Salt Biostratigraphy: An Untapped Source of Data?

Salt and evaporites in general are often regarded as both an excellent seal for hydrocarbons and an operational challenge to drill through – but they can also be turned into a valuable source of information.

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Biostratigraphy in O&G

Biostratigraphy is a key discipline in hydrocarbon exploration and production as it allows a cost-effective, quick and logistically simple way to determine sedimentation ages and to provide insights into sedimentary environments. From real-time analyses at the rig site to long-term regional-scale studies, biostratigraphy provides vital information to geoscientists in their quest for hydrocarbons. There are now biozonation schemes for most of the Phanerozoic with a resolution close to or under one million years, depending on the stratigraphic interval, fossil group and area of the globe.

Although many fossil groups and biostratigraphic disciplines have stratigraphic relevance, by far the most commonly used in the industry are micropalaeontology (usually referring to foraminifera and to a lesser extent ostracods and other calcitic fossils), palynology (spores/pollen, chitinozoans, dinoflagellates, etc.) and calcareous nannofossils.

These disciplines have been used successfully in the industry for decades. The main reasons for their success is, firstly, the small size of the fossils used in all these techniques – mandatory when the samples are commonly cuttings; secondly, their general abundance, although that is variable depending on lithology and sedimentation environment; and lastly, their rapid speciation and extinction rates, resulting in different fossil assemblages in each stratigraphic interval.

In recent decades high-resolution biostratigraphy with close-spaced sampling has been used as a sequence stratigraphic tool, for example for interpreting shallowing/deepening trends, by typing the characteristic assemblages of each system tract and for the identification of maximum flooding surfaces, hiatuses and sequence boundaries.

In operational geology there are many well-known examples of bio-steering, in which one or more biostratigraphic disciplines are used to guide horizontal drilling in order to keep the borehole within a specific bed (usually the reservoir) that has a characteristic fossil assemblage.

Palynology in particular allows for very detailed palaeoenvironmental interpretations, due to the fact that it studies organic particles derived from terrestrial and marine settings. This is particularly relevant for characterising potential source rocks, as the proportions and characteristics of the various organic particle types are used as indicators of source rock types and potential – a valuable add-on to geochemical analyses. In addition, the sensitivity of organic matter to temperature – it becomes darker with increasing temperature – allows us to estimate palaeo-peak temperatures attained by the rocks that contained the organic particles. Phytoclasts, the small plant remains that palynologists observe, is just another name for vitrinite, the standard material used to determine palaeo-temperatures in sedimentary rocks by measuring its reflectance under reflected light microscopes.

Syn-depositional centimetre-scale fold-and-thrust structures of salt and salt-rich shale layers of the stratified member in the Wieliczka salt mine, southern Poland.

Bas-relief in the Wieliczka salt mine, southern Poland. The magnificent statues and other artistic wonders were carved by salt miners over the centuries in hundred metre-scale hard salt boulders.

Salt: Friend or Foe?

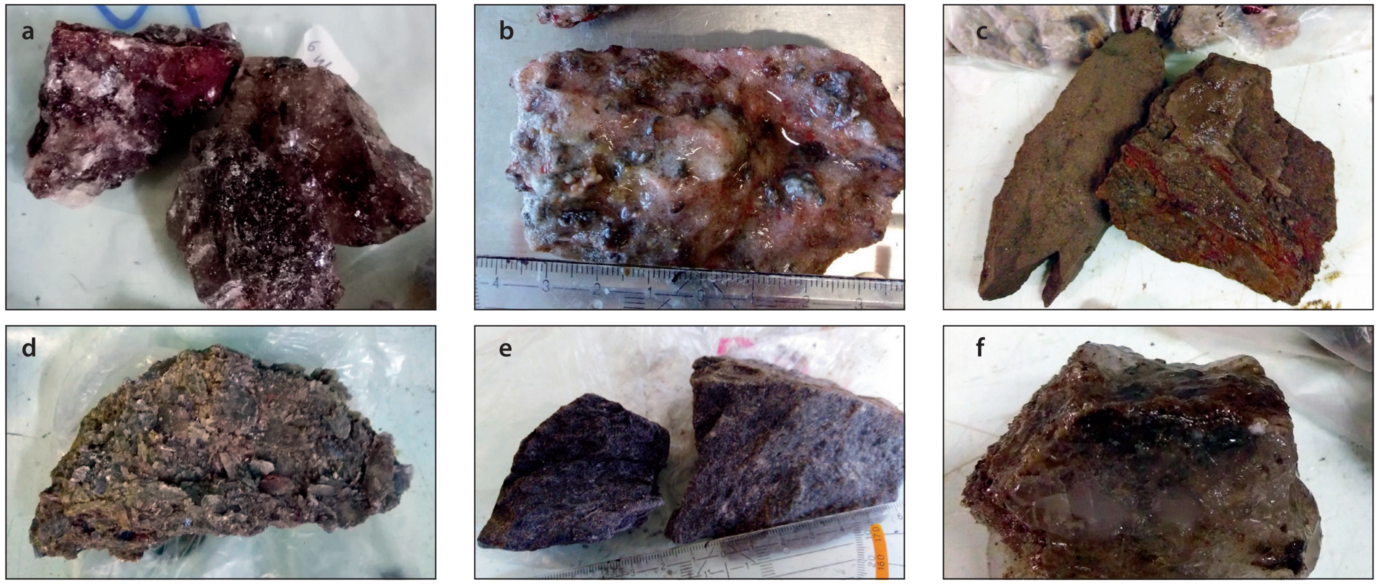
Salt in the form of evaporites plays a key role in petroleum systems, as it acts as an effective seal, greatly influences thermal fluxes and frequently provides effective trapping mechanisms.

