Fossil Content of Salt and Association Evaporites

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ABSTRACT

Known and promising sites of fossil objects in salt and associated deposits include (a) residual brines entrapped in negative crystals of halite (b) liquid inclusions in epigenetic anhydrite (c) oil-stained salt (d) anhydrite-dolomite laminae in banded salt with pyrite and carbonaceous material localized along laminae (e) rock salt with disseminated iron oxides (f) entrapped evaporitic shales in halite (black salt) (g) shales interbedded with halite, gypsum, or associated with polyhalite (h) fissure-filling shales (i) fetid dolomites associated with evaporites (j) laminated anhydrite.

American Silurian and Permian salt deposits have yielded plant debris [Prototaxites (?)] and fossil wood (gymnosperm tracheids). American Permian salt deposits (Kansas) have yielded bacteria, an ostracode valve, a bryozoan statoblast (?), and a suite of spores and pollen. Potash salt from a Texas salt dome, and ferruginous salt cores from Kansas and Oklahoma contained the blue-green alga, Phormidium antiquum. Interbedded shales of the Leonardian Annelly gypsum contain crustaceans -- the clam shrimp Cyzicus, and a suite of spores and pollen. A ferruginous salt core from the British Permian contained iron bacteria, Gallionella, Leptothrix, etc. The Mesozoic hystrichospaerid, Leiosphaera, has been reported from subsurface salt in Alabama. Spores and pollen are found in the European Permian and Triassic salt deposits. Plant debris, reptiles, birds, amphibians, mammals, mollusks, insects, and fish are known from various Tertiary gypsum and salt deposits of Europe.

A relatively unexplored field of salt research is the microbiological study of included fluids, carbonaceous shales, ferruginous salts, etc. Viable bacteria of Permian age have been reported independently by Reiser and Tasch from salt obtained from the Kansas Leonardian and by Dombrowski from German Zechstein salt deposits. Viable bacteria from salts of other ages have also been reported by these investigators.

Another line of research still in its infancy is the palynological study of interbedded and entrapped shales in evaporite sequences. Practical applications include: more precise dating and refined correlation of separated deposits, clarification of the paleoecology, and the developmental history of ancient evaporite deposits.

INTRODUCTION

That high salinities in existing basins act as an ecologic fence to exclude all forms of life was a long-held notion and still persists in many circles. The view has been untenable for at least the past two decades.

BIOTAS OF EXISTING EVAPORATING BASINS

Smith and ZoBell (1937) reported that at least "nine distinct morphological varieties of bacteria occurred with regularity" on slides immersed in water of the Great Salt Lake. Elazari-Volcani (1940) found the following flora in Dead Sea Water: denitrifying bacteria, aerobic cellulose decomposing bacteria, and fibrinolytic bacteria. In mud samples from the sea floor (1940, 1943), he found sulphur oxidizing organisms and glucose fermenters among other physiological grades, as well as a rich algal microflora. Included in the latter were blue-green algae (Aphanocapsa), diatom skeletons (Navicula, Pinnularia, Gomphonema, etc.) and green algae (Duniella). It is important to note that muds of this type will become evaporitic shales interbedded with and/or entrapped in salt deposits of the future rock column.

Another form known to be ubiquitous in the Great Salt Lake, is the brine shrimp Artemia salina, a soft-bodied crustacean belonging to the brachiopod anostracans. Fecal pellets of this form constitute a main component of the bottom sediments (Eardley, 1938). Ciliate protozoans, fly larvae and nine algae (including Aphanocapsa) are also present in this lake (Pack, 1919).

In a marine estuary, Bocana de Virrila (N.W. Peru) gypsum is being precipitated near the head, and in the upper reaches, halite. The biota found with the salt consists of red and green algae and insect larvae. The pink color found in Bocana evaporites and which is also characteristic of evaporating pans along the western coast of Peru is attributed to red algae in the water (Morris and Dickey, 1957; see also Hedgpeth, 1957, Emery and Stevenson, 1957; Johnson and Sparrow, 1961).

