

Short-note

A morphotectonic study of environmental impact on ground water in Southern Iran and under the Persian Gulf

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With 5 figures

Abstract

The Zagros Mountain Ranges (ZMR) in southern and southwestern Iran consisting mainly of limestone are a large and very valuable catchment area, which recharges the aquifers in vast areas of Iran and of the Gulf States beyond the Persian Gulf. The collision resulting from the opening of the Red Sea and the convergence of Arabia towards Iran increases the rock porosity and thus the internal drainages. This helps to recharge the aquifers, but the ground water becomes more vulnerable to the growing landfill. Another source of ground water contamination is the Lower Paleozoic salt which crops out in the form of numerous salt plugs.

The Makran Mountain Ranges (MMR) in southern and southeastern Iran are also a large catchment area and subjected to subduction. They have therefore different lithology and are less exposed to contamination.

Because of the ongoing tectonic activities in different stages of plate convergence from subduction to incipient and advanced collision, the migration of ground water under the Persian Gulf to the Gulf States, the contamination of ground water by salt plugs and growing landfill, and the degree of rock exposure, a study of the relation of morphotectonics to ground water and its contamination in southern Iran seems to be required and promising.

Introduction

In the current decade the shortage of fresh water is the most important problem of the countries in the Middle East, especially of those around the Persian Gulf, where the climate is very arid and the salinity is high. There are two other main factors which deteriorate the problem:

a) A strongly growing population, 3.7% in recent years, consumes more fresh water and produces more landfill.

b) Geological conditions make a contamination of ground water easier. These conditions are:

1) The primary porosity of the outcropped rocks. 95% of the surrounding rocks northwest of the Strait of Hormuz are carbonates.

2) Secondary porosity in response to the shortening, i.e. folding and faulting, due to the convergence of the Arabian plate towards Iran. Together with the primary porosity, this results in the penetration of landfill seepage waters into the ground water.

3) Numerous salt domes, of mushroom appearance, crop out northwest of the Strait of Hormuz. They originate from a thick evaporitic layer, the Hormuz Formation, at the base of the Phanerozoic column.

The contamination of ground water in southern Iran becomes in so far more important as recent investigations have shown that it migrates partly from

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Iran towards the Arabian countries under the Persian Gulf. This paper discusses the ground water resources of the area and their vulnerability to land-fill and salinity due to active tectonism and makes preventive suggestions.

Regional Setting and Geomorphology

Southern Iran consists of the approx. 500-km-long coastal area, the Iranian part of the MMR, to the east of the Strait of Hormuz, and a vast area (1100 km long) of the ZMR northeast of the Persian Gulf (Fig. 1). The so-called Oman line at the Strait of Hormuz is the boundary between the oceanic plate overlain by flysch (Fig. 2) with numerous mud volcanoes in the MMR, and the continental plate overlain by carbonate rocks with many salt plugs (Fig. 3) in the ZMR (FARHOUDI & KARIG, 1977). The resulted morphology on both sides has, however, following common aspects:

1) There is a mainly Tertiary and Quaternary volcanic belt in each area confining and parallel to the ZMR to the northeast and the MMR to the north respectively. The Taftan volcano is the only still active one, in the fumarolic stage, and with an elevation of 4000 m the highest peak north of the MMR.

2) There is the several-hundred-kilometer-long Gavkhuni Depression and its prolongation at the foot

and to the southwest of the volcanic belt of the ZMR in which the elevation gets down to 1300 m, before rising again to an average elevation of 2500 m and peaks up to 4500 m. Corresponding depressions in the Makran area are the Jaz Murian Depression in the Iranian Makran, with an elevation of 300 m, and several smaller depressions in the Makran of Pakistan. The Jaz Murian, Gavkhuni and smaller depressions on their prolongations are intermontane depressions.

3) The uplift in the outer arc of the ZMR is stronger than in the MMR. At the end of Pliocene, it was even up to 12000 m in the area of the Dizful Embayment (FALCON, 1974), where the foldings are tighter, but similar to the uplift in the MMR, being cumulative over a vast area.

