

# Saline diapirism, pulsating hydrothermalism and Zn-Pb deposits: the N. Tunisian basin

A. Charef

INRS, BP 95, Hammam-Lif, Tunisia

S. M. F. Sheppard

Laboratoire de Science de la Terre (CNRS, UMR 5570), Ecole Normale Supérieure de Lyon, 69364 Lyon 07, France

Halite-dominant diapirs in sedimentary basins may arrive at or near the water/sediment interface from depths of 10–15 km. They may be mantled by cap rocks (anhydrite-gypsum-calcite) and associated with Zn-Pb-(Sr-Ba) mineralization, oil, gas and/or native sulphur. In N. Tunisia and NE Algeria, most of the >100 diapirs of Triassic salt and cap rocks in the ~300 km long NE–SW trending ~80 km wide dome zone are accompanied by a wide variety of neoformed minerals: quartz, dolomite, magnesite, talc, etc...Igneous enclaves are found in some and may be related to magmatism associated with Triassic rifting. Halite has only been observed by drilling. Reconstruction of the basin is complicated by Alpine tectonics.

## Fluid inclusions

Complex fluid inclusions are trapped in neoformed minerals (Guilhaumou *et al.*, 1981; Charef and Sheppard, 1987; Sheppard and Charef, 1997; this study): (1) primary inclusions (generation I; magnesite) in the system CO<sub>2</sub>-H<sub>2</sub>O-NaCl with a homogenization temperature (Th) peak at ~365°C, (2) primary inclusions (generation II; dolomite 1 & 2, quartz) of N<sub>2</sub> and/or CO<sub>2</sub> gas with others in the system H<sub>2</sub>O-NaCl-KCl ± N<sub>2</sub>-CO<sub>2</sub> representing heterogeneous trapping, with Th peaks at ~260° and ~160°C, and (3) secondary inclusions (generation III; magnesite, dolomite 1 & 2, quartz) of H<sub>2</sub>O-CO<sub>2</sub>-NaCl-hydrocarbons with Th peaks at ~148°, ~105° and ~65°C. Values of δD-H<sub>2</sub>O (SMOW) and δ<sup>13</sup>C-CO<sub>2</sub> (PDB) are, respectively, -18‰ and 0‰ for generation I, -34 ± 10‰ and -1.5 ± 4‰ for generation II at ~260°C, -48 ± 2 and -9 ± 4‰ for generation II at ~160°C, and -70 ± 14‰ and -19.5‰ for generation III.

Several different generations of fluid inclusions are also observed in massive halite, massive anhydrite and vein baryte within both halite and anhydrite from the Fedj-el-Adoum diapir. Because these minerals and their inclusions are easily modified, step heating

and cooling data were only accepted as probably being valid if all the values could be reproduced, the value did not change with time and no volume or aspect changes were observed on returning to room temperature. Also, for a given type of inclusion, dispersion of the measurements was limited. For Th measurements, samples were not heated to higher values to avoid deformation, etc. of the inclusion. No problem was observed with inclusions of monophasic liquid CO<sub>2</sub> or CO<sub>2</sub>-H<sub>2</sub>O-NaCl with V<sub>H<sub>2</sub>O</sub>/V<sub>t</sub> < 0.3. For other types of inclusions, about 10% gave both reproducible results and no metastability problems. About 20% of the halite samples showed evidence for leakage, necking down and/or metastability but these processes were very rare in anhydrite and baryte.

