Overview of Salt Occurrence in the Persian Gulf and Red Sea Region

S. Folle and Th. Beutel

Kavernen Bau- und Betriebs-GmbH (KBB), Karl-Wiechert-Allee 4, 30625 Hannover, Germany

The salt deposits of the Gulf states are of Cambrian, Jurassic, Tertiary and Quaternary age. Only minor occurrences of potash salt are known. The Eocambrian Hormuz salt in the southern Gulf is marked by strong diapirism. The Jurassic evaporites of the northern Gulf are primarily flat and deep-lying. The Tertiary and Quaternary evaporites are also diapiric, at least to the north of the Zagros. Tertiary evaporites in the Red Sea area are largely flat bedded and layered, and potash bearing in part. A few salt accumulations have also been observed. The deposits are often affected by graben tectonism. Jurassic evaporites have been affected by diapirism in the southern part of the Arabian mainland.

1. INTRODUCTION

The focus of this paper is on the areas in the vicinity of the two marine basins. Deposits on the mainland are also considered.

The information is derived from the literature and from observations on site.

A number of evaporite deposits have recently been geologically investigated and described. Oil and gas exploration has provided additional information on evaporite deposits. Information is also available from extractive operations involving solution mining as well as conventional mining. Only a few of these operations produce at a large industrial scale. Other deposits have been explored but never been progressed into the development phase.

The following provides an outline of the deposits in the Gulf Region and the Red Sea Region which can be devided up into several major tecto-genetic units, most of them associated with rifting and continental plate tectonics. Tectonism, volcanism and salt deposition are all mutually dependent: tectonics and volcanism are directly associated with the rifting processes, whilst salt deposition is an indirect consequence of subsidence and trangression.

2. THE GULF STATES

Iran has the largest evaporite deposits in the Gulf states. They are primarily of Eocambrian and Tertiary age. Jurassic deposits are rare. Diapirism is widespread and lifts the evaporites to extractable depths. Iraq is primarily characterised by Tertiary bedded salt which lies at relatively shallow depths and extends into Iran. Flat bedded and relatively deep Jurassic salt occurs in southern Iraq and in Kuwait. The oldest evaporite deposits in the region occur in the United Arab Emirates as well as Oman and Iran. Diapiric structures bring these deposits close enough to the surface in some areas to be extracted.

2.1. Kuwait

The exploration and production of the enormous oil and gas reserves in Kuwait and the neutral zone jointly shared with South Arabia led to the discovery of the exclusively subsurface evaporites of the *Gotnia Formation* of Upper Jurassic age. Several marine basins developed on the Arabian platform at this time. The Gotnia Basin was characterised by the deposition of evaporites including rock salt in the central parts. Sedimentation was strongly influenced by the old structural elements of the north-south oriented Kuwait arch. The total thickness of the Gotnia Formation is around 480 m [1]. It has been encountered at drilled depths from approx. 2700 m to 4500 m [2]. The structures are marked by elongated saddles and synclines.

The evaporites were laid down in four cycles. The halite horizons (max. 90 m) are separated by approx. 10 m to 50 m thick anhydrite layers. The rock salt