4) In both areas the sediments from the sea to the watershed become progressively older. Together with the cumulative uplift, this results in the outcrop of older formations near the watersheds. While these formations in the ZMR are well developed carbonate aquifers which continue under the Persian Gulf, average depth 35 m, toward the Gulf States (FARHOUDI et al., 1989), there are flysch type aquicludes in the MMR.

The ZMR act as a barrier to the clouds moving from the Mediterranean Sea and causing precipitation. The prevailing winds do not permit the moving of clouds from the Persian Gulf and Indian Ocean to



Fig. 1. Outline of some tectonic elements in southern Iran and the location of some of the units mentioned in the text.



Fig. 2. Bedrock consisting of flysch in Makran. Even in imperious rocks, the hydraulic permeability is much higher when they are tectonized. The figure clearly shows fracture cleavage in vertical direction suggesting strong lateral pressure. Although the cleavage does not pervade the sandstone interbeddings, combined with a fault, the permeability of the whole rock increases considerably.

the north. Although the region has an arid climate, the mountains receiving more rain and snow can be described as mesic and semi-arid. The higher parts of the range are covered with snow several months of the year. There is even one active mountain glaciation (Zard Kuh). The average rainfall decreases from ca. 800 mm/year in the elevated areas in the western part of the Zagros to 70 mm/year in their lower parts to the east.

In the MMR the climate is more arid than in the ZMR, being farther away from the Mediterranean Sea and of lower average elevation, although some high mountains north and northwest of the Jaz



Fig. 3. Satellite photograph showing some of the anticlines and numerous salt plugs (dark patches) in the ZMR near the Strait of Hormuz; to the right Isle of Qeshm.

Murian Depression are covered by snow during winter. The contamination of ground water is less problematic than in the ZMR because of the absence of salt domes and the fact that the flysch type rocks are usually aquicludes. Moreover, the area is very thinly populated due to the aridity.

The climate is even much more arid beyond the Persian Gulf on the Arabian side, where there is sometimes no rain for several years. Extreme aridity and high temperature, up to 50 °C, lead to salinity up to 70‰ on the Arabian side of the Persian Gulf.

Regional Geology

The convergence of the Arabian and Iranian plates since the Cretaceous has also been manifested in the isopach maps based on data obtained from oil drillings (FARHOUDI, 1978). They indicate continuous convergence, but at a different rate during that time. Higher speed of movements resulted in two major crustal shortenings. The first one occurred in the Upper Cretaceous and produced the prototype ZMR (FALCON, 1974), which is in the northeasternmost part of the present ZMR, the imbricated zone. The second shortening, which was stronger and resulted in the actual Zagros orogeny in the Pliocene, is continuing presently, but at a lower rate. It includes the whole ZMR down to the southwest margin of the Persian Gulf. Some giant oil fields on the Arabian side of the Persian Gulf, e.g. Ghawar anticline, owe their existence to the cross-foldings resulted from the superposition of the northwest-trending (Zagros trend) folds on the north-south-trending (Arabian trend) growth structures. The basement of the ZMR, which is metamorphosed, broken and thrustured (FARHOUDI, 1978), is covered by 10-12 km sedimentary rocks. The latter consist of 1-3 km (KENT, 1970) Infra-Cambrian evaporitic Hormuz Formation, overlain by epicontinental terrigenous deposits of Paleozoic age. There was a remarkable facies change, as several thousand meters of mainly miogeosynclinal carbonates with few marly formations deposited from Permian to Lower Miocene time. At the end of this time the sedimentation of the evaporitic Gach-Saran Formation and then sandy marly Aghajari Formation was the response to the oncoming tectonic movements which climaxed in the Pliocene and resulted in the unconformable deposition of molasse type Bakhtiari Formation at the end of this epoch.