Caspers (1957) reviewed what is known of the biota of coastal limans and lagoons of Bulgaria, Rumania, and the Russian Sea of Azov. All of these are hypersaline bodies. Salinity varies seasonally due to evaporation, inflow of fresh water, infiltration of sea water across sand barriers, etc. None of these basins can be viewed as uniformly saline in an areal or volumetric sense since there are brackish marginal zones, stratified upper sweet water zones, and areas of high salt concentration. Corresponding to each of these zones is a characteristic biota. For example, the abundance of some forms, the phytoplankton, in the Sea of Azov, that is, dinoflagellates[1] and diatoms, may reach a count of 4,500,000 per cubic meter. The zooplankton (copepods, cladocerans, tintinnids, barnacle and molluscan larvae) vary in density seasonally. Tintinnids may number as many as fifty million specimens per cubic meter of water. For our purposes, it is unimportant that some of these forms are restricted to the sweet water area, others to brackish marginal areas, and that still others are immigrants or relicts in a cut-off basin. What is significant is the biomass presently represented by such organic individuals in existing hypersaline bodies. Any evaporite deposits forming in such basins that become part of a future rock column will have a considerable organic content and/or numerous protist fossils in interbedded or entrapped clay muds.

Fungi are known from salt lakes such as the Salton Sea (Anastasiou, 1961). A group of fungi called "salt fungi" occur in many existing estuaries and lagoons (Johnson and Sparrow, 1961). Such fungi have been found as fossils in red Zechstein salt (Müller and Schwartz, 1955).

The studies of Smith and ZoBell, Elazari-Volcani, Caspers, and numerous others lead one to expect to find some fossil content in mine salt and associated evaporites in deposits of various geologic ages.

The age of a given salt deposit will, of course, eliminate the possibility of finding fossils of certain forms. For example, the brine shrimp and diatoms will not be found in salts of the Paleozoic. Brine shrimp fossils will not be found in the Mesozoic, since, apparently, they had not yet evolved. The oldest known marine diatom is from the Upper Cretaceous and fresh water forms are unknown before the Tertiary. The occurrence of diatom skeletons in some Tertiary salts cannot be ruled out although none have been reported. In the Great Salt Lake area, the brine shrimp cannot be dated back further than some 600,000 years ago. This estimate is based on

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[1] A hystrichosphaerid is known from one subsurface salt deposit (Woods, 1955). Hystrichosphaerids are a polyphyletic group with some forms representing dinoflagellate cysts. Accordingly, one can expect to find dinoflagellates or their cysts in some salt deposits.

core data published by Eardley, et al., and is derived from the oldest occurrence of fecal pellets in the core.

FOSSILS IN SALT, GYPSUM, AND ASSOCIATED DEPOSITS

Fossil objects found in salt, gypsum, and associated evaporitic deposits may represent either indigenous (authochthonous) components of the biota of a salt sea, lake, liman, lagoon or alien components. The latter were either inswept marine plankton, feeder stream inhabitants, stream transported vegetal debris, wind carried spores and pollen, inhabitants of relict ponds marginal to, or land areas on the periphery of, an evaporating basin, or are represented in detrital biosediments.

Walther (1903) reviewed the reports of fossils found in various Tertiary gypsum and salt deposits of Europe. These included: plant debris (tree trunks, leaves, fruits, pine cones); reptiles (Testudo, crocodiles, tracks); birds (eggs, tracks, etc.); amphibians (frogs); a variety of mammals from rodents to pachyderms; insects (dragonfly larvae, beetles); fish (fresh water Lebias).

In the particular example of the salt beds of Wieliczka, Galicia, the fossil biota in the salt consisted of various plant remains, swarms of small beetles (Ptinus), abundant marine worms, and small undeveloped larvae of marine mussels. The latter represented a planktonic swarm enclosed in the crystallizing salt only to be destroyed.