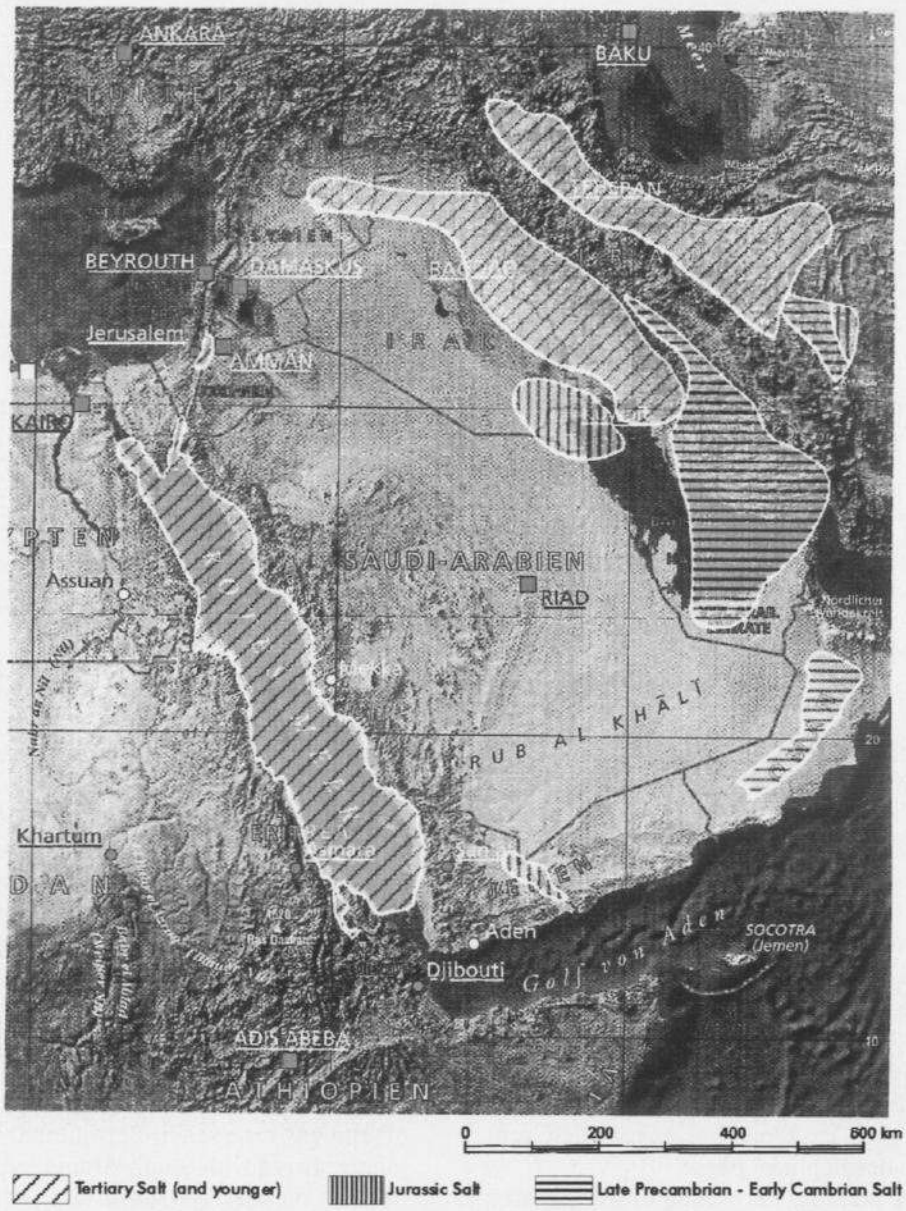

Figure 1. Distribution of main salt deposits

horizons contain occasional thin beds of anhydrite, carbonate and claystone. The salt extends into Saudi Arabia and Iraq.

2.2. Iraq

Similar to Kuwait, extensive oil and gas exploration and development has provided a great deal of information on the evaporite deposits throughout Iraq.

The *Jurassic salt* described in the previous section extends from Kuwait into the southernmost part of Iraq. The Miocene evaporite sequences are much more extensive. They occur in the northeast of the country in the Zagros foreland (foothill zone) and

stretch right across into Iran. The evaporites were deposited in two major cycles in several locally occurring basins [3]. On the one hand, in the *Dhiban Formation* (lower Miocene) on the other hand in the *lower Fars* (middle Miocene). The Dhiban Formation west of Mossul contains an evaporitic sequence whose salinity increases with depth.
The lower part is dominated by the Lower Salt Bed whose top lies at depths of > 1000 m and has thicknesses of up to 200 m. Notable minor constituents are anhydrite and polyhalite. The structure of the evaporitic sequences is typically relatively flat bedded with uniform depositional conditions in a zone dominated by gentle anticlines. Additionally, two of the evaporitic cycles in the lower Fars contain rock salt - the Lower as well as the Upper Salt Beds. To the east (e.g. around Kirkuk) bedding is only rarely flat and uniform. The structuration in this foothill zone is characterised by halotectonic salt accumulations around the crestal faults of anticlines with associated marked structural complexity.

2.3. Iran

In the western mountainous part of Iran large salt deposits are found. Their age is the latest Precambrian - early Cambrian [4] as well as Tertiary. Jurassic evaporites are rare.

The Infracambrian - Cambrian *Hormuz Salt* occurs in a large number of diapirs primarily in the south central part of the country, following the Zagros Trend. Typical exposures are in the islands of the Gulf. The diapirs on the mainland are also frequently associated with anticlinal trends. Strong compressive tectonism since the Eocene led to the still continuing uplift of the salt which in some places has generated glacier-like conditions on gently sloping surfaces [5]. Insolubles in the rock salt - which only rarely contains other salt minerals - include dolomite, anhydrite, clastic sediments and acid volcanics with exhalative accessory mineralisation - primarily haematite. Volcanic dykes are rare, stratiform deposits are more common, intercalating the salt units as well as massive dolomites and clastics.

