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How subaerial salt extrusions influence water quality in adjacent aquifers

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SUMMARY

Brines supplied from salt extrusions cause significant groundwater salinization in arid and semi-arid regions where salt rock is exposed to dissolution by episodic rainfalls. Here we focus on 62 of the 122 diapirs of Hormuz salt emergent in the southern Iran. To consider managing the degradation effect that salt extrusions have on the quality of adjoining aquifers, it is first necessary to understand how they influence adjacent water resources. We evaluate here the impacts that these diapirs have on adjacent aquifers based on investigating their geomorphologies, geologies, hydrologies and hydrogeologies.

The results indicate that 28/62 (45%) of our sample of salt diapirs have no significant impact on the quality of groundwater in adjoining aquifers (namely Type N), while the remaining 34/62 (55%) degrade nearby groundwater quality. We offer simple conceptual models that account for how brines flowing from each of these types of salt extrusions contaminate adjacent aquifers. We identify three main mechanisms that lead to contamination: surface impact (Type A), subsurface intrusion (Type B) and indirect infiltration (Type C). A combination of all these mechanisms degrades the water quality in nearby aquifers in 19/62 (31%) of the salt diapirs studied. Having characterized the mechanism(s) by which each diapir affects the adjacent aquifer, we suggest a few possible remediation strategies to be considered. For instance, engineering the surface runoff of diapirs Types A and C into nearby evaporation basins would improve groundwater quality.

1. Introduction

Salt is generally impermeable and any internal groundwater is likely to flow only via fissures and solution cavities (Ford and Williams, 2007). Plastic creep during salt deformation tends to close fissures by geopressure at depths of a few tens of meters (Anderson and Browns, 1992). Therefore, salt rock can be considered impermeable beneath the local base level of salt karstification of subaerial salt extrusions. Salt dissolution seems to be mainly limited to the vadose zone and deep karstification in salt rock is unlikely because infiltrating water is rapidly saturated, open fissures are unlikely below base level and deep cavities tend to collapse or anneal rapidly at depth under lithostatic pressure (Frumkin, 2000).

There are 122 salt diapirs in southern Iran that have breached the surface in the last 10 Ma (Fig. 1). The diapiric salt rock of southern Iran belongs to the Precambrian–Middle Cambrian Hormuz Formation with a total thickness of at least 1000 m (Kent, 1979). This formation only reaches the surface as salt diapirs. Tectonics of Iranian salt diapirs have been the subject of interest by many researchers (Jackson and Talbot, 1986; Jahani et al., 2007, 2009; Kent, 1958, 1979; Talbot, 1979; Talbot and Jarvis, 1984; Talbot et al., 2000) while few is known on karst hydrology of salt diapirs. Bosák (1998) used morphologies and evolutionary stages to classify exposed salt diapirs of southern Iran into three categories: active, passive, and ruins of salt diapirs (Fig. 2). An active salt diapir (Fig. 2a and b) has a positive relief with high height differences (more than 500 m) of the summit, and significant exposure of salt rock. As a diapir is degraded, it evolves into the passive stage (Fig. 2d and e). At this stage the salt diapir has still a distinct morphology with a domed shape, but the height difference has decreased because of following local closure of the source layer and consequent surface erosion. Salt exposures on passive extrusions disappear beneath increasingly thick surficial residual soils that represent accumulations of insoluble impurities left after dissolution of surficial salt. The thickness of residual soil typically increases with the age of salt extrusion and can be used to constrain the rate of salt extrusion and downslope flow (Zarei et al., 2012). After diapirism has ceased, extruded salt is dissolved and transported away so the diapir degrades to ruins composed mainly of non-evaporitic residual sediments. Although limited areas of ruined diapirs might remain uplifts (Fig. 2f), ruined emergent diapirs eventually degrade to breccia chimneys with negative morphology (Fig. 2c).

