Middle East Salt Deposits – Distribution and Potential Use

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Abstract

The use of local salt deposits in the Middle East is developing slowly from open pit table salt production to the utilization of brine in Ethylene Dichloride plants and the construction of cavities for strategic and commercial storage of oil, oil products and gas. Underground storage of waste is discussed as well. There is a need and the potential for such a market but still it is not a focus of authorities and companies of the region. Most of the projects stuck in the exploration phase. Nevertheless it may be a question of time when industrial development or the need for security of supply accelerates the use of salt deposits.

This paper is discussing the potential of locations under geological aspects keeping in mind the infrastructure and the specific local requirements. Beside mining of natural outcrops, trap forming salt deposits have mainly been encountered by oil and gas wells.

The evaporites are of Cambrian, Jurassic and Tertiary age. Iran has the largest evaporite deposits. They are primarily of Eocambrian and Tertiary age. Diapirism is widespread and lifts the evaporites to extractable depths. Iraq is primarily characterized by Tertiary bedded salt which lies at relatively shallow depths and extends into Iran and Syria as well. 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 in Oman and Iran. Saudi Arabia is characterized by very deep deposits in the Gulf Region but also shallower ones at the shore of the Red Sea. At many places diapiric movements are responsible for the elevation.

The political situation of the entire region has an influence on strategic storage considerations. Pipelines are vulnerable with respect to war or terroristic attacks. Long distances from selected sites to e. g. export terminals should be avoided.

Introduction

This article deals with a region that is rapidly developing or has the potential to develop rapidly. Beside huge gas & oil reserves it is a region where salt occurs at many places under suitable conditions.

Storage of hydrocarbons in general is related to seasonal fluctuation of consumption, trading, strategic security and/or as a mean to guarantee delivery. These issues are going to be discussed concerning their relevance for the specific countries.

The storage of oil is linked to the potential oil supply disruptions (strategic reserves). In the EU for instance countries have to stockpile a 90 days consumption amount of oil. Such reserves are under environmental and safety aspects better stored in the underground. The same principle applies for the storage of refined products. In order to safe the own consumption and contractual duties related to the export this may become more important even to the oil producing countries.

LPG storage sites exist particularly in regions with comparably poor gas distribution net and high consumption of gas. This rule of thumb appears to be applicable here in particular apart from the big cities.

Even in gas producing countries storage of natural gas becomes an item due to shortages in extremely populated areas on the one hand and export commitments on the other hand. Since the consumption of gas is increasing and trading systems have become a means of political pressure storage becomes more and more important.

LNG terminals are widely spread in the Gulf and their number is increasing. From the strategic point of view it may be worthwhile to consider gas storage close to the liquefication plant in order to guarantee supply at a high level of safety.

The production of Ethylene Dichloride is based on salt, oil and energy. Oil and gas producing countries are excellent locations for the implementation of such an industry. World Chlor-Alkali capacity is on the increase and that additional capacity is apt to be primarily in the Middle East.

Finally waste disposal in underground facilities alternatively to landfill may become an issue as it was discussed in Israel in the last decade.

The political situation of the entire region has an influence on strategic storage considerations. Pipelines are vulnerable with respect to war or terroristic attacks. Therefore the selected sites should be situated close to terminals, refineries etc.

No political stand concerning the current political system of each country is going to be taken here, nonetheless the individual situation has an influence on the attractiveness of business development.

Middle East Geological Overview

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 solution mining. The following provides an outline of the deposits in this region (Fig. 1).

Iran has the largest evaporite deposits in the Gulf states. They are primarily of Infra-/Eocambrian and Tertiary age. Jurassic deposits are rare. Diapirism is widespread and lifts the evaporites until the surface. Iraq is primarily characterized 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 whereas the oldest evaporite deposits are known from the United Arab Emirates as well as Oman and Iran.