Pollen and spore assemblages have been found in Triassic salt deposits particularly those associated with black evaporitic shales (Luck, 1913; Klaus, 1953). The red fissure salts of these deposits were found to be sterile (Klaus, 1953). Klaus (1955) and Leschik (1956) extracted spores from the evaporitic shales of the German Zechstein salt deposits (U. Permian, equivalent to our Ochoan). Shaffer (1961) processed shales interbedded with Middle Permian salt (Leonardian) at two Kansas mines and found a rich microflora. Tasch (1962) found spores and other micro-objects, including plant debris, in shales entrapped in Carey mine salt and in shale in-fills of solution cavities.

Potash salts of a Texas Salt Dome (De Golyer, 1925; Powers, 1926), ferruginous salt cores from Kanopolis, Kansas, and a well in northwestern Oklahoma yielded the blue-green alga, Phormidium antiquum (Tilden, 1930).

The Mesozoic hystrichosphaerid, Leiosphaera, has been reported from subsurface salts in Alabama (Woods, 1955).

Other objects found in entrapped Permian mine salt include an ostracode valve and a fragment of an alga found elsewhere in algal reefs of the Wellington formation. Fossil wood (gymnosperm tracheids) were recovered from shale interbedded with this same salt (Tasch, 1960). Shale in-fills subsequently studied by the writer contain abundant gymnosperm tracheids. Dellwig (1955) reported Silurian plant debris resembling Prototaxites in carbonaceous material from the anhydrite-dolomite laminae associated with Salina salt. Shaffer (1962, personal communication) has found a variety of distinctive plant cells throughout the complete fifteen hundred feet of the Salina salt.

Strong (1956) found thread-like bacteria and species of iron bacteria, Gallionella and Leptothrix, in Permian ferruginous crystalline rock salt obtained from a deep boring in northeast Yorkshire, England. These were dead bacteria retrieved from a stored core. He found no organic remains in white rock salt from the same core. Similar bacteria were reported by Rippel (1935) and Müller and Schwartz (1953) from German Permian salt. Strong (1956) also found iron bacteria in the Devonian salt of Saskatchewan, Canada.

Reiser and Tasch (1960) microscopically observed bacteria, that is, inert, diplococcus-like forms, in some salt crystals. They performed a series of experiments to obtain viable bacteria cultures from Permian salt. Carey mine salt yielded one successful culture of bacteria (Idem., Experiment 9). The precautions to prevent contamination were more stringent than those employed by any other investigators that had come to our attention up to that time. However, because of the difficulty of replicating results at will, we preferred to consider our results "suggestive rather than conclusive."

Salts from the Silurian of New York State, Mississippian of Nova Scotia, Jurassic salt from an Humble Oil Salt Dome, and various Tertiary salt dome samples, were also processed. Some samples of each of these salts yielded viable diplococcus-like forms after culturing in broth and 24-hour incubation. (Rieser and Tasch, 1960). Viable flagellate bacteria from the M. Devonian of Canada have since been reported (Dombrowski, 1961, Figs. 4, 5).

The reports of Elazari-Volcani, Smith and Zobell, Strong, Rippel, Müller and Schwartz, and particularly Dombrowski, all tend to increase one's confidence in the findings noted above. An independent verification of bacteria in the Carey Mine salt came from an unexpected source in 1959. Methane gas was found to emanate from one pit newly excavated by the A. E. C. in connection with experiments for the disposal of radioactive wastes. The chemist who discovered this informed the writer that the gas must have been generated by bacterial action.

No petroliferous pockets or oil-stained salt are known from this mine (personal communication, 1962, Leo Reed, mine superintendent). In pockets of oil-stained salt from the Avery Island and Jefferson Island mines, Taylor (1937) noted that when they were first uncovered, there was a seep of "a light amber-colored oil accompanied by methane gas." This report can best be appreciated in light of one by Elazari-Volcani (1943). From core samples of Dead Sea bottom sediments, he found "bacterial growth...in enrichment cultures containing kerosene and petroleum as the only source of carbon." The evidence suggests that the "methane" of both reports cited above was generated by bacterial action (cf. Salle, 1954:357-358 on methane bacteria).