Tertiary salt occurs in the Fars Basin (Miocene) of southern Iran on the border with Iraq and is similar to the deposits described there. Other deposits are found in the Central Basin (Miocene and Eocene) and in the northwestern Iranian Basin (Oligocene/Miocene) at Tabris. Whilst the deposits in this area are relatively unknown, those in the Central Basin have been extensively explored. The tectonic conditions here have also led to strong compression of the salt so that the horizontal extent of the salt at depth is far less than that at the surface. Glacier-like situations occur in places (fig. 2). In the area around Garmsar and especially to the south of Semnan (Great Kavir) there are large numbers of diapirs occurring within a relatively small area. This has led to surface coalescing in some cases. Accessory minerals in the rock salt are clay, gypsum, marl and intermediate to basic volcanites which have been carried along with the salt masses.

The only form of salt extraction is in open cast mining and the salt it is mostly sold directly. Potash bearing deposits - particularly in the Tertiary sequences - are primarily known from the northwest of the country. However, no extraction is currently taking place.

2.4. United Arab Emirates

The Arabian Infracambrian extensional system established rifted salt basins also in the eastern Gulf. The Lower Cambrian *Hormuz salt* in this area contains basalt, rhyolite and related tuffites, suggesting tectonic extension at this time [6].

Figure 2. Glacier-like salt movement with boulders of andesite (Kuh-e-Namak, Qom)

A number of diapiric islands in the Gulf as well as the Jebel Dhanna peninsula owe their relief to the diapiric movement of salt which has pierced and deformed the overlaying strata. Most of the islands are evidently small erosional relicts originally blanketed by Neogene to Recent sediments [7]. They appear as subcircular domal anticlines. The Miocene is gently dipping and the Pleistocene to Recent strata, when consolidated, are more or less horizon-

tal due to decrease in salt movement. Additionally, phases of compression favored the piercement of the salt body and could be responsible for narrowing of the structure at depth.

Figure 3. Outcropping caprock with dolomite and volcanic rocks forming hills (Jebel Dhanna)

The Hormuz series is characterised by a regionally consistent stratigraphy. It is typified by evaporites interbedded with clastic and carbonatic sediments, with stratiform deposition as well as vein intrusions of volcanic rocks. The occurrence of haematite is characteristic. The insoluble components are concentrated in the outcropping structures (fig. 3) having lost most of the original halite by solution.

2.5. Oman

Oman, touching the Gulf in the very east, contains three known salt basins: the South Oman Salt Basin, the Ghaba Salt Basin and the Fahud Salt Basin. These basins are bordered to the north by the thrust front of the Oman Mountains. Evaporites have mainly been encountered in oil and gas wells. The thick Cambrian *Ara Salt*, which is analogous to the Hormuz Series, includes carbonate stringers, e.g. which are the targets of hydrocarbon exploration. Six surface outcrops are known within the Ghaba Salt Basin. They have an analogous appearance to the caprocks above salt domes in Abu Dhabi [7]. They consist of dolomites and volcanites. Halite crops out at the surface in one structure. The structure of the interbedded Ara stringer indicates the existance of salt pillows. The undisturbed evaporite deposit is considered to be at a depth of > 3500 m.

3. RED SEA REGION

The Red Sea graben is part of the African and Indian Ocean rift system and was mainly developed from the early Tertiary on. The resulting initial Red Sea rift continued to develop further during all of the Oligocene and into the early Miocene.

Miocene sedimention with Mediterranean fauna indicate the presence of a land barrier during the Miocene in the Gulf of Aden area [8]. The Gulf of Suez was cut off from mediterranean influences during the late Miocene to early Pliocene. Restricted basin depositional conditions causing salt evaporation came to an end during the Pliocene when the southern barrier of the Red Sea was breached by a new phase of rifting to connect the Red Sea with the Indian Ocean.

3.1. Israel

The Israeli salt deposits are located at the Dead Sea. The most famous is the Mt. Sdom occuring at the surface. Halite has also been encountered in numerous wells around the Dead Sea.

The uplift of Mt. Sdom occurred after the Pliocene extension of the graben had come to an end. The outcrop comprises an interbedded sequence of thick salt and thin sulphates, dolomite, marl, clay and silt interbeds [9].

The salt layers are cyclical, i.e. each unit comprises an insoluble layer at the base followed by rock salt, and finishing with potash bearing minerals which favour the direction of the karst system (fig. 4). The cycles are part of the *Sdom Formation* of upper Miocene age. The salt is overlain by an approximately 30 - 50 m thick caprock of anhydrite, gypsum, marl, dolomite and clastic units which are of Pleistocene age.