Of special interest are the some 200 outcropping salt plugs and diapirs (Fig. 3) originating from the Hormuz Formation. They are mainly in the

southeastern part of the ZMR, in the Persian Gulf and in some of the Persian Gulf states. They have brought to the surface huge amounts of rocks of small or large sizes up to 4 km in diameter. Numerous springs, some of them with high volumes of discharge, became salty due to the contact with the salt plugs. They have contaminated large areas otherwise very fertile for agriculture.

In the MMR the thick Tertiary flysch sediments cover the onshore area uniformly almost up to the Jaz Murian Depression.

The relation of tectonic activities to the flow of ground water is illustrated by the following case study.

Case Study Sabzpushan

The 55-km-long Kuh-e (Kuh means mount) Sabzpushan in the ZMR, located to the southwest of Shiraz city, is a suitable example to illustrate morphotectonic conditions of the ranges and their relation to the underground water flow. The culmination reaches an elevation of 2822 m (point C, Fig. 4). The difference in elevation from the valley plain to the top is over 1200 m. There are different kinds of vegetational cover scattered over the Sabzpushan.

Weathering and erosion have been very active in the Sabzpushan area. The presence of large amounts of detrital rocks shows the activity of physical weathering due to the strong difference of temperatures by day and night. Numerous deep and linear canyons on both flanks of the mountain suggest rejuvenation. The area is still in the youth stage of the erosional cycle, although the adjustment of topography to lithology has been reached in many places. There are even reverse topographies, e.g. in the form of synclinal uplands, one of which is found in the northeast of the Sabzpushan Anticlinorium (point B, Fig. 4). They are covered by Bakhtiari Conglomerate Formation.

The outcropped rocks consist of the dolomitic Eocene Jahrom Formation in the core of the anticline, underlain by marly Paleocene Pabdeh Formation and overlain by the Asmari Limestone Formation of Oligocene and Lower Miocene age. Then follow the evaporitic, marly and sandy Razak Formation, which is a less evaporitic facies of the Gachsaran Formation, and the Aghajari and Bakhtiari Formations (Fig. 4 and 5).

Kuh-e Sabzpushan is an anticlinorium composed of 6 anticlines, most of which are located around the southeastern part. The main anticline displays bifurcation on the northwestern end. It is crushed at

