Earth-Science Reviews 165 (2017) 302–341

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Invited review

Salt usually seals, but sometimes leaks: Implications for mine and cavern stabilities in the short and long term

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ARTICLE INFO

Article history:
Received 10 May 2016
Received in revised form 28 November 2016
Accepted 29 November 2016
Available online 16 December 2016

Keywords:
Salt anomaly
Salt seal
Salt leakage
Salt texture
Salt cavity
Salt mining
Water inflows in mines
Storage cavity
Waste storage

ABSTRACT

Thick evaporite masses (bedded and halokinetic) dominated by the mineral halite, are currently mined using conventional solution mining techniques. After excavation, the resulting salt cavities are sometimes used as subsurface storage vessels for hydrocarbons or various types of waste, including low-level nuclear waste. There are plans being discussed to use purposed-designed solution cavities in thick salt masses for the long term storage of high-level nuclear waste. If high-level nuclear waste is ever to be safely stored in salt, it will involve a need for the encasing salt not to leak over time frames measured in tens of thousands of years. Understanding how, where and why accessible salt masses leak is the rationale for this review. It is the first step in assessing it a particular site's salt geology is suitable for storage.

We know salt can act as an excellent longterm seal over hundreds of thousands of years, as evidenced by its ability to hold back significant columns of highly overpressured fluids, even in structurally complex settings. But we also know that locally salt bodies do occasionally leak large volumes of fluid, as evidenced by the loss of a number of salt mines to uncontrolled floods, the rapid creation of solution dolines atop subcropping salt masses and to black salt haloes around highly pressurized hydrocarbon reservoirs. These types of leakage are usually tied to the edges of a salt body being exposed to longterm crossflows of undersaturated pore waters or to the build-up of internal pressure to levels that exceed lithostatic.

In fact, most zones where a salt body is liable to leak, or has leaked, are indicated by anomalous textural or mineralogical features when compared to the regional character of the salt. The time of leakage can be early (eogenetic), related to burial (mesogenetic) or related to uplift (telogenetic). If the salt mass is not entirely dissolved in the fluid crossflow, then the remaining salt tends to re-seal, especially in zones of ongoing salt flow. However, if non-salt sediment remains in the re-annealed salt mass, it will tend to retain permeability, and when intersected in a salt mine or by a well bore it will flow fluid. More problematic in terms of significant leakage are zones in contact with an aquifer external to the salt mass. These anomalous areas can transfer large volumes of fluid. For this reason, active telogenetic anomalies in a salt mass are the most problematic in terms of both mine safety and waste storage.

Identifying the type of salt anomaly, the time in diagenesis when leakage occurred and proximity and volume of intersected fluids in the zone of leaking salt is fundamental to mine safety and reliable waste storage.

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http://dx.doi.org/10.1016/j.earscirev.2016.11.008
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1. Introduction

In this review, I discuss salt's ability to act as a fluid seal in a variety of bedded and halokinetic settings and how variation in this ability impacts on salt mining and the possibility of using man-made cavities in massive salt bodies for longterm waste storage. We shall consider the macro and microscopic nature of the sealing salt, its evolution during burial, halokinesis, and finally salt's ability to uphold and maintain long term seal capacity.

We shall use the diagenetic classification of Choquette and Pray (1970) in our discussion of poroperm evolution in salt in the subsurface. Their classification, first designed for use in carbonate sediments, divides the diagenetic realm into three zones; eogenetic, mesogenetic and telogenetic. The eogenetic zone extends from the surface of newly deposited sediment to depths where hydrological processes genetically related to surface become ineffective. The mesogenetic zone lies below major influences of processes operating at the surface and is often considered equivalent to the zone of burial diagenesis. The telogenetic zone encompasses uplifted and eroded sediments. It extends from an uplifted and typically eroded surface down to depths where major surface-related geohydrological processes become ineffective. Below a subaerial erosion surface, the practical lower limit of telogenesis is controlled by the position of the watertable and the base of the related surface-driven zone of phreatic meteoric water circulation, it includes both unconfined and confined aquifers. The three terms —eogenetic, mesogenetic and telogenetic— also apply to time, processes, or features developed in their respective hydrological zones.

Texture is important in documenting present and past salt leakage in both the bedded and halokinetic seals. Immediately after it is deposited (as a primary precipitate), a salt bed is both porous and permeable, but primary porosity and permeability are quickly lost during the early stages of burial. Cores collected from a variety of Quaternary-age salt units in continental sumps have lost all effective porosity and permeability by depths of 60 to 100 m (Fig. 1). Salt beds tend to lose primary porosity via ongoing cementation as the basin subsides and the saline sediments accumulate in a longterm brine curtain constructed by reflux brines, typically saturated with respect to $CaSO_4$ and halite. Oscillation in salinity in a holomictic brine body is the main eogenetic process driving both reflux and the associated subsurface halite cements, so inducing loss of primary porosity (Warren, 2016; Chapter 2 for details). Throughout this paper, we shall assume that all the salt deposits under consideration have lost primary porosity during early burial and are essentially impermeable on entering the mesogenetic realm.

2. When salt is a seal

The ability of evaporites to form highly efficient seals is clearly demonstrated by an inventory of instances where significant hydrocarbon reserves are sealed by evaporites (Warren, 2016, Chapter 10). Even though evaporites constitute <2% of the worlds sedimentary rocks (compared to mudstones and shales which comprise 65%), 14 of the world's 25 largest oil fields and 9 of the world's 25 largest gas fields are sealed by evaporites. Unlike thick shales, once a salt bed is buried below depths of a few hundred meters of overburden, subsurface salt better fits Hunt's (1990) definition of a pressure seal. A pressure seal

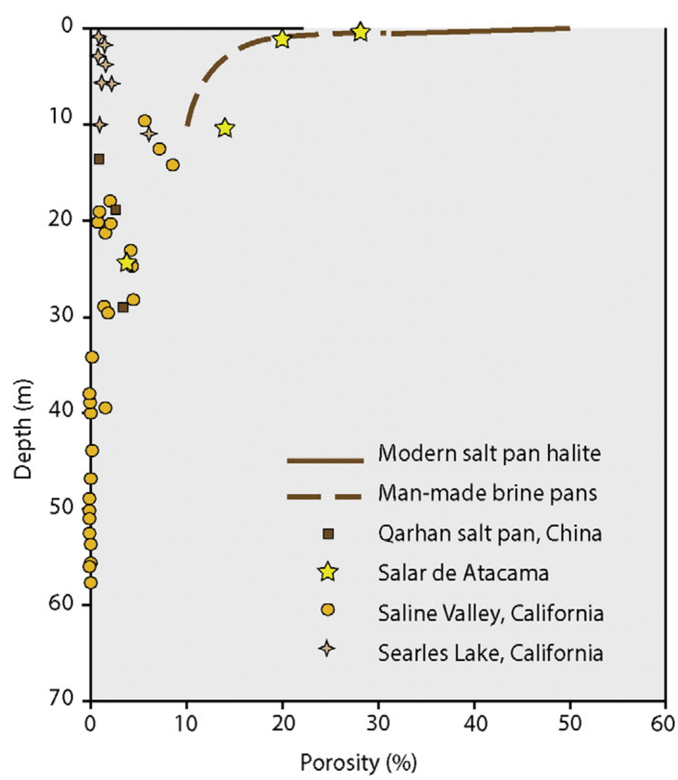

Fig. 1. Primary halite beds have lost effective primary porosity by 70–100 m burial (after Casas and Lowenstein, 1989).

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