References


4.19.3 Salinity from Faunal Analysis and Geochemistry

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Introduction

Salinity is one of the main controls on the distribution of the aquatic biota, and the estimation of palaeosalinities has concerned many palaeoecologists. Most work has involved benthic invertebrates with calcium carbonate hard parts, although palynology has important applications. Fossil occurrences of particular taxa or assemblages may be compared to modern distributions. Alternatively, fossils can be analysed geochemically, as convenient samplers of the waters they inhabited. Sedimentological evidence also should be sought.

The usual result of such studies is an empirical estimate of the palaeosalinity, or range of salinities, experienced by the organisms, and is generally expressed in parts per thousand or in the ’Venice System’ (Fig. 1). The recognition of fully-marine faunas is generally not controversial; nor, in Mesozoic and Cenozoic rocks, is that of freshwater lake faunas. Most palaeoenvironmental interest thus centres on the brackish water and hypersaline faunas of estuaries and other coastal environments, and of saline lakes.

Most brackish systems are labile, and the range and rate of salinity change may have as great an effect as mean salinity. Water bodies whose salinity varies are commonly also variable in temperature, depth, food supply, etc., and are often underlain by soft, organic-rich substrates. Therefore effects on biotic distribution caused directly by salinity are hard to disentangle from those which are due to other controlling factors.

Besides palaeoenvironmental interpretation, more fundamental questions concern: the mechanism(s) by which salinity control operates; whether there is a special brackish water fauna as opposed to merely a reduced-marine one; the evolutionary origin of brackish water faunas; and the relationship of brackish water faunas to the invasion of freshwaters or land by various groups of organisms. On the long time-scale, there is also the possibility that the composition of seawater itself may have changed. Palaeontology supplies essential historical data bearing on these biological and geochemical questions.

Faunal analysis

The normal palaeoecological precautions about working with in situ assemblages obviously apply; in particular, because salinity in estuaries and lagoons can vary so rapidly, the importance of finely-controlled collecting cannot be overstressed. Even so, some time-averaging of fine-scale variation inevitably occurs.

Many higher taxa of plants and animals today are effectively marine-stenohaline and their occurrence, especially in combination, can be used to infer fully marine salinity: viz. corals, cephalopods, echinoderms, bryozoans, articulate brachiopods, planktic and larger benthic foraminifers, and many calcareous red and green algae. Most of these, however, include some partially euryhaline forms extending into polyhaline waters. Only a small number of higher taxa thus account for most of the modern brackish and freshwater shelled fauna, i.e. bivalves, gastropods, ostracodes, smaller benthic foraminifers, and charophyte algae. Non-calcified arthropods are important but seldom preserved except as trace fossils (conchostracans being an exception). Many ‘fish’ are and have been euryhaline, although often also migratory and subject to vagaries of preservation. Even among these groups, few lower taxa have given rise to genera or species tolerant of mesohaline or more dilute waters. Most freshwater taxa are strictly stenohaline.

It follows from these considerations that brackish and freshwater faunas are of low taxonomic diver-
sity and comprise distinctive taxa. Few taxa are specifically adapted to brackish water and most of these are not normally capable of fossilization. They occur along with the more euryhaline members of the marine fauna and in mesohaline waters the latter generally dominate. A few freshwater forms penetrate oligohaline waters. Thus the diversity minimum is generally identified at 5–9% salinity, as first recognized by Remane in the Baltic Sea (Fig. 1). The reasons for this minimum have been much debated. It now appears that it does not correspond to a particularly sharp change in ionic ratios in most estuarine or lagoonal settings. A change from (Na⁺, Cl⁻) to (Ca²⁺, HCO₃⁻) dominated chemistry does, however, occur in more dilute waters in some areas and creates a sharp distinction between marine-derived brackish and non-marine ostracode faunas (Forster & Brouwers 1985). In inland lakes, ionic ratios, more than total salinity, control ostracode distributions (Forster & Brouwers 1983).

Brackish waters are often very productive because nutrients introduced from the land and estuarine circulation, with inflow of enriched subsurface seawater, can turn estuaries into nutrient traps. This combination of high fertility with physiological stress gives brackish water faunas their well known character of containing few species but many individuals. The species tend to be morphologically 'generalized' and the individuals small. This is both because the species are opportunists, r-selected for rapid exploitation of unstable resources and therefore commonly of small adult size, and because populations may contain many juveniles.