Reconstruction of Pangea in the late Precambrian shows,

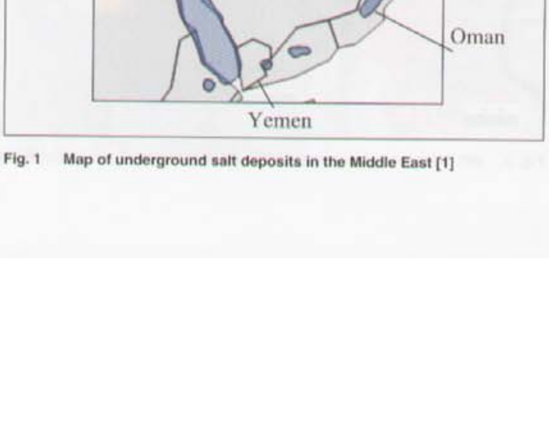

Fig. 1 Map of underground salt deposits in the Middle East [1]

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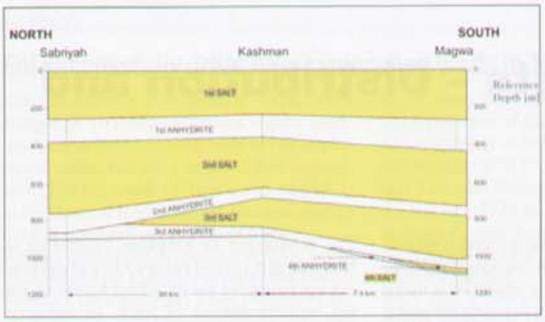

Fig. 2 Stratigraphic cross section Gotnia Salt Formation [2]

that the subsiding evaporitic basins of the Persian-Arabian Gulf, Oman and Pakistan/India were oriented in a belt following the same latitude, bounded by carbonate platforms such as Zagros crush zone, Huqf axis and the Qatar arch. The proximity of emergent shields respectively paleo highs determined the quantities of clastics, carbonates and evaporites.

Mesozoic and Tertiary activation of faults are most probably associated with the main phases of plate tectonic movements that affected the Eastern Arabian sub-plate with resorption of the Thethys, opening of the Indian Ocean, development of transform faults and the NE-movement of Arabia related to Africa and Iran resulting from the spreading of the Red Sea. During collision and partial subduction of the eastern Arabian sub-plate in Late Cretaceous pronounced salt movement occurred.

The Red Sea is part of the African and Indian Ocean rift systems and had already started to subside during the Jurassic and Cretaceous in a pre-rift stage. However, the main graben development did not take place until the early Tertiary. During the late Eocene, the Arabian-African shield began to separate. The initial Red Sea rift resulted from this movement and continued to develop further during all of the Oligocene and into the early Miocene.

Miocene deposits are largely identical with the current extent of the Red Sea. Miocene sedimentation with Mediterranean fauna is observed along the coastal strips of Egypt as well as Yemen and Saudi Arabia. They indicate the presence of a land barrier during the Miocene. At the end of Miocene/early Pliocene the Gulf of Suez was cut off from the Mediterranean Sea. Lateral facies interfingering reveals the existence of a flat evaporitic basin subjected to extreme arid climatic conditions during sedimentation of the evaporites. Restricted basin depositional conditions 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 as far as the Gulf of Suez with the marine Indian Ocean.

Kuwait

The exploration and production of the oil and gas reserves in Kuwait and the neutral zone jointly shared with Saudi Arabia led to the discovery of the exclusively subsurface evaporites of the Gotnia Formation of Upper Jurassic age (Kimmeridge – Tithon).

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 structures are marked by elongated saddles and synclines.

The Gotnia Formation has a thickness of approx. 230 to 490 m consisting of cyclic alternations of salt, sulfates and carbonate. It has been encountered at drilled depths from approx. 2700 m to 4500 m [2]. The series are covered by anhydritic limestone of the Hith-Formation.

The evaporites were laid down in four cycles (Fig. 2). The salt units vary from approx. 60–100 m. The lower ones (4th and 3rd salt) are highly variable in thickness, the upper ones (1st and 2nd salt) are more constant. The halite horizons are separated by approx. 10 m to 50 m thick anhydrite layers. Rock salt horizons contain occasional thin beds of anhydrite, carbonate and claystone. The salt strata are supposed to extent far into Iraq and offshore.

Due to the depth of salt strata brine production for the chemical industry could be taken into consideration.

Iraq

Extensive oil and gas exploration and development have provided a great deal of information on the evaporite deposits throughout Iraq.

The Jurassic salt described in the previous section is supposed to extend from Kuwait into the southernmost part of Iraq.

The Miocene evaporite sequences however are much more extensive. They occur in the northeast of the country in the Zagros foreland and stretch right across into Iran. To the east (e. g. around Kirkuk) bedding is only rarely flat and uniform. This foothill zone is characterised by halotectonic salt accumulations around the crestal faults of anticlines with associated marked structural complexity [3].