In halite, 4 types of primary carbonic and/or aqueous inclusions occur with 2 secondary types. Carbonic inclusions are only primary whilst hydrocarbon inclusions are only secondary. In the anhydrite, 2 types of primary aqueous and 1 secondary aqueous, and both primary and secondary hydrocarbon types are observed. In baryte 4 types of primary inclusions (carbonic and aqueous-carbonic) and 2 secondary types occur as in halite. Monophasic liquid CO<sub>2</sub>, always associated with other minor constituents (probably N<sub>2</sub>, CH<sub>4</sub> and/or H<sub>2</sub>S), and aqueous-carbonic inclusions in halite and baryte are comparable and primary. These fluid inclusions share certain similarities with some of those in neoformed minerals (generation I and II). However, unlike neoformed minerals, N<sub>2</sub> rich gaseous inclusions are not observed. Additionally, liquid CO<sub>2</sub> inclusions are pure in neoformed minerals. In massive anhydrite, all fluid inclusions are either aqueous or hydrocarbon, primary (similar to generation II) and secondary. Secondary aqueous inclusions in halite and anhydrite are similar to secondary inclusions in neoformed minerals (generation III). Because the acceptable measurements had to meet all of the selection criteria and the values on different samples are consistent, with limited dispersion and comparable for different mineral hosts (halite and baryte), they are considered

to be interpretable and not to be artefacts of the measurement procedures.

The time of last recrystallization of the initially Triassic halite is not known. It may be post-anhydrite cap rock because the same type of baryte fills fractures in both anhydrite and halite. In the classic cap rock formation model (e.g. Sheppard *et al.*, 1997), massive anhydrite represents the recrystallization, in a near-surface environment, of the 1–5% of salt-hosted anhydrite remaining as a residue after dissolution of the halite. The summit of the diapir was being eroded at least by the Upper Aptian, the oldest exposed wall rocks, because neoformed minerals occur in these sediments. If the primary liquid CO<sub>2</sub> and H<sub>2</sub>O-CO<sub>2</sub> inclusions are either essentially contemporaneous or represent the trapping of a continuously evolving fluid, then the pressure has to be about 1.5–2 kbar for a trapping temperature of 200–250°C.

What are the implications of such high trapping pressures following a near-surface erosion history? Although the Fedj-el-Adoum diapir was buried under Upper Cretaceous and Lower Tertiary sediments before re-arriving at the surface by the Upper Eocene, it is not known whether these were equivalent to ~6 km of sediments. Alternatively, the southeastern limit of the probably <6 km thick Tunisian nappes, which are now ~50 km to the northwest, extended over the area.

## Conclusions

Based on the inferred relative chronology of the neoformed minerals and their primary and secondary inclusions, and the primary and secondary inclusions in halite and its cap rocks, several pulses of hot (~365°, ~260°, ~145°, ~105°, and 65°C) fluids of quite variable chemistry (dominated by one or more of the constituents H<sub>2</sub>O, CO<sub>2</sub>, N<sub>2</sub>, NaCl, KCl, hydrocarbons) and distinctive H- and C-isotope compositions circulated within the salt formation and its subsequent diapir and cap rock system.

Because the inclusions in halite, anhydrite and baryte are later than the primary inclusions in the neoformed minerals, the temperatures of the pulsations initially decreased to at least 145°C before increasing to 200–250°C during the late high pressure event. Thermal events at 110° and 70°C associated with the two major Zn-Pb mineralizations at Fedj-el-Adoum (Charef and Sheppard, 1987) are considered to be later than the high pressure event. The H- and O-isotope compositions of generation I fluids are typical of crustal fluids where carbonate is the probable dominant source of carbon. An organic carbon source of CO<sub>2</sub> is unambiguously necessary for generation III fluids together with a probable organic water contribution to the D/H ratio associated with bacterial sulphate reduction reactions (Charef and Sheppard, 1987; Sheppard *et al.*, 1997); organic water was produced during the oxidation of hydrocarbons (oil and/or methane). The intermediate δ<sup>13</sup>C-CO<sub>2</sub> values of some generation II fluids, particularly in quartz, are similar to mantle values, but are more probably of mixed crustal carbonate-organic carbon in origin, in the light of the proposed origins of generation I and III CO<sub>2</sub>. The variations in δD and δ<sup>13</sup>C-CO<sub>2</sub> among the different fluid generations imply that both different source reservoirs within the sedimentary basin and probably its crustal basement and fluid producing processes were active during the various hydrothermal pulsating events which culminated in the formation of a few million ton polyphase Zn-Pb ore deposit.

## References

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