently folded Kavir sediments.

Of the over 50 known salt diapirs of the Kavir about a dozen of the more northerly salt domes contain basic volcanites related to the Eocene salt. Three of these domes have been visited in the field by the writer, dome 17, 22 and 28. (See Fig. 14, the numbering of the salt domes refers to Jackson et al. 1990.) The mode of emplacement of the visited volcanic inclusions sitting on top of the Eocene salt is surprising. They form prominent hills, capping the underlying salt like glacier tables. All visited volcanic rafts are still in a conformable upright position, with well exposed chilled contacts against the underlying salt, often with intervening thin gypsum films and baked clay. The volcanics consist of augite (olivine) dolerites, locally altered to diabase (Fig. 14 and 15a–d). Of special interest is the basic cap of dome 22A (Fig. 15a). Here the augite dolerite contains xenoliths of a fine grained, well rounded diorite and white hornblende pegmatites. Both plutonic rocks are older than the enclosing dolerite.

Table 1: Analysis of syenite inclusion of salt dome 22, Kavir, Iran

Main Elements	(weight %)	Trace Elements	(ppm)
SiO_2	38.89	F	492
TiO_2	2.34	Ba	216
Al_2O_3	14.53	Rb	20
Fe_2O_3	10.82	Sr	5178
FeO	0.00	Pb	9
MnO	0.37	Th	36
MgO	4.17	U	22
CaO	13.81	Nb	308
Na_2O	5.29	La	128
K_2O	0.46	Ce	289
P_2O_5	0.92	Nd	86
G.V	0.00	Y	47
CO_2	0.00	Zr	464
Cr_2O_3	0.02	V	203
NiO	0.00	Cr	<10
		Ni	23
Total	91.62	Co	23
		Cu	55
		Zn	202
		Sc	<2
		S	815

The geological facts suggest that the basic volcanics intruded (sills) or have formed flows in the original salt horizons. They must have travelled with the salt several 1000 m to the present surface during the diapiric phase. And yet they still retain their original position and thermal contacts with the salt. It is difficult to reconcile a mushroom-type salt dome, assumed by Jackson and some of his coworkers for most of the Kavir diapirs (Jackson et al. 1990), with observations made on some of the volcanic inclusions.

Andesitic volcanism is widespread in the Eocene of Central Iran. Most of the inclusions in the salt domes of the Kavir are however basaltic. An exception is the well known salt dome Kuh e Namac of Qum with coarse-grained hornblende andesites, also with a chilled though discordant contact against the layered salt (Gansser 1960). Basalts are rare in the Eocene volcanics surrounding the Kavir basin (Geological map of Iran 1985 and 1977). The basaltic salt dome inclusions suggest that basaltic volcanics were restricted to the Kavir salt basin.

The most extraordinary and enigmatic inclusion of the Kavir diapirs was found by the writer while revisiting dome 22 in December 1990. Just to the north of the volcanic table mountain (Fig. 15b) a 2–3 m^3 large, well polished and rounded boulder of a coarse grained magmatic rock sits on top of a half a meter high pillar of salt protected by the boulder. This peculiar inclusion consists of a medium grained, pink aenigmatite bearing nephelinite. I am grateful to Volker Dietrich (Zürich) for the geochemical analysis of this peculiar rock (Table 1).

While the main elements are conform to the analysed rock type, the trace elements have an extraordinary high Sr content of 5178 ppm![2)] This syenite must have been picked up by the Eocene salt from a syenitic pluton with no known equivalent in the wider surroundings of the Kavir. The only similar rock types are more acid, pink granites to granosyenites exposed in a perfect domal anticline with a plutonic core transgressed by Miocene beds with a basal conglomerate. This dome, called Kuh e Airakan (the fire mountain), occurs in the southern Kavir, 190 km to the south of dome 22 (Fig. 16). It is situated to the south of the great Kavir fault which divides two different structural provinces (Stoecklin 1968b). The Airakan pluton has been dated by Rb/Sr and gave a Middle Jurassic age (Berberian & Berberian 1981). The inclusion of dome 22 is most unlikely to be derived from the Airakan region itself but similar plutons could be hidden below the wide Kavir cover, even to the north of the Great Kavir fault.