Dombrowski (1960, 1961) reported viable bacteria, Pseudomonas halocrenaea, and Bacillus circulans, as well as other strains, from Zechstein salt.

KNOWN AND POSSIBLE SITES FOR FOSSIL OBJECTS IN EVAPORITES AND PROCEDURES FOR RECOVERY

Without excluding other possibilities, one can indicate known and promising sites of fossil objects in salt and associated evaporite deposits. In addition, procedures for recovery of fossils from each site are given below.

Site A: Residual brines entrapped in negative crystals of halite.

Site B: Liquid inclusions in epigenetic anhydrite.

Procedure: Remove fluid under sterile conditions with an hypodermic needle. Contents of needle should then be released into a sterile broth and incubated. An oil immersion lens should be used to scan for viable bacteria after a drop of broth has been fixed on a slide. (For detailed procedure, see Reiser and Tasch, 1960; cf. Dombrowski, 1960, 1961; Müller and Schwarz, 1955).

Site C: Oil-stained salt.

Procedure: For initial procedure, see Site E below. Since there is a possibility of viable bacteria being present, the sample should be inoculated in sterile broth and incubated, as in procedure indicated for Sites A and B.

Site D: Anhydrite-dolomite laminae in banded salt with pyrite and carbonaceous material localized along laminae.

Site E: Shales interbedded with halite, gypsum or associated with polyhalite.

Procedure: Megascopically examine carbonaceous material for plant debris (Dellwig, 1955: 96-97). Prepare wet mount of crushed carbonaceous debris and apply organic stain (Tasch, 1960: 24-30) to distinguish microscopically cellular plant structures.

Site F: Rock salt with disseminated iron oxides.

Procedure: (1) Dissolve salt to release iron oxide mats. Wet mount and scan for fossil algae and/or salt fungi. (2) Allow thoroughly washed fragment of salt core to melt in distilled water. Organic content will float to top and can be pipetted onto a slide. Wet mounts can be made of either sterilized brine or distilled water. Emerging dead bacteria may be microscopically observed in a small chip of a salt core which has been allowed to dissolve in a petri dish containing distilled water. The scanning magnification should be X250 and X1250. (Strong, 1956.)

Site G: Entrapped evaporitic shales in halite (black salt).

Procedure: Allow crystals to dissolve in boiling water after they have been thoroughly washed. This will release the entrapped shales. Dual processing of completely dried shales may then be attempted. Successive rapid decantings in 1,000 ml. cylinder will release fragments of, or entire megascopic fossils (if any) and mineral content. Palynological processing of another portion of sample will yield any microfloral content present. Interbedded shales of thick gypsum deposits may contain megascopic fossils that require no processing, such as clam shrimps (Tasch, 1961) and can yield a microflora when processed (Shaffer, 1961).

(Shales may also be processed for viable bacteria at Sites G and E, by methods given above.)

Site H: Fissure-filling evaporitic shales.

Procedure: Megascopically examine successively smaller chips for megafossils. The sample may also be processed palynologically for the microflora, if any.

The bituminous matter associated with evaporites represents the organic residue of numerous planktonic organisms that were swept into the evaporating basin from the adjacent sea (for example, Qara Boghaz Gulf, eastern border of the Caspian Sea), or a biota brought in by feeder streams (for example, diatoms brought into the Great Salt Lake), or saprophytic bacteria in the sweet water layers of the Dead Sea (Walther, 1903; Udden, 1924; Eardley, 1938; Elazari-Volcani, 1943; Caspers, 1957). Such residues have been neglected. Thus, two sites require a special approach.

Site I: Fetid dolomites associated with evaporites.

Site J: Laminated anhydrite.

Procedure: Apply paper chromatography techniques to identify the amino acids present, if any. A positive result in this example may have the same index value as fossils.