The Mobile Group of Lower Fars age (Middle Miocene) contains rock salt – the Lower and the Upper Salt Beds (Fig. 3, right). In the Kirkuk oil field (Baba Dome) caverns for LPG were built in the upper saliferous beds of the Lower Fars at shallow depth. The presence of oil reservoirs and refineries suggest the industrial development potential associated with the chemical use of brine. Beside the storage of LPG other oil products could be stored more safely in the underground.

The Dhiban (Lower Miocene) 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 evaporitic sequences are typically relatively flat bedded with uniform depositional conditions in a zone dominated

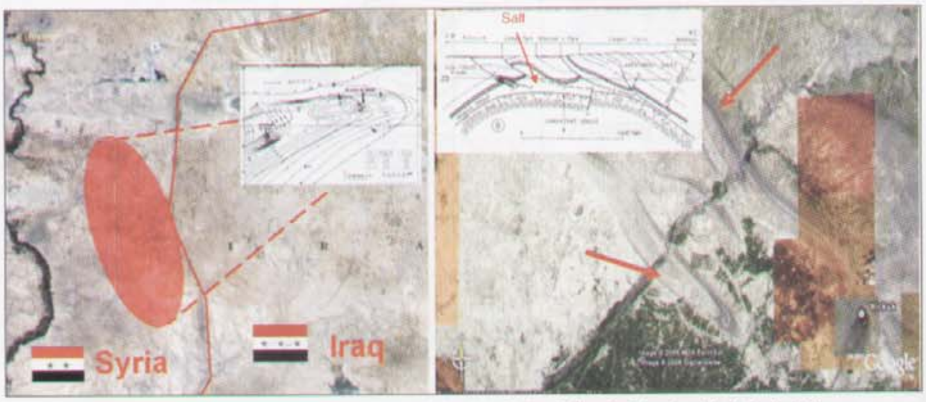

Fig. 3 left: Major salt structures in NW-Iraq extending to Syria; right: Salt anticlines in E-Iraq (aerial photos by [5])

Fig. 4 Rim of a salt glacier where insolubles are accumulated (arrow shows one exemplary block)

by gentle anticlines, e. g. the Ain Ghazal Anticline and the Tel Hajar Anticline extending into Syria (Fig. 3, left).

In Syria the salt basin is subdivided in a northern and a southern basin. In the latter the Lower Miocene salt is rather pure. Beneath approx. 650 m cover rock the thickness is up to 250 m [4].

The infrastructure in the western area is rather poor and needs enhancement before the creating of storage volume or the industrial use of brine could be taken into economic/strategic consideration. The entire region becomes in so far important that it comprises planned oil and gas priority axes to Europe [6].

Iran

Tertiary salt occurs in the Fars Basin (Miocene) of SW-Iran on the border with Iraq and is similar to the deposits described there. Other deposits are found in the Central Basin (Eocene-Miocene) and in the northwestern Iranian Basin (Oligocene/Miocene) near Tabris. Whilst the deposits in this area are relatively unknown, those in the Central Basin have been extensively explored.

Glacier-like structures appear in places. 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 forming salt canopies (conjunction of overhangs) in some cases. In the core the diapirs contain relatively pure Eocene salt surrounded by a second generation of Miocene evaporites, both of them piercing through 5000 m of Upper Red Formation [7].

To the west the main salt bearing strata are younger, i. e. of Oligocene/Miocene age. A very famous and well investigated structure is the Kuh-e-Namak north of the city of Qum. It is positioned on the flank of the Alborz anticline. Apparently very strongly squeezed in the underground a salt glacier is formed carrying volcanic rocks, which are accumulated finally at the rim like a moraine (Fig. 4).

The Precambrian-Cambrian Hormuz Salt occurs in a large number of diapirs primarily in the south central part of the country, following the Zagros Trend (Fig. 5). The diapirs in the Zagros chains are famous for their glacierlike occurrence at the flanks or plunging ends of anticlines on gently sloping surfaces. Insolubles in the rock salt include dolomite, anhydrite, clastic sediments and volcanic rocks with exhalative accessory mineralisation – primarily hematite. Typically the sediments are sometimes bituminous. By some authors the first generation of salt is related to magmatogenic processes [8].