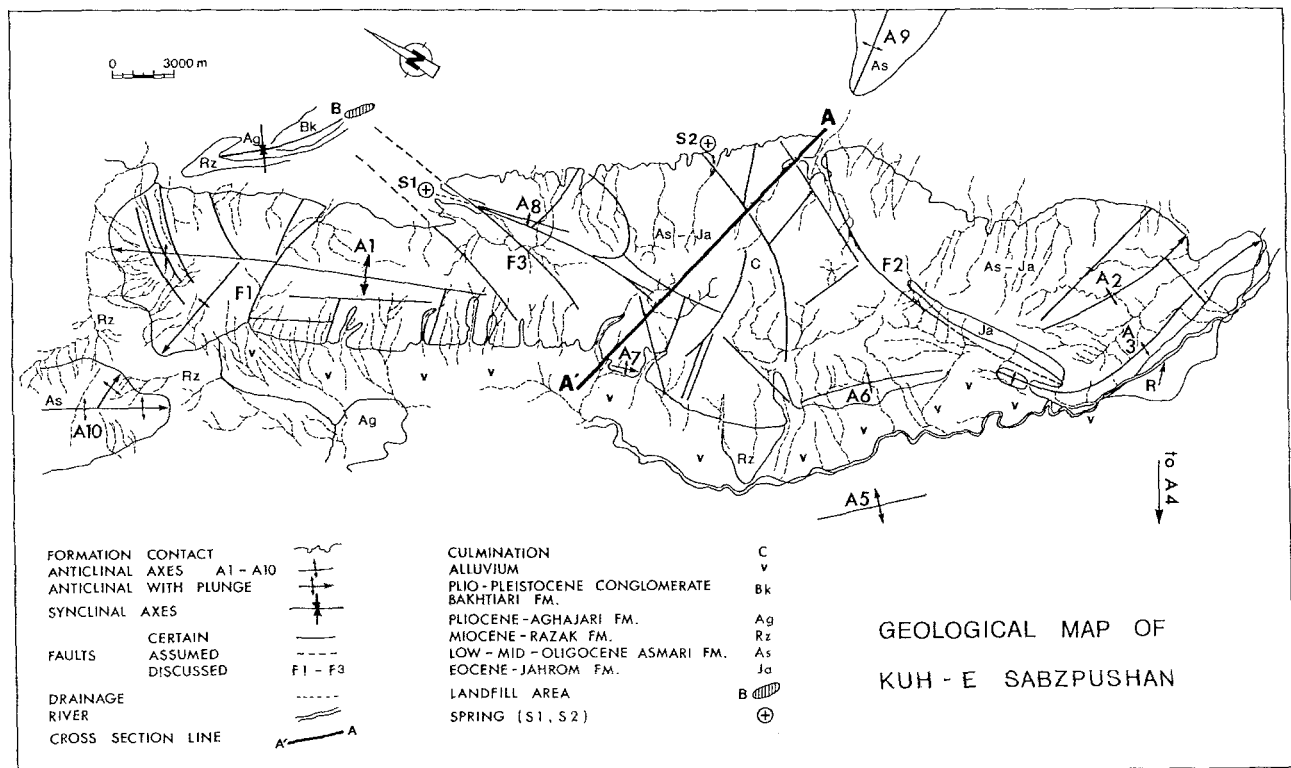


Fig. 4. Geological map produced by 1:50000 aerial photographs and field check. Only the main faults are shown.

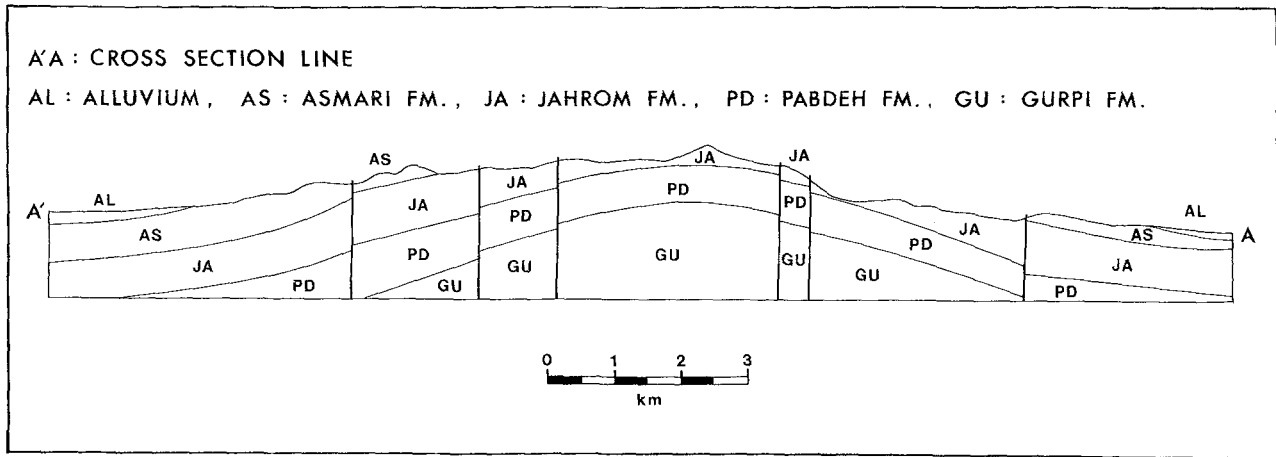


Fig. 5. Geologic cross section of Kuh-e Sabzpushan. The cross section line A-A' is shown in Figure 4.

several places of the axis. Its northwestern half still has the shape of a simple fold although it has been cut by many fractures, especially at the northeastern flank. The centre of the anticlinorium has been crushed, widened and uplifted to domal shape. This is where the tectonic intensity is strongest.