APPLICATION TO CORRELATION, PALEOECOLOGY, ETC.

Klaus (1953, 1955), Shaffer (1961) and others have attempted to apply spore diagnosis charts in correlation of salt deposits. Such charts are compiled from palynological analysis of samples taken vertically in a given salt deposit and at more than one locality. Tasch is presently attempting to zone an evaporite (Annelly gypsum) using both microfloral content of interbedded shales and megascopic clam shrimp horizons. It would seem plausible that Tertiary salt domes, midcontinent Permian salt, and other widespread salt deposits, may be correlated more exactly by microfloral analysis.

Megascopic fossils, bacteria, algae, and other microfloral content of evaporitic deposits should help to clarify with some precision, the paleoecological setting at the time a given evaporite was deposited (cf. Tasch, 1960). See Addendum, page 102.

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ADDENDUM

Since this paper was written, some pertinent new information has either just become available or been brought to the writer's attention.

Ulrich Jux (The palynologic age of Diapiric and bedded salt in the Gulf Coastal Province. Louisiana Geological Survey, Geol. Bull. #38, 46 p., 1961) described a floral suite consisting mostly of spores but also of pollen and fungi, of late Triassic-early Jurassic age, which was obtained from Gulf salt domes. F. Kirchheimer (Mikrofossilen aus Salzblagerungen des Tertiärs. Paleontographica, B, v. 90, 127-160, 1950) studied Tertiary salt of the Upper Rhone Valley and found a pollen flora. In each of these examples, palynological data helped to shed new light on the age of the salt and/or paleogeography and climatic conditions.

W.T. Holser (Symposium on Salt, Northern Ohio Geological Society, Cleveland, Ohio, Abstracts, 1962, p. 3) found, from a chemical study of brine inclusions in Hutchinson salt, that they represented primary bitterns or residual Permian brines. It was in such Permian bitterns, entrapped in negative crystals of halite, that Reiser and Tasch (1960) first observed dead diplococcus-type bacteria.

G. Claus and B. Nagy (Nature, 193, 11-15, Figs. 4a-b, 5a-c, 1962) reported microfossils embedded in salt (epsomite) of carbonaceous chondrites. The writer had an opportunity to see some of these specimens. They resemble terrestrial protists of the chrysophyte and hystrichosphaerid-dinoflagellate groups. F.L. Staplin [Microfossils from the Orgueil meteorite, Micropaleontology, in press, 1962 (preprint)], after palynological processing of a sample from a carbonaceous chondrite, found that several of the microfossils were closest to the hystrichosphaere-leiosphaere group, while others were closest to the chrysophytes. Footnote 1 of the present paper indicates another report of a leiosphaere-type found in terrestrial salt. The apparent occurrence in both terrestrial and extraterrestrial salts of a similar type of microfossil is of unusual interest.

Dr. Heinz Dombrowski [Bacteria from Paleozoic salt deposits. Conference on the Problems of Environmental Control on the Morphology of Fossil and Recent Protobionta. N.Y. Acad. Sci., April 30-May 1, 1962 (Abstract)] reported viable bacteria from Pre-Cambrian Siberian salt in addition to salts of other ages. In his talk, he presented evidence on the physiological differences between the salt bacteria of various ages and their living equivalents. The Zechstein species, Bacillus circulans, for example, grew in all types of carbohydrate substrates, while the modern form of the same species does not.

The problem as to whether these salt bacteria are truly fossils, awakened to life after tens and hundreds of millions of years of entrapment in buried salt deposits, is still an open one for biologists. Independent verification from many investigators will be needed. Suppose, however, that it turns out that the salt bacteria are modern forms which, via groundwater or other means, invaded the salt and there experienced subspeciation. Suppose, further, that such subspeciation expressed itself not morphologically, but on the physiological level. What then? From a geologist's point-of-view, the existence of physiological types of salt bacteria at different levels in the same deposit and in salt deposits of different ages, would still permit us to use them as "index" fossils for bacterial zonation of evaporites.