The faunas of hypersaline lagoons have some similarities to those of brackish lagoons, and the same major groups are involved. However, the lower taxa are generally different (e.g. miliolid rather than rotaliid foraminifera), and so are the sedimentary facies associations. Saline continental lakes may have different chemistry from seawater and have special faunas. Large inland seas of marine origin, such as the Caspian Sea, are also special cases.

**Geochemistry**

The trace element content of carbonate and phosphate shells must be related to that of the water their bearers inhabited, but there are many chemical, physiological, and diagenetic complications in applying this relationship in fossils. Relationships between the strontium:calcium ratio, for example, and salinity have been established for particular marine taxa and regions, but cannot as yet be generalized. In simple lacustrine settings the strontium:calcium ratio of ostracode shells correlates with salinity (Chivas et al. 1985). The distribution of the stable isotopes of carbon and oxygen, while also not free of complications, has been of more general utility (Dodd & Stanton 1981). The $^{18}O/^{16}O$ ratio in seawater has been rather constant ($\delta^{18}O_{SMOW} = \ldots$)
-1 to 0%; Section 4.19.2), at least since the Late Palaeozoic. Meteoric water is variably 18O depleted (δ18O = −3% in the humid sub-tropics, −50% in polar ice). Dissolved bicarbonate in seawater is relatively 13C rich (δ13CDOC = 0 to 3%); river and lake bicarbonate generally contains carbon derived from the oxidation of plant material, and is thus variably 13C enriched (δ13C = −5 to −12%). In a simple river estuary, therefore, salinity, δ18O, and δ13C are all linearly correlated, and the isotopic variations are reflected in the shells of molluscs living along the estuary (Mook 1971). (Temperature also affects δ18O, as discussed in Section 4.19.2, but seawater–freshwater mixing in a small area generally outweighs the temperature effect.)

These principles can be applied to well-preserved fossils. The best criterion of isotopic preservation is the retention of original aragonite in molluscs. Complications include the fact that δ18O can be increased by evaporation of freshwater as well as by mixing, so that low-salinity water can contain positive δ18O values, as in the Florida Everglades (Lloyd 1964). Humid-region lakes generally have negative δ18O and δ13C values in fossils; arid-zone lakes can be variable in both ratios. Especially in the Palaeozoic, time-related changes have occurred in the δ13C and δ18O of even fully-marine carbonates, making salinity-related changes harder to detect.

Conclusions

By using a combination of facies analysis, diversity studies, and taxonomic uniformitarianism, brackish water faunas of marginal-marine environments can be recognized with some assurance. In Cenozoic and even Mesozoic rocks faunal assemblages can be assigned to specific salinity ranges (e.g. Fürsich & Werner, 1986). Where fossils are well preserved, isotopic analyses provide further quantification. In Palaeozoic rocks, taxonomic uniformitarianism is at best doubtful, and variations in the isotopic composition of ocean water may have occurred. We have the prospect of studying the origin and evolution of the brackish and freshwater fauna that we know today, which goes back at least to the Mesozoic. It is uncertain whether Palaeozoic brackish water taxa (e.g. in the Carboniferous Coal Measures) are the direct ancestors of the modern taxa. We may eventually elucidate the fundamental controls on the nature and history of these successive faunas (Gray 1988).

4.19.4 Oxygen Levels from Biofacies and Trace Fossils

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Introduction

Marine strata deposited in environments characterized by low levels of bottom-water oxygenation are common in the Phanerozoic stratigraphic record. These strata are important as petroleum source beds and as the common host rock for many fossil Lagerstätten, such as the Cambrian Burgess Shale (Section 3.11.2) and the Jurassic Posidonienschiefer (Section 3.11.6). Such strata also act as important indicators of both long- and short-term fluctuations in levels of oxygenation and, hence, circulation rate in the Earth’s oceans. These factors have produced a need for continued refinement of biofacies models that permit the reconstruction of palaeo-oxygenation of ancient basin bottom-waters.