

Stable isotopic constraints on palaeoenvironment, temperatures and fluids, from silica and carbonate phases; East Kirkton, West Lothian, Scotland

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Geological setting

The Lower Carboniferous, East Kirkton Limestone (EKL) is of palaeontological significance as it is host to a unique terrestrial fossil assemblage, including amphibians considered to be the precursors of the first terrestrial reptiles. The EKL probably formed in part of Lake Cadell, an extensive freshwater lake which deposited the sediments of the West Lothian Oil Shale Formation. By late Visean times, Lake Cadell had begun to recede, and it is likely that the lower stratigraphic levels of the EKL document sediment deposition in a smaller body of water which had become isolated from the main lake. During the Lower Carboniferous, this area of Scotland lay at low palaeolatitude, close to the equator.

The East Kirkton Limestone consists mainly of laminated and spherulitic limestone, interbedded with volcanoclastic sediments, and includes thin chert laminae. It is separated from the sedimentary sequences below, and above, by thick units of local volcanic ashes and lava. The next overlying limestone, the West Kirkton Limestone, represents a major marine incursion. Lower Carboniferous volcanic activity in this area occurred in an extensional regime and is typical of continental, intra-plate, alkali basaltic volcanism.

The palaeoenvironmental setting appears to be analogous to the present day setting of alkaline lakes in the East African Rift e.g. Lake Magadi. However, petrography reveals that the depositional environment for silica and carbonate is quite distinct from that of modern, low-latitude, alkaline lakes. Mineral phases and textures which are typical of alkali-rich brines are not present at East Kirkton, and its silica layers are a distinctly primary feature.

Geochemical constraints

There are two main geochemical arguments, based on evidence from stable isotopic analyses, against the East African, evaporitic-alkaline-lake, chert analogy. Fifteen samples of EKL primary silica have $\delta^{18}\text{O}$ spanning 21.3 to 26.9‰ (mean 24.7 ± 1.6 ‰, 1σ): by contrast, significantly higher $\delta^{18}\text{O}$ values are found for magadi-type chert ranging from 32.1 to 44.1‰ (O'Neil and Hay, 1973). The East Kirkton material has therefore been interpreted as a hydrothermal precipitate (McGill *et al.* 1994) rather than a diagenetic transformation to chert from a magadiite-like precursor.

The local isotopic composition of meteoric water is a function of latitude, altitude and geographic setting *inter alia*, and therefore may change significantly over geological time. In a silica $\delta^{18}\text{O}$ against δD diagram, the primary silica from EKL plots close to, and around, the line defined by Devonian and Tertiary agates from Scotland (Fallick *et al.* 1985). This line has a slope of 7.9 and is sub-parallel to that defined by present day meteoric waters, evaporitic trajectories usually have a slope of around 5.

Interpretation.

From consideration of the stable isotope fractionation between measured agate data and presumed parental meteoric waters, Fallick *et al.* (1985) hypothesised a formation temperature of 50–60°C. On the interpretation presented here, such a formation temperature would also apply to the primary silica laminae at East Kirkton and this implies that the Lower Carboniferous meteoric water which fed the East Kirkton lake had $\delta^{18}\text{O}$ of around -3‰, and $\delta\text{D} \sim -15$ ‰, consistent with its low palaeolatitude.

The sediments are also characterised by

unusual spherulitic and botryoidal carbonate, with $\delta^{18}\text{O}$ typically $\sim -7\text{‰}$ P.D.B. (24.9‰ S.M.O.W.) (Walkden *et al.* 1994). Assuming a water $\delta^{18}\text{O}$ of -3‰ S.M.O.W., this implies a formation temperature for carbonates of around 20–30°C. Perhaps growth of these carbonates occurred during quiescent periods outwith the influence of hydrothermal fluid influx. It also seems unlikely that there has been any significant influence of magmatic fluids ($\delta^{18}\text{O} \sim +8\text{‰}$) or fluid with $\delta^{18}\text{O}$ increased through water–rock interaction.

Conclusions.

The stable isotopic composition of primary silica and carbonate are consistent with formation from a plausible Lower Carboniferous meteoric water ($-3, -15$) at warm (50–60°C) and cool (20–30°C) temperatures respectively.

This illustrates the importance of looking at the geochemistry and isotope systematics of as many components of a sedimentary sequence as possible, because different phases may elucidate different aspects of the processes operating.

References

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