The further to the south the deeper is the base of the salt. The islands in the Gulf (Fig. 5) are often associated to diapirism. Larak Island and Qeshm Island are classic cases as the name giving Hormuz Island. The mobilization of the salt is considered syn- or postorogenetic, some authors put the first movements into Triassic, others into Cretaceous, the youngest was starting in Late Tertiary and often still active with flow rates of approx. 2 mm/a. The uplift occurs from approx. 10 km depth max. to the surface. Active structures have a domal shape, others are plugged and could not pierce through all covering rocks, but are still stable, the so called passive ones finally often appear with a negative morphology due to dissolution processes. On top of the outcropping active diapirs residual rocks are common.

The saline series of Kerman in southern Central Iran are considered to belong to the Hormuz series deposited in a separate subbasin divided by a carbonate platform from the main Hormuz depositional area.

For economic use the huge salt structures of the Great Kavir appear to be geologically suitable but the infrastructure is very poor. The northwestern structures are less explored but they are told to be located more favorable. The Kuh-e-Namak salt dome close to Tehran is unique and very complicated. The infrastructure for a gas storage would be excellent. Finally the salt domes in the south at the Gulf could be of interest under the aspect of strategic storage of oil products respectively to secure continuous oil export.

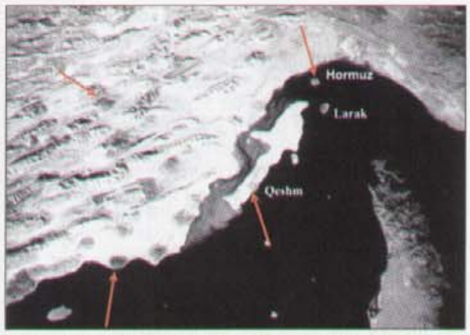

Fig. 5 Zagros chains, salt domes on- and off-shore are characterized by dark subcircular structures on this Landsat image

United Arab Emirates (UAE)

The Arabian Infracambrian to Cambrian extensional system established rifted salt basins in the south-eastern Gulf. Since halokinesis has strongly influenced the formation of structural traps in a number of oilfields offshore these structures are comparably well delineated.

The first phase of salt mobilization was in Permo-Jurassic during the opening of the Neo-Tethyan associated with the reactivation of basement faults (extension). In Early Cretaceous the 2nd phase of salt movement was initiated by compression stress due to the movement of the Afro-Arabian Plate. The 3rd phase in Late Cretaceous was caused by the closing of the Neo-Tethyan. In Mid

Fig. 6 Jebel Dhanna salt dome with caprock at the surface. Tank Farm on top, harbor, refinery and good road connections characterize this excellent location

Tertiary compression stress forced the salt to pierce through the cover rock (4th phase). In this 4th phase thrusting in Oman and folding of the Zagros occurred. In Late Tertiary (Miocene) the uplift during the 5th phase was less significant and slowed down respectively stuck until present. Dead structures as the Jebel Dhanna (Fig. 6) are covered by residues of the salt sequence several hundred meters thick due to a stop in the uplift and subrosion.

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 forming subcircular domal anticlines. The Miocene is gently dipping and Pleistocene to recent strata are more or less horizontal due to decrease in salt movement [9].

The Hormuz salt in this area is characterized by a regionally consistent stratigraphy. It is typified by evaporites interbedded with clastic and carbonatic sediments as dark Dolomite as well as vein intrusions of volcanic rocks such as Rhyolite, Trachyte, Dacite, Andesite and Tuffite. The occurrence of Hematite is characteristic. The insoluble components are concentrated in the outcropping structures having lost most of the original Halite by dissolution.

The infrastructure at specific locations is good to excellent. Alternatively to tank farms at export terminals caverns could be used subsequent to brine/chlorine production for industrial applications associated with refining of oil. Strategic storage of oil products may also be an issue.

Oman

In Oman, there are three 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.

The depositional environment in Late Precambrian is comparable to the one in UAE and Iran.

The focus here is the Ara Group, with a base dated to 550–570 Ma [10]. It comprises a carbonate/evaporate sequence with thick salt, which spans the Pre-Cambrian to Cambrian boundary. The salt pinches out at the Huqf Axis, is well developed to west and pierced in a number of plugs in the desert plains of central Oman up to the surface where dark carbonates cover anhydrite and salt. During collision and partial subduction of the eastern Arabian sub-plate in Late Cretaceous pronounced salt movement occurred mainly in the northern salt basins.