There are numerous springs, especially in the northeastern flank of Kuh-e Sabzpushan. Two of them have a high volume of discharge, i.e. on an average more than 500 l/sec. These are Spring Pirbanow at point S₁ and Spring Berenji at point S₂ (Fig. 4) with electrical conductivities of 400 and 800 micro Siemens respectively. Due to the abundance of water, the cultivation of crops and even of rice has been possible in this area. The Power Supply Department has recently completed 15 deep wells in limestone in the Sabzpushan area. They are of high discharge from 60 to 100 l/sec and are preserved for industrial purposes. The drinking water for Shiraz City with a population of one million is delivered partly by well fields around Shiraz and partly by a pipeline which carries the water from Dez Dam, 100 km to the northwest. Most of the water for irrigation purposes for Shiraz and its vicinity is provided by a well field, wells completed in alluvium or in limestone, some 15 km to the northwest, with an amazingly high volume of discharge. Other well fields and springs in Shiraz area are of much less discharge.

It is intended that the landfill of Shiraz City will be deposited on the synclinal upland (point B Fig. 4) in the near future. This has the shape of a closed basin, but cut by many fractures. It is assumed that the underlying marls, especially those of Razak Formation, are impermeable even when they are fractured.

Interpretation

The widened and uplifted centre of the main anticline which has a domal shape, the presence of Hormuz Formation, numerous salt domes in the region, and the increased electrical conductivity from Spring Pirbanow to Spring Berenji led to speculation about an unpierced salt dome pushing up in this place. Field studies combined with interpretation of aerial photographs and landsat images contradict this assumption:

The southeastern half of the anticline has been broken and deformed to a greater extent than the other half. In many places only patches of the northeastern flank are intact. The tightly folded small anticlines A₂ and A₃ are parallel and contiguous to the Dalu Anticlinorium, A₄. The southwestern flank of A₃ appears very steep, almost overturned. It seems that it has been squeezed between the Gareh Anticline, A₉, and A₄, which also has very steep beddings towards Kuh-e Sabzpushan. Field studies revealed abnormally frequent and large detached rocks and landslides between the two anticlinoria, originating from Sabzpushan. The presence of a tight anticline on the northeastern flank of the Dalu, A₅, and two others, A₆ and A₇, on the southwestern and one, A₈, on the northeastern flank of the Sabzpushan Anticlinorium also confirms tight folding in this area and upheaval of the Sabzpushan. The mentioned rejuvenation has probably been the result of this upheaval and can also be observed at point R, where the Ghareh Ghach River turns into a rather linear and deep stretch for ca. 6 km. The starting point of the pressure from A₉ can be seen clearly at point A. This pressure together with the one of A₄ resulted, among other facts, in rotation of A₂ and

A₃. Fault F₂ shows the path where rotation, mainly in the southeastern half of the Sabzpushan, has taken place. If the pressure was due to an uprising salt dome, it would be rather equally distributed on all sides than such a sudden change in direction in one part. It is possible that the Hormuz Salt Formation has been moved upward in the centre of Kuh-e Sabzpushan as a result of strong squeezing, although the 3000 m deep borehole drilled down to the Cenomanian Sarvak Formation for oil by the German company Deminex in 1975 could not confirm this.

Only the northwestern end of Sabzpushan has kept its actual Zagros trend, therefore cut by fault F₁. The main anticline A₁ shows a 30° clockwise rotation, while the small anticlines have their own deviations. There are numerous other faults, only the major ones have been shown on Fig. 4. Fault F₃ has probably originated Spring Pirbanow. It is a dextral fault breaching and bending the synclinal upland at point B (Fig. 4) and passing through the mentioned well field. Field studies have shown that F₃ acts like an underground channel. All wells along its path have a high volume of discharge, while those outside are almost dry. The abundance of water in the well field has been explained (FARHOUDI & RAEISSI, 1987) by the existence of a cross fault cutting F₃ in that point. The higher conductivity of Spring Berenji might be due to its link, by means of faults, to the Maharlu Salt Lake located northeast of A₉.