3.3. Jordan

The country produces evaporation products out of the Read Sea. Water underground salt deposits are expected to occur in the Dead Sea area especially on the Lisan peninsula.

3.4. Egypt

Egypt has rich halite deposits along the southern Gulf of Suez. Major potash deposits have also been discovered along the west coast of the Gulf of Suez since 1982 by oil exploration wells. The potash deposits are extracted in conventional mines.

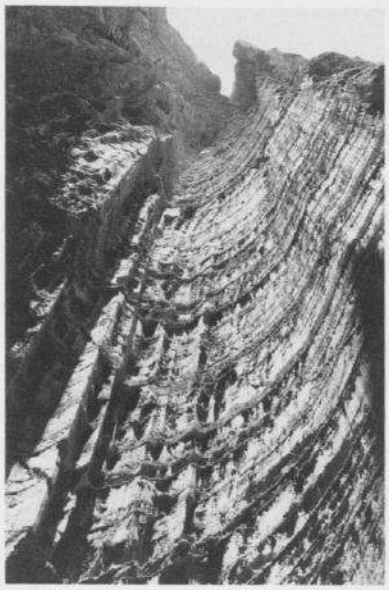

Figure 4. Solution funnel as karst features on the east flank of Mt. Sdom.

The evaporites were deposited in the tectonically controlled centre of the Miocene Gulf of Suez [10]. Equilibrium between sea water inflow and evaporation, as well as the continuous subsidence of the basin begun in the late Oligocene and led to the deposition of thick evaporite deposits of the *Ras Maalab Group*. The thickness of the salt deposits varies considerably whether they occur either in horsts or in sub-graben zones. The thickness of the halite sequences generally increases to the south. The Ras Malab Group is divided into 4 sub-divisions. Halite precipitation was restricted to the two youngest formations, South *Gharib* and *Zeit* (middle Miocene). The cyclic interbedding of shale, anhydrite and halite characterises the evaporitic sequence which in parts included the precipitation of potash salt deposits. The evaporites reached thicknesses of up to 1500 m. Massive salt deposits form structures ranging from salt pillows in the centre of the Gulf to embryonal salt domes in the south.

3.5. Sudan

Sudan has a 700 kilometre long eastern coastline along the Red Sea. Middle Miocene coastal outcrops are present in Sudan to the north of Port Sudan. A borehole drilled on Maghersum Island encountered 460 m of halite within the *Maghersum Formation* overlain by gypsum and anhydrite [2]. These middle Miocene deposits are considered to be analogous to the Ras Maalab Group in the Gulf of Suez Region [8].

3.6. Eritrea/Ethiopia

Miocene halite deposits have been encountered below Pleistocene and Pliocene sediments in boreholes drilled on the Dahlak Islands off the Eritrean coast [2]. The authors consider this to indicate that the *Miocene to Pliocene* salt basin is connected via the Bay of Mersa Fatuma to the Danakil Depression to the south.

The potash and halite deposits on the mainland are genetically closely related to the deposits in the Red Sea.

The halite deposit at Dallol in the salt desert to the north of the Danakil Depression stretches to the north crossing the Eritrean/Ethiopian border. Current small scale exploitation is carried out by the indigenous Afar tribes: salt blocks are excavated from the upper salt crust. Major salt deposits were discovered in this area.

The Danakil Depression is a half graben located along the north-south main fault of the rift system. The Danakil Alps in the east once formed a significant evaporitic basin barrier which temporarily sealed off the Red Sea. The barrier was periodically inundated with fresh salt water which entered the asymmetric basin [11].

In the centre of the depression above the tectonically active graben axis, there are salt uplifts associated with a wide array of volcanic features. The most spectacular salt uplift is Mt. Dallol (fig. 5) which rises up to 40 m above the salt plain and has a diameter of around 3,000 m.

The oldest salt deposits were laid down at the base of the *Upper Danakil sequence* (Pliocene) and is correlatable with the youngest salt deposits laid down in the Red Sea. The Pleistocene *Zariga sequence* comprises potash-bearing layers in the western part of the basin consisting of up to 50 % sylvinite [12].

3.7. Yemen

In addition to Miocene evaporites consisting of gypsum/anhydrite or halite along the coast of the Red Sea, Yemen has upper *Jurassic* halite deposits. Numerous salt pillows and salt domes have been described and mapped in the southwestern Hadhramaut.