In petroleum system analysis, knowing the sedimentation age of the salt layer is critical in order to properly understand basin evolution, timing of fluid flow and trap formation, and the onset of salt movement, among other processes. Similarly, for basin analysis, forward modelling and structural reconstructions, knowledge of the age of the salt layer is extremely important. The sedimentation age of salt is commonly estimated based on the age of the underlying and overlying strata, as seen on seismic and/or from well data. This allows a crude estimation of the age, but is often biased, especially when salt is mobile and the bounding strata mark the stages of salt movement, rather than its sedimentation age. These methods also fail to determine the time span of salt deposition.

What About Salt Biostratigraphy?

There are several ways of dating salt deposits. Geochemical methods have been used recently, but the simplest and most effective way is to use biostratigraphy, specifically palynology. Although typically palynology uses shales and siltstones, many other lithologies are suitable, including evaporites. Along with different salt mineralogies, such as halite, sylvite and gypsum, evaporite sequences usually include impure salts, containing clays and organic matter, as well as shales and carbonates. Palynology sample sizes vary, but usually 100g or less are more than sufficient to obtain significant results, thus well samples are suitable. There are some examples of this usage in salt deposits in the literature, but its use in the oil and gas industry is surprisingly scarce.

Chronosurveys, a Portuguese-based consultancy which specialises in stratigraphy, has refined a method of extracting palynomorphs from evaporites and interbedded sediments. Contrary to usual palynological techniques – which involve aggressive acid attacks, using hydrochloric acid for carbonates and hydrofluoric acid for silicates – organic matter in evaporites is extracted through the dissolution of halite and gypsum with hot water, with



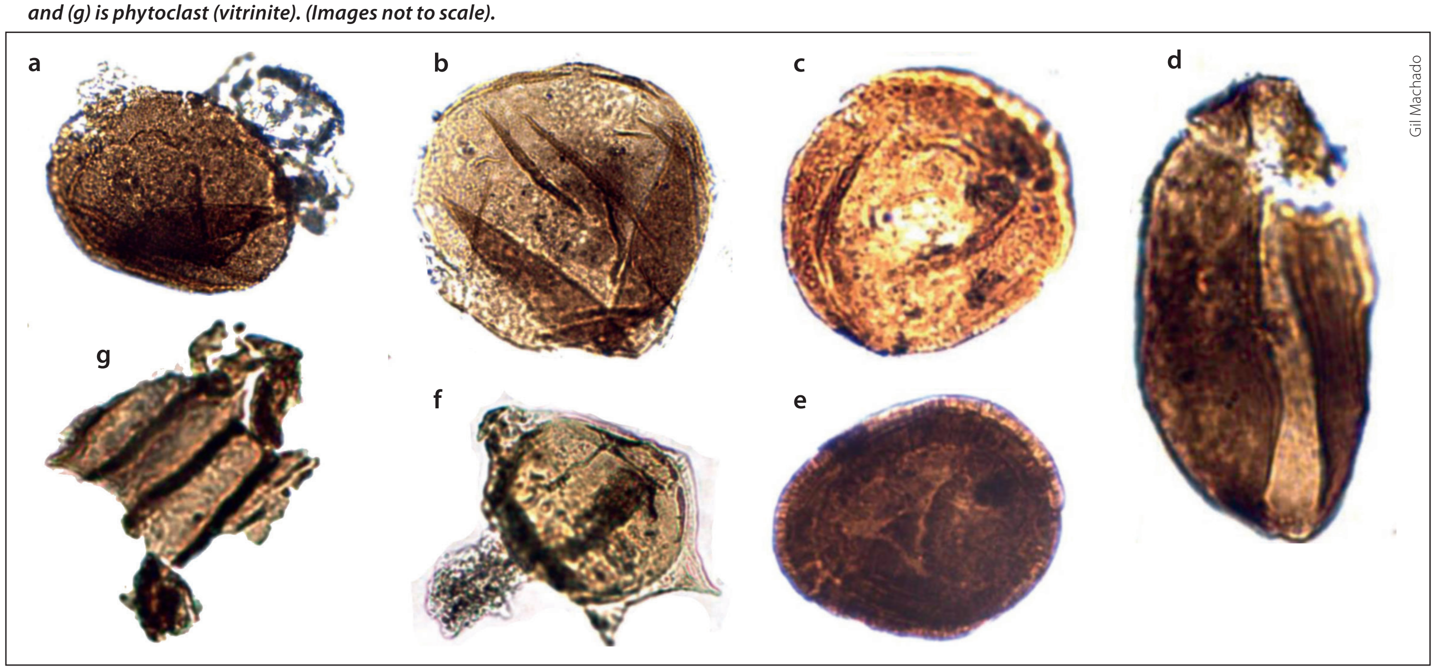
Examples of lithologies with positive palynological results. (a) impure red halite (Souss-Massa mine); (b) impure halite (Loulé mine); (c) green salty shales (Wieliczka mine); (d) granular grey gypsum (Santana quarry); (e) Coaly mudstone (Loulé mine); (f) blackish halite (Wieliczka mine). (Images not to scale).