Discussion

The ZMR with a considerable amount of precipitation represent one of the largest catchment areas in the Middle East with enormous capacity to recharge the aquifers. The primarily porous carbonates combined with the secondary porosity provide the best possible reservoir rocks not only for oil and gas, for which they are famous in the world, but also for ground water. The presence of numerous sinkholes, many of them connected by subterranean flows, dolines and poljes with karst springs at the head and sinkholes at the end, indicate an advanced stage of the karst geomorphic cycle in the ZMR.

The orogenic movements have decreased in the Quaternary, but are still active. There are not many records of geodetic precision measurements to follow the rate of movements, but detailed studies of morphology indicate continuation of tectonism and its control of the flow of underground water. There are numerous known cases like the area around Kuh-e Sabzpushan in the ZMR.

The Quaternary movements have been manifested mainly by following phenomena:

a) There are numerous indications of recent or current shortening accomplished by folding and faulting, some of which resulted in rotation. The uplift of one anticlinal axis has been measured to 20 m in the last 1700 years (FALCON, 1974).

b) Upheaval of the whole range northeast of the Persian Gulf to the amount of at least 1 mm/year since the late Pliocene (SNYDER & BARAZANGI, 1986), and subsiding of its southwest edge at the Persian Gulf (KASSLER, 1973).

c) The Zagros is seismically one of the most active areas of the world. There is a line in the Persian Gulf southwest of which no epicentres have been found (GUTENBERG & RICHTER, 1954). This line coincides most probably with the axis of the Persian Gulf (FARHOUDI, 1978).

The Research Council of Shiraz University is trying to find out if there are severe damages of ground water by landfill deposition on the synclinal valley (point B). This kind of research needs long-term investigations. The authors of this paper suggest additionally intensive use of experiences of highly industrialized countries. Thus, e.g. the ground water has been contaminated by landfill through jointed layers of mica clay near Hamburg, Germany. The jointing has resulted from the ice movement in the Pleistocene (BRUNS, 1988). According to that paper, the hydraulic permeability has been 3 times higher than in the unjointed layers. The permeability would probably be higher if pressures were continuing. Thus highly tectonized areas of the MMR, despite far less primarily porous rocks than in the ZMR, are not suitable for landfill deposition. This has also been demonstrated by Figure 2. The secondary porosity is probably responsible for the fact that flysch has become the reservoir rocks for hydrocarbons, e.g. in the MMR of Pakistan (FARHOUDI, 1980).

The shallowness of the Persian Gulf, its strong asymmetrical shape, the continuation of aquifers under the gulf and the considerable recharging capacity of the ZMR are the reasons (FARHOUDI et al., 1989) for the very high volume of discharge of some springs, and the yield of well fields on the extremely arid Arabian Homocline. Therefore great attention should be paid to the treatment of ground water in the ZMR.

The tectonic activity is not homogenous in all areas of the ZMR. Kuh-e Sabzpushan appears to be the most tectonized anticlinorium and best aquifer around Shiraz. Therefore it is not difficult to find less tectonized aquiclude layers for the deposition of landfill, if necessary far from the city. Higher

transportation costs should be taken into account.

A solution for the salty springs is more difficult. Through a good knowledge of ground water flow, which is hard to acquire in karstic areas, the ground water can be tapped before contacting the salt diapir.

Conclusion

Although the whole area of southern Iran has been subjected to the compression resulting from continental convergence, tectonic activity has also been controlled by local conditions. Therefore a careful morphotectonic study is essential prior to choosing places for the deposition of landfill.

Areas of active tectonism are not suitable for disposal sites. In such areas layers susceptible to karst are most vulnerable, but even usually aquiclude layers show much higher permeability.

Active faults are often natural channels for the ground water flow. Their study is a prerequisite for choosing well sites and also helps to tap the ground water before it is contaminated by the salt diapirs in the ZMR.

The ground water deserves careful treatment in the ZMR because they recharge not only the aquifers in southern Iran, but also those in the states beyond the Persian Gulf.

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