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Triassic subsurface evaporites and outcropping solution-collapse breccias of the Ionian zone (Western Greece)

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Deep drilling in search of hydrocarbons and performed in the Ionian zone (Western Greece) has proved the existence of well developed subsurface Early to Middle Triassic evaporites, mainly consisting of halite and anhydrite (IGRS-IFP, 1966; BP, 1971).

Evaporites, recovered from cores in salt bodies at depths ranging from 1000 to 3500m, were texturally studied. Most specimens are layered halites composed of halite crusts dominated by growth-aligned, elongate, subvertical to vertical crystals (Pomoni-Papaioannou et al., 2004). Halite layers are typically rich in clay and carbonaceous material, which implies the development of reducing environment, as does the presence of associated euhedral to subhedral pyrite crystals.

Halite crystal styles in the Ionian evaporites show remarkable similarities to the "seasonal layers" in Holocene halites (saline-pan type). Halite crystals are characterized by curved compromise boundaries, forming a characteristic "puzzle-like" texture. Individual crystals are made up of alternating inclusion-rich and inclusion-free zones. Fluid (brine) inclusions are concentrated in layers parallel to cube faces (100), giving birth to chevron-type halite crystals. Clear halite without inclusions occurs between the inclusion-rich, chevron–type halite crystals. It formed by a combination of preferential dissolution along crystal interfaces in pre-existing halite (due to undersaturated brines), and subsequent precipitation of sparry (inclusion-free) halite in the resulting voids. In some cases the halite crystals seem to have experienced syndepositional fracturing, disaggregation and redeposition (Pomoni-Papaioannou et al., 2004).

Anhydrite accompanies the halite, appearing either as dispersed subhedral to euhedral crystals or as spherical to ellipsoidal nodules. Internally the anhydrite nodules are characterized by mosaics of variable-sized subhedral to euhedral crystals. Argillaceous matrix between anhydrite crystals/nodules is enclosed suggesting displacive poikilotopic growth of anhydrite.

Pleochroic dolomite crystals are concentrated along halite crystal boundaries and brownish clay-rich sutures. Dolomite typically grew on halite crystal surfaces as an early diagenetic mineral but also occurs as pseudomorphs after anhydrite.

Throughout geological time evaporite sediments have formed by solar-driven concentration of a surface or nearsurface brine (Warren, 2009). Halite crusts typically grow contemporaneously beneath shallow at-surface brine sheets, possibly recording annual precipitation. Brine re-concentration can occur via subsequent brine evaporation, but such a process only takes place in brines of relatively small volume. Inclusion-rich zones in halite crystals typically form when brines are over-saturated and crystal growth is rapid. In contrast, reduced brine concentration facilitates slower inclusion-free halite growth. The alternation of inclusion-rich and inclusion-poor zones in halite is an indicator of shallow water precipitation and associated fluctuations in brine saturation. Moreover, the puzzle fabric of halite is unlikely to develop by displacive growth of halite in the host sediment (Pomoni-Papaioannou et al., 2004).

On the other hand, the close association of layered halite with nodular anhydrite cannot exclude the possibility of halite precipitation in a periodically emergent environment, via displacive growth driven by capillary evaporation (Shearman, 1966; Holliday, 1967). Zonal arrangement of the inclusions could then be considered as an indication of fluctuating rates of displacive growth in near surface sediments.

Taking in consideration all the above data, an analogous mechanism to that described by Shearman (1970) is suggested as more appropriate for the Triassic evaporite formations of the Ionian zone, namely initial accumulation in a standing body of brine and subsequent texturally modification in a shallow groundwater zone. In this case, the achievement of the great thicknesses of Ionian zone evaporites would require excessively high rates of relative subsidence.

Triassic subsurface evaporites of the Ionian zone typically crop out as evaporite dissolution-collapse breccias and secondary gypsum outcrops (Pomoni-Papaioannou, 1980; Pomoni-Papaioannou, 1983; Pomoni-Papaioannou et al., 1983). The sedimentological study of outcropping evaporitic material suggests formation by lateral and vertical accretion in supratidal flats and lagoons (Pomoni-Papaioannou, 1985).

Different stages of brecciation have been verified starting during early diagenesis and continuing to post-orogenic "carneulisation" (formation of rauhwackes). And yet the study of the subsurface evaporites shows no evidence of widespread brecciation, only local, minor in-situ pseudo-brecciation attributed to desiccation in subaerial environment (Karakitsios & Pomoni-Papaioannou, 1998). It seems most outcropping evaporite solution-collapse breccias formed telogenetically, mainly in the meteoric zone, and well after the Ionian zone orogenesis.

This accords with outcrop and seismic evidence for widespread halokinesis that began in the Early Jurassic and triggered associated diapirism and inversion tectonics during Ionian basin orogenesis (Karakitsios, 1992; Karakitsios, 1995). According to Karakitsios (2003) and Karakitsios & Rigakis (2007) the pre-evaporitic basement does not participate in the deformation of the sedimentary cover, rather there is major décollement of the sedimentary cover at the evaporitic level. Pre-evaporitic basement is under-thrust by the more internal zones, thus being subject to basement deformation related to continental subduction east of the Ionian zone. This structural style does not allow the formation of the hydrocarbon traps between the evaporites and the pre-evaporitic basement, but it is favourable for subthrust plays in deep compressional duplex structures.

1. Conclusions

Halite crystals of the Ionian evaporites show remarkable similarities with the "seasonal layers" of Holocene halites (saline-pan type).

Chevron-type halite supports accumulation beneath a body of brine, possibly recording annual precipitation cycles. However, its close association with nodular anhydrite cannot exclude the possibility of halite development, in a shallow-water or periodically emergent environment via displacive crystal growth in capillary brines. In this case, the achievement of great thicknesses of the Ionian zone evaporites would require excessively high rates of relative subsidence. Nevertheless, since the studied halite crystals show evidence of mineral replacement and displacement, we suggest a mechanism analogous to that described by Shearman (1970), which includes accumulation from a standing body of brine and subsequent textural modification in the shallow groundwater zone.

Although, Ionian subsurface evaporites have undergone the above mentioned diagenetical processes, they still retain their primary textural characteristics. No evidence of widespread brecciation has been detected in subsurface, except of an in-situ pseudo-brecciation attributed to desiccation in subaerial environment. This observation clearly shows that the outcropping evaporite solution-collapse breccias were formed telogenetically in the realm of meteoric zone and after the Ionian zone orogenesis.

The pre-evaporitic basement of the Ionian Zone does not participate in its deformation of the sedimentary cover, due to a major décollement of the sedimentary cover at the evaporitic level. Pre-evaporitic basement is under-thrust by the more internal zones. This structural style is favourable for subthrust plays in deep compressional duplex structures of the sedimentary cover.

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