A total of 29 salt structures have been identified in the Ghaba Salt Basin, ranging in type from relatively low relief, deeply buried salt pillows to narrow, high-relief salt diapirs [11]. The six surface-piercing salt domes in North Oman are located in this basin (Fig. 7). Structurally, they are extremely high-relief features (as much as 9 km deep) that

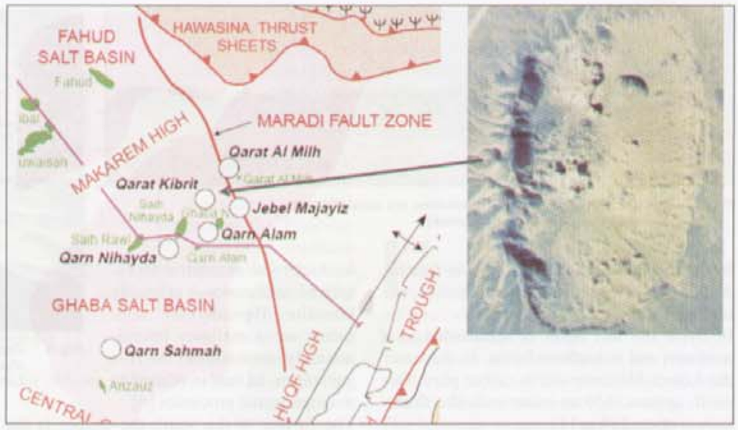

Fig. 7 Ghaba salt basin with close to surface salt domes. Exemplary aerial photo displays residues of eroded caprock respectively cover rock [11]

pierce the entire stratigraphic post-Ara Group sedimentary succession in the Ghaba Salt Basin. Some of them are located on a strike-slip fault zone.

The rock salt consists of massive or laminated, coarse crystalline halite with various trace impurities. It is interbedded with red sandstones and siltstones, sulphates or dolomite streaks. In the vicinity of the intercalated stringers the salt is often black due to liquid hydrocarbon. Sporadic occurrence of relatively thick potassium salt hints on distinct more isolated parts of the basin.

The area of the northern salt domes is linked by gas and oil pipelines to the northern shore near Muscat. There are an oil refinery and a LNG terminal. Arguments for the creation of storages appear to be weak due to the great distance of terminals/refining capacities and potential areas for storage respectively salt recovery. There are by far less gas than oil fields. It may be an issue to secure gas delivery via caverns to the LNG plant/terminal.

Saudi Arabia

Edgell [12] stated a structural dependency of the oil bearing anticlines in the Gulf offshore Saudi Arabia and more or less deep seated salt movement. This assumption is based primarily on gravity and supported by seismic data. The thickness of the sediments overlying the basement varies from approx. 4500 m to 13 700 m, thickening towards northeast. The elongated anomalies are thought to be related to salt walls, the circular ones single salt diapirs. The uplift (Mid Cretaceous-recent) is considered to be related to strike slip faults cutting the Hormuz series and providing release to the lighter salt. The thickness of the salt is assumed with up to 2000 m. These structures and the salt deposition is stated to extent into Kuwait and Iraq. Some Jurassic salt (Gotnia Salt) occurs at the boundary to Kuwait and is described there in detail.

Very thick Miocene evaporites have been encountered in offshore and onshore wells as well as in shallow outcrops at the Red Sea. Open cast halite mining operations are located in Jizan (Fig. 8) and Yanbual Bahr. Miocene salt was also penetrated at greater depth on the Saudi Arabian islands. 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. Miocene salt deposits are also known to exist to the north and south of Jeddah on the coastal plain.