[2)] Comment by V. Dietrich, Zürich: The chemistry of this highly undersaturated hypabyssal rock is similar to hypabyssal nephelinitic intrusions and lavas in rift-systems associated with alkaline volcanics (e.g. Rhinetalgraben, East African rift valley, Cameroon line: Tröger 1969). The extraordinary chemical composition with very high contents of strontium, the light rare earth elements, thorium, uranium and zirkonium matches the compositions of the Mt. Etende nephelinites which border the active basaltic Mt. Cameroon volcanoe (Nkoumbou 1990). The high niobium content of 308 ppm demonstrates the alkaline nature of this unique inclusion as well as its highly differentiated magmatic character.

Tröger, W.E. 1969: Spezielle Petrographie der Eruptivgesteine. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Nkoumbou, Ch. 1990: 1) Etude géologique des Monts Roumpi: un ensemble plutonique et volcanique de la "Ligne du Cameroun". 2) Données pétrologiques sur les néphélinites du Mont Etinde (Cameroun). Thèse, Université de Nancy I.

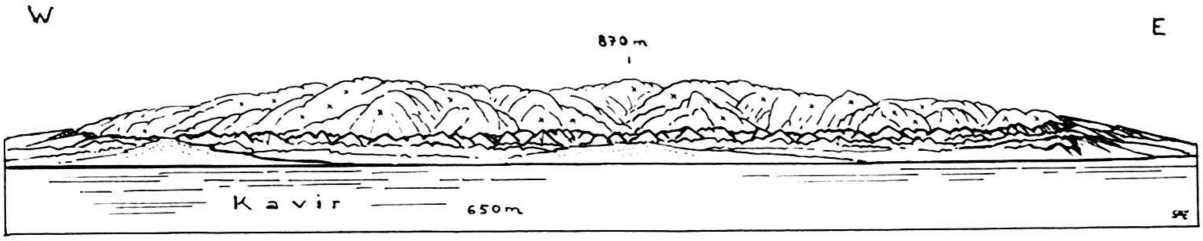


Fig. 16. The Kuh e Airakan, a perfect Miocene domal anticline with a core of a coarse grained pink granite to grano-syenite, dated as Middle Jurassic. The massive granite shows NS fractures and contains irregular pink aplites. The gypsiferous sandy marls of Middle to Upper Miocene expose a thin, fine grained basal conglomerate at the contact with the granite. The Airakan mountain must have formed a granite island in a very shallow Miocene sea. The Kuh e Airakan is surrounded by salt flats of the southern Kavir.

Conclusions

The origin and mode of emplacement of the huge inclusions in many Persian salt domes remain enigmatic. No convincing explanation can yet account for the observed facts. It is generally assumed that the diapiric movement of a salt dome is highly complex as the salt rises many kilometers from the original saline deposits to the exposed surface (Khrushchof & Shekchunova 1990, Kockel 1990, Jackson et al. 1990, Richter-Bernburg 1980, Trusheim 1974). Most theories are incompatible with the observed final emplacement of inclusions, such as several kilometers large, coherent sedimentary rafts and other blocks still in their "original" position. How did they travel 8–10 kilometer, "undisturbed" within a salt diapir? Peripheral brine springs in various Persian salt domes emphasize the importance of water in the evolution of salt diapirs. Observations in some Texas salt mines confirm the presence of water in a very mobile rim, which contrasts with a much more competent core. The characteristic vertical gypsum rim of the Kavir salt domes could represent such a peripheral zone of mobility. The more competent core of a dome may allow the undisturbed transport of inclusions of limited size. Water content is most likely more important than temperature in the evolution of salt diapirs.

The origin of many diapir inclusions is known. Examples are the Hormuz sediments in the Hormuz salt of the Zagros and the Eocene volcanics in Eocene evaporites of the Great Kavir. The mechanism explaining their introduction into the rising diapir is still questionable. The well documented northwest German salt structures offer suggestions which may be partly applicable to the less well known Persian salt diapirs. "In contradiction to the assumption of autonomous halokinesis our analysis of more than 300 Northwest German salt structures showed that nearly all of them stride across important basement faults, which at different times and with different direction of movement triggered salt flow movements above" (Kockel 1990, p. 228). Such a basement fault, still not proven, may be responsible for the enigmatic plutonic inclusions of Hengam island. On the other hand, based on the evolution of the Gulf area, the Zagros range as well as the Kavir basin in Central Iran, an autonomous halokinesis is the most likely driving factor for the formation of most of its spectacular salt domes.

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