alkaline solutions applied for other, more resistant evaporitic minerals. Heavy liquid separation greatly helps to improve the quality of the final organic residues to be observed.

This salt biostratigraphy methodology has been tested at five locations using more than 30 samples. The rocks tested included early Jurassic, Miocene and Permian evaporites and associated sediments, with samples taken from outcrops, wells and mines. The sampled locations were:

- Loulé salt mine in southern Portugal, which is in Early Jurassic mobile salt. Impure halite, coaly shales and dolomitised/silicified gypsum were sampled from the mine.
- Souss-Massa salt mine in Morocco – an Early Jurassic non-mobile salt, where core samples from red, pinkish, grey and brown impure halite, grey and red shales were obtained.
- Wieliczka salt mine in southern Poland, which comprises Miocene mobile salt. Several types of salt and interbedded grey to brown shales were sampled. Don't worry, the beautiful salt-carved statues of the tourist route, as shown in the photo on the previous page, were not tested, although samples were taken from equivalent lithologies.
- Zechstein salt in northern Poland, where red and grey shales, impure black halite, dolomites and black shales were sampled from a mine.
- Santana gypsum quarry in central Portugal, where outcrop samples of recrystallised and re-precipitated white-pink gypsum and primary grey gypsum were obtained.

Examples of palynomorphs extracted from evaporites and associated sediments. Images a – e are spores and pollen; (f) is a dinoflagellate cyst; and (g) is phytoclast (vitrinite). (Images not to scale).



Promising Results

Not all samples were successful, indicating that some lithologies and specific evaporite basin settings do not favour organic matter preservation. It is particularly difficult to obtain stratigraphically relevant organic particles from dolomite – a fact known to palynologists for a long time. Heavily recrystallised or re-precipitated halite and gypsum are also difficult samples because, while they can contain organic matter, most particles will be unrecognisable. Crystal size, however, does not seem to have a direct impact on organic matter preservation and samples: evaporite crystals from a centimetre down to sub-millimetre-size produce well-preserved assemblages.

As with other lithologies, the best results can be obtained from rocks with dark grey and black colours – a well-known indication of the presence of organic matter. Nevertheless, good assemblages were also recovered from pink-red impure halite samples.

The success rate using the refined extraction method is comparable to 'normal' non-evaporite routine biostratigraphy. Overall, assemblages are dominated by spores and pollen and other terrestrially-derived organic particles. This suggests that the salt was being deposited or formed in a terrestrial environment or that sea water was only sporadically present. Normal sea water conditions – notably salinity – were probably not the norm as dinoflagellates and other marine organisms are either very rare or totally absent in all the studied samples. Naturally, the palaeoenvironmental interpretation will vary from one locality to the next.

The thermal maturity of samples varied greatly, from very pale-yellow organic particles in the Wieliczka mine samples to dark brown-black in the northern Poland Zechstein samples. All observed samples also contained phytoclasts, or vitrinite, so the palaeo-peak temperatures the rocks were exposed to can be quantitatively determined.

New Perspectives

Salt basins are present in all continents and the vast majority of them contain proven petroleum systems. Salt is often regarded merely as the seal for hydrocarbon traps and a nuisance for drilling operations – but what if it there was a way to obtain valuable information from it? For example, is it possible to know the age of the salt seen on seismic or that of salt that has been drilled through? How long did it take to deposit? What about the stringers within it? Is it possible to calibrate the petroleum systems model with data from within the salt bodies and can the palaeoenvironment where salt formed be understood? Finally, can wellsite geologists know when the base of salt is about to be penetrated?

The tests performed show that samples from quite varied lithologies, ages, thermal maturation degrees and salt deformation stages and from non-mobile to allochthonous evaporites, can produce positive results, as long as the correct extraction method is used. Salt basins around the world, from the stratified salt of the Santos Basin in Brazil to the complex diapirs of the Gulf of Mexico, all have potential to provide valuable data for geoscientists.

Salt biostratigraphy opens a new highway of information, waiting to be untapped! ■