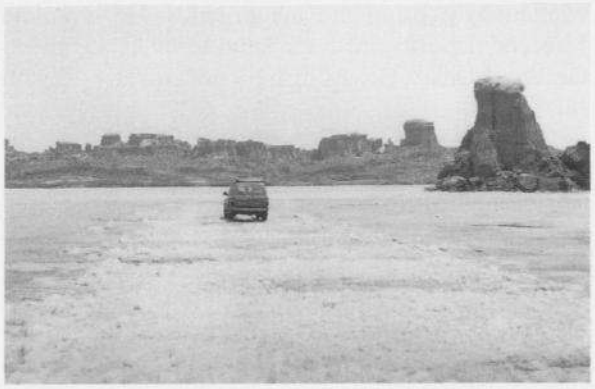

Fig. 5. Mt. Dallol with spectacular pinnacles and pillars of rock salt protected by gypsum caps.

The *Miocene evaporites* which are partially diapiric crop out at the Red Sea coast. Analyses indicate a middle to upper Miocene age for the salt. The Salif salt domes stretch over several kilometres east-west. Their centres are strongly folded [2].

3.8. Saudi Arabia

The coast stretches along the eastern boundary of the Miocene evaporite basin. Very thick *Miocene evaporites* have been encountered in offshore and onshore wells as well as in shallow outcrops. Open cast halite mining operations are located in Jizan and Yanbu'al Bahr. In Jizan the domal structured occurrence contains approx. 5 % impurities within the rock salt. Miocene salt was also penetrated at greater depth on the Saudi Arabian islands of Farasan and Jizan. On the island of Farasan-Kebir on the east coast of the Red Sea, a salt dome has been drilled whose top is covered by an up to 285 m thick overburden. The halite contains potash salt inclusions as well as 5 % insolubles comprising anhydrite, dolomite and clay.

A further Miocene evaporite sequence over 1300 m thick was penetrated in an offshore well near Al Lith at 2670 m depth. Miocene salt deposits are also known to exist to the north and south of Jeddah on the coastal plain. A halite package up to 45 m thick consisting of almost pure halite with minor argillaceous inclusions was encountered between 145 m and 1890 m depth [2].

Jurassic salt occurs at the boundary to Kuwait.

REFERENCES

1. M.A. Ali, Gotnia Salt and ist Structural Implications in Kuwait, Geo '94, the Middle East Petroleum Geosciences, Vol.I, 1994, pp.133-142.
2. S.J. Lefond, Handbook of World Salt Resources, Plenum Press, New York, 1969.
3. H.V. Dunnington, Salt Tectonic Features of Northern Iraq, Proc. Symp. Int. Conf. on Saline Deposits, Houston, 1962, Geol. Soc. of America, Spec. Paper No.88(1968), pp.183-227.
4. J. Stöcklin, The Vendian Lower Cambrian Salt Basins of Iran, Oman and Pakistan: Strat. Corr., Paleogr., Sci. de la Terre, Mém. 47 (1986), pp.329-345.
5. A. Gansser, The Enigma of the Persian Salt Dome Inclusions, Eclogae geol. Helv. 85 (1992) 3, pp.825-846.
6. Geol. Surv. of Iran, New Indications of Potash in Iran, in: Proc. of the Seminar on Sources of Mineral Raw Materials for the Fertilizer Industry in Asia and the Far East, Mineral Res. Develop. Series no. 32, pp. 355-356, New York, 1968.
7. A.S. Alsharan, M.G. Salah, Tectonic Implications of Diapirism on Hydrocarbon Accumulation in the United Arab Emirates, Bull. Canadian Petrol. Geol., 45 (1997) 3, pp. 279-296.
8. F. Heybroek, The Read Sea Miocene Evaporite Basin, in: Inst. of Petroleum, Salt basins around Africa, Elsevier, Amsterdam, 1965, pp.17-40.
9. A. Frumkin, Uplift Rate Relative to Base-Levels of a Salt Diapir (Dead Sea Basin, Israel) as Indicated by Cave Levels, Salt Tectonics, Geol. Soc. Spec. Publ. No. 100 (1996), pp.41-47.
10. G.M. Friedman, Significance of Red Sea in Problem of Evaporites and Basinal Limestones, American Ass. of Petrol. Geol. Bull., 56 (1972) 6, pp.1072-1086.
11. M. Kürsten, Tektonik, Salz und Vulkanismus in der Danakil – Senke Äthiopiens, Geol. JB 90 (1972) 297.
12. U. Holwerda, R.W.Hutchinson, Exploration, Geology and Origin of Potash Deposits Danakil region Ethiopia, Econ. Geol. 63 (1968) 2, pp.124-150.