Strategic storage of oil products was always an issue. Energy supply and refinery capacities should be suitable for further industrial

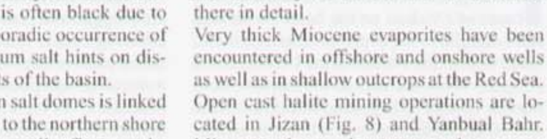

Fig. 8 One of the Red Sea salt occurrences in the Jizan region [13]

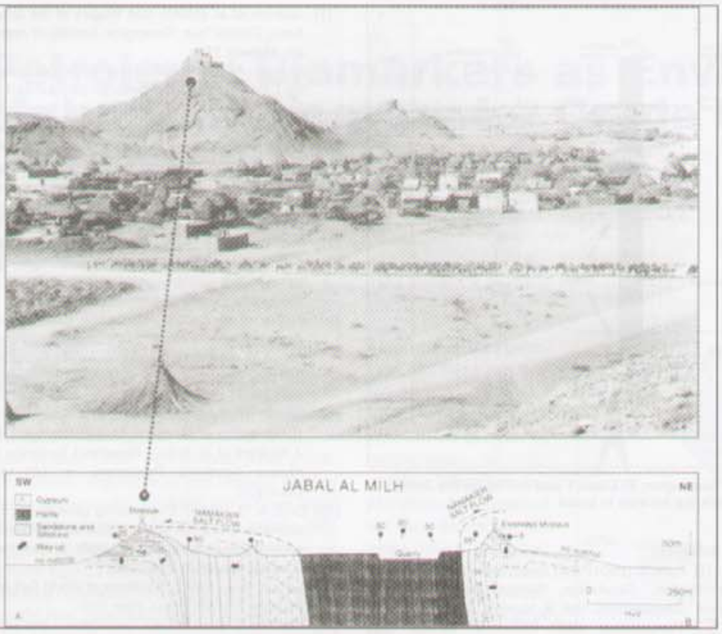

Fig. 9 Outcropping Jabal Al Milh Salt Dome with residues, approx. 50 km north of well known Al Salif Diapir [15]

development in combination with the use of brine. LPG may be an issue with respect to the remote areas. Since the natural gas & oil pipelines from the East of the country to the Red Sea are very long and therefore vulnerable the supply at e. g. Yanbu could be safeguarded by a cavern field – assuming suitable structures occur as indicated.

Yemen

In addition to Miocene evaporites along the coast of the Red Sea, Yemen also has upper Jurassic halite deposits. Numerous salt pillows and salt domes have been described and mapped in the course of oil exploration in the south western Hadhramaut, Marib Shabwa and Sir Sayun Basins.

The Miocene evaporites which are partially diapiric crop out at numerous locations along the shore of the Red Sea. The basement and the Jurassic and Cretaceous sediments subsided along faults running parallel to the Red Sea Graben and were buried by evaporites in the Miocene. The salt deposits in the Salif area (Fig. 9) stretch at least 40 km to the east where they have been penetrated by boreholes near Zaydiyah [14]. The centres of the salt domes are strongly folded, with oil shales at the top. They are flanked by gypsiferous sandstone and claystone. A small scale open cast mine is operated on one salt dome.

In the Hadhramaut storage of oil is obsolete due to the vicinity of oil fields and long distance to the shore. There are still no refineries. The export terminal is far from the salt structures.

The situation is different at the Red Sea. Salt occurrence, export terminal, pipeline and refining capacities are not too far from each other. Therefore secure export of oil and the industrial use of brine may be good reasons for the future use of the salt dome occurrences.

Israel and Jordan

The Dead Sea between the Jordan Valley in the north and the Arava Valley with the Gulf of Eilat in the south is the topographically deepest section of the Jordan Graben which is part of the African rift system. The Jordan Graben developed along a transform fault as a Neogene-Pleistocene rift graben. An evaporitic sequence more than 4000 m thick was deposited under continental conditions.

The Dead Sea basin has a number of diapirs and salt structures encountered at Mt. Sdom (Fig. 10) and in numerous wells around the Dead Sea as on the Lisan peninsula.

The salt is non marine and deposited in a playa lake, originally derived from fault-associated springs and flood waters. After sedimentation and consolidation, the consolidated salt sequence subsided within an extension zone at the western main fault system of the Dead Sea Graben.

Mount Sdom is located on the west bank of the Dead Sea. The salt ridge is covering an area of approx. 11 x 1.5 km. The maximum elevation above the Dead Sea level (400 m bsl!) is approx. 240 m. The associated uplift occurred after the Pliocene extension of the graben had come to an end. The outcrop comprises sequences of insoluble layers at the stratigraphic base followed by rock salt and finishing with potash bearing minerals (Carnallite, Sylvite and Polyhalite). The cycles are part of the Sdom Formation of upper Miocene age. The salt is overlain by an approximately 30–50 m thick caprock.

