A world-wide 2.2–2.0 Ga-old positive $\delta^{13}C_{carb}$ anomaly as a phenomenon in relation to the Earth's major palaeoenviromental changes

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Introduction

The Precambrian isotope excursion of carbonate carbon remains a matter of considerable controversy. Two major problems are discussed here in connection with the secular variation of $^{13}C_{carb}$. The first is: are uniformitarian or unique variations applicable to the Archaean and early Proterozoic isotopic records? The second is, what is the significance of $^{13}C_{carb}$ fluctuations, and the mechanism behind them? These questions are being currently discussed in the scientific literature and still represent challenging problems.

Geological material

The carbonates involved in our study are derived from ten different areas in the Fennoscandian Shield and from two areas in the northern Canada. The $^{13}C_{carb}$ data recently published for the Fennoscandian Shield are also compiled. The Imandra/Varzuga Greenstone Belt and the Pechenga Zone are used as the reference provinces represented by six informal lithostratigraphical subdivisions which are dated by U-Pb (zircon) and Sm/Nd techniques, namely, *Sumian* (2.5–2.42 Ga), *Sariolian* (2.42–2.33 Ga), *Lower Jatulian* (–2.1 Ga), *Upper Jatulian* (2.1–2.06 Ga), *Ludicovian* (2.06–1.9 Ga), *Kalevian* (1.9–1.8 Ga).

Results

$^{13}C_{carb}$ values have been measured from 279 samples from the Fennoscandian Shield, and 14 samples from Canada using standard techniques. Fig. 1 summarises all original ^{13}C determinations as well as the data compiled for southern Karelia and Finland from other studies.

$^{13}C_{carb}$ of carbonates ranges from –25‰ to + 18‰. Histograms reveal two to three maxima at about 9‰, + 2‰, and between + 7‰ and + 10‰. The first maximum represents diagenetic carbonate bands and concretions; the second is similar to normal sedimentary carbonates; the third belongs to carbonates highly enriched in $^{13}C_{carb}$ relative to average 'normal' marine carbonates. On the Fennoscandian Shield the isotopically 'normal' carbonates dominate in pre-Jatulian time, while the $^{13}C_{carb}$-rich carbonates belong to the Lower and Upper Jatulian formations. The isotopically light diagenetic carbonates were exclusively formed synchronously with the post-Jatulian sediments.

A new province with high ^{13}C carbonates dated at around 2.0 Ga has been discovered in the Canadian Shield.

Discussion of results

Almost all investigated Jatulian formations of the Fennoscandian Shiel show an enrichment in $^{13}C_{carb}$ over an area of ca. 800,000 km^2. The Polmak-Pasvik-Pechenga-Imandra/Varzuga-Ust'Ponoy Greenstone Belt, one of the largest on the Fennoscandian Shield, and discontinuously developed over a distance of 1000 km, consistently exhibits positive anomalous values of $^{13}C_{carb}$. It is the most continuous geological structure with positive anomalous $^{13}C_{carb}$ values ever reported.

The general secular $^{13}C_{carb}$ trend on the Fennoscandian Shield demonstrates variation in $^{13}C_{carb}$ from 'normal' marine, averaging around –3‰ (between 2.6 and 2.2 Ga), with a rapid excursion to positive $^{13}C_{carb}$ values of around + 5‰ to + 8‰, which are followed by isotopically light and 'normal' carbonates. The positive excursion is bracketed between 2.2 and 2.06 Ga. Thus the duration of the latter event as a whole is around 140 Ma which is about 700 times the residence period of carbon in the modern ocean (2×10^5 a, Schidlowski and Aharon, 1992). A high-resolution time-scale cannot yet be constructed for this period. This makes it uncertain whether the Jatulian phenomenon represents a large-scale single positive excursion in ^{13}C or a series of medium- to small-scale excursions.

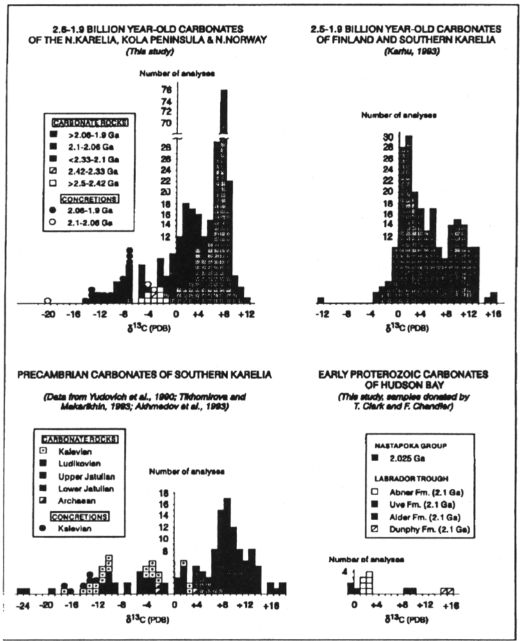

FIG. 1. Histograms of $\delta^{13}C_{carb}$ of Precambrian carbonates.

As is well known, the operation of the carbon cycle can be monitored through isotopic mass balance: $\delta_{in} = f_{carb}\delta_{carb} + f_{org}\delta_{org}$. In the Fennoscandian Shield, over a period of 140 Ma, carbonates are characterised by an average δ_{carb} value of +5‰ which can indicate a value for f_{org} of 0.4. This is twice the 'normal' burial rate. Assuming the Jatulian 'heavy carbon phenomenon' to be a global event caused by perturbation in a vast carbon reservoir, resulting in subsequent disequilibrium of the carbon cycle and a complementary release of oxygen, this process should have phenomenal reverberations on the sedimentation and diagenesis as well as on the interrelated sulphur, oxygen, and iron cycles.

Evidence for the global carbon cycle perturbation

Carbonates with isotopically heavy carbon are common in the geological record between 2.2 and 2.0 Ga. The list of provinces includes the Lomagundi Belt, (Schidlowski *et al.*, 1976) and the Francevillian Series (Gauthier-Lafaye and Weber, 1989), Africa; Fennoscandian Shield (Baker and Fallick, 1989*a*; Yudovich *et al.*, 1990; Karhu, 1993; this study); Scotland (Baker and Fallick, 1989*b*); Australia (McNaughton and Wilson, 1983); Labrador Trough, Canada (this study).

The 2.2–2.0 Ga-old 'heavy carbon phenomenon' was preceded by the 2.3 Ga-old world-wide Huronian glaciation and coincides in time with the following major events: (1) continental rift expansion; (2) development of carbonate platforms ; (3) high diversity and abundance of stromatolite taxa; (4) the first stromatolite reef development; (5) widespread formation of dolomite; (6) the first pronounced evidence of evaporite formation; (7) sedimentary phosphate accumulation; (8) world-wide 'red beds' development; (9) definite Fennoscandian excursion of heavy ^{34}S of both sulphate and sulphide; (10) the first development of diagenetic concretions with highly oxidised iron and manganese, and carbonate concretions as a result of C_{org} oxidation.

Conclusions

The early Proterozoic $^{13}C_{carb}$ excursion together with a series of major global palaeoenviromental changes resembles but is more intense than the Precambrian/Cambrian transition events. All these can be understood within a framework of the irregular cyclic oxidation of the Precambrian hydrosphere-atmosphere-lithosphere terrestrial system.