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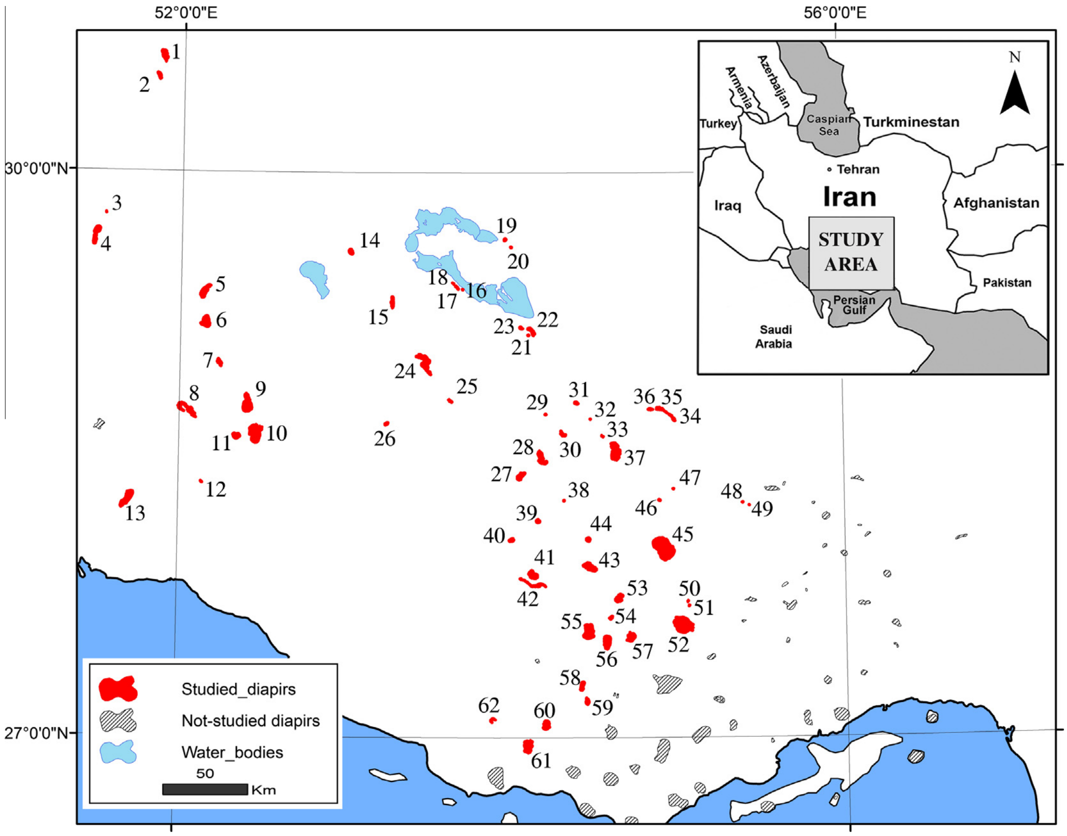

Fig. 1. Distribution of exposed salt diapirs in southern Iran. The numbers indicate the code of 62 diapirs studied in this work. See Table 1 for the name of the studied salt diapirs.

The effects of some individual salt diapirs on water quality in adjacent aquifers in southern Iran have been studied during the past decades, but little attention has been paid so far to how brines from salt extrusions intrude local aquifers. For instance, Raeisi et al. (1996) studied the role of the Sarvestan salt diapir in salinization of the adjacent alluvial Plain. Using hydrochemical investigations, they identified that the salt diapir accounted for the high salinity of groundwater in the alluvial aquifer. The effect of Korsiah salt diapir on the quality of the adjacent alluvium aquifer has been studied by Sharafi et al. (2002). They recognized that the surface saline run off originating from the diapir causes salinization in the southern alluvial aquifer. Lately, Zarei and Raeisi (2010) studied the effect of the Konarsiah salt diapir on the adjacent karstic and alluvial aquifers. They identified that the intrusion of 2 l/s brine from the Konarsiah diapir into the adjacent carbonate aquifer increases the salinity of a karstic spring to about 6000 mg/l.

Brines draining from 122 subaerial salt extrusions contaminate water resources of southern Iran and cause major groundwater salinization in the region. To prevent salinization of groundwater is of significant importance in this arid region with scarce fresh water resources. To achieve this goal, the mechanism of salt diapirs impact on the adjacent aquifers must be taken into consideration first. Therefore, 62 salt diapirs in southern Iran were selected to characterize how these diapirs deteriorate the water quality of adjacent aquifers.

2. Method of study

The geology, geomorphology, hydrology and hydrogeology of 62 emergent diapirs in southern Iran and their surroundings (Fig. 1) were studied from 2010 to 2014 to investigate how they influence the quality of adjacent aquifers.

Geomorphologies: The geomorphologies of the selected salt diapirs were investigated using 1:20,000 or 1:40,000 scale aerial photographs, satellite images and field surveys. The salt karst features of each of the salt diapirs were mapped, especially sinkholes, caves and brine springs, so as to constrain the base level of salt karstification.

Geologies: Geological structures and the exposed geological formations were evaluated using published geological maps, aerial photographs and field surveys. The impermeable and permeable geological units in contact with each salt diapir have been characterized on maps and cross sections.

Hydrology and hydrogeology: Surface drainage networks on each diapir were delineated on 1:25,000 topographic maps and aerial photographs to examine their surface influence on adjacent aquifers. Data gathered by the relevant Fars and Hormuzgan Regional Water Authorities were used in order to evaluate depth to water table, salinity, groundwater type and the flow direction in adjacent aquifers. Equipotential maps and contour maps of the depth and salinity of the adjacent aquifers were used to analyze the influence of each diapir on the local groundwater quality. More than 400 groundwater and surface water samples were taken in the cases where available data were not adequate to assess the role of a salt diapir on the quality of the adjacent water resources. The samples have been analyzed for the major ions including Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-} and HCO_3^{-}, and total dissolved solids (TDS) in the Hydrochemical Lab of Shiraz University.

3. Results and discussion

The results indicate that 28 of the 62 studied salt diapirs have no influence on the quality of the adjoining water resources leaving 34 diapirs that do impact water quality. A conceptual flow model of brine from the diapir into adjacent aquifers has been prepared

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