Since Israel – and this is also valid for Jordan – has no significant oil and gas resources it is strongly dependent on imports. Therefore storage of gas, oil and oil products should be a vital issue. The use of brine from solution mining is dependent on the Dead Sea salt production – especially potash salt may be leached out of the Mt. Sdom in addition to the natural brine of the Dead Sea. Alternatively to landfill underground waste disposal was discussed in the nineties.

Jordan has access to the eastern shore of the Dead Sea and extracts potash and halite products by evaporating brine pumped out of the Dead Sea into evaporation pans. There are thick salt strata encountered by wells, e. g. in the underground of the Lisan Peninsula (Fig. 11) in the southern Dead Sea. With respect to energy supply the situation is similar to Israel.

Egypt

Egypt has halite deposits along the Gulf of Suez and is Africas most important halite producer. Egyptian potash deposits are extracted in conventional mines. In addition major potash and salt deposits have been discovered along the west coast of the Gulf of Suez by oil exploration wells. The potash occurrences are thick enough with concentrations to be commercially interesting [16].

The Miocene sediments in the Egyptian part of the Gulf of Suez overlie a highly variably

Fig. 10 Subvertical, slightly folded outcropping salt at Mt. Sdom, cap rock visible on top

tectonised and eroded basement (Precambrian to Eocene). The evaporites were deposited in the deeper, tectonically controlled centre of the Miocene Gulf of Suez [17]. The marine sedimentation can be divided into a clastic phase and the overlying evaporite phase (Ras Maalab Group). The thickness of the salt deposits varies considerably depending on the paleo subsea relief (Fig. 12) but generally increases to the south. Halite precipitation was restricted to the South Gharib and Zeit Formations (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 [18].

Concerning oil production the Gulf of Suez is well developed. Refineries and export terminals exist (Fig. 12). The oil as well as gas pipeline system is located on the western bank. Since gas is transported from the Nile Delta, regional supply could be safeguarded by storages. In order to secure the export terminals of crude oil or oil products as well as under strategic aspects storage could become important. The use of brine for chemical purpose would also be an option for further industrial development.

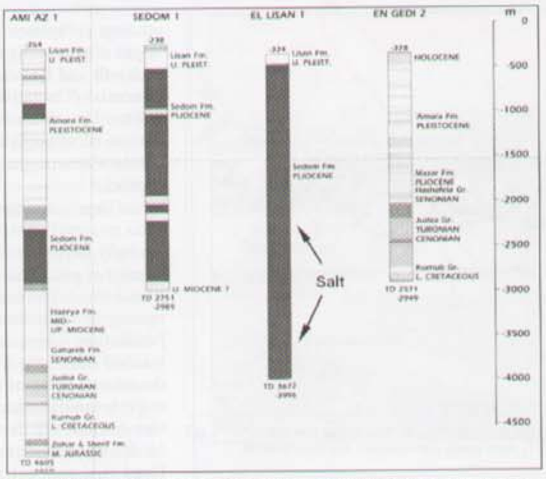

Fig. 11 Wells in the Dead Sea region; El Lisan 1 was drilled on the Jordan bank, the other wells are located in Israel

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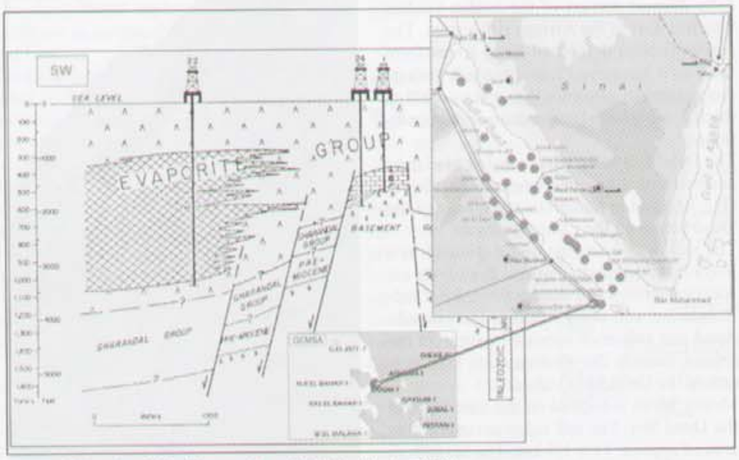

Fig. 12 Salt at the Gulf of Suez and gas & oil infrastructure [19]

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