

18. Stable Isotope Ratios and the Dynamics of Caliche in Desert Soils

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Introduction

Calcium carbonate is deposited in the soils of arid and semi-arid regions, where it forms calcic or petrocalcic soil horizons that are often known as caliche. When the parent materials are calcareous, massive deposits of secondary carbonate may form through the dissolution and reprecipitation of the parent minerals. However, caliche also forms on noncalcareous parent materials, as calcium derived from the weathering of aluminosilicate minerals or from atmospheric deposition is carried into the soil profile by the downward percolation of rainwater. Caliche is ubiquitous in the arid regions of all continents and forms a major pool in the global carbon cycle (Schlesinger 1982). The rate of deposition is typically 1.0 to 3.5 g CaCO₃ m⁻² yr⁻¹ (Schlesinger 1985). Soil carbonate progressively develops indurated horizons that are designated as B_{km} (Gile et al. 1966). As a prominent soil layer, caliche is important to the structure and function of desert ecosystems through its control on plant-water relations (Cunningham and Burk 1973), plant distributions (Hallmark and Allen 1975), primary production (Burk and Dick-Peddie 1973), and phosphorus nutrition (Musick 1978).

Stable isotope ratios, ¹³C/¹²C and ¹⁸O/¹⁶O, are widely used to interpret environmental conditions during precipitation of marine carbonates. Similarly, it is tempting to use this approach to elucidate the processes leading to the formation of caliche. This approach is difficult in regions of calcareous parent

materials, because the measured ratios are derived from a mixture of parent and secondary carbonate. Nevertheless, several studies have used differences in the stable isotope ratios to distinguish the proportion of parent and secondary carbonate in the soil profile (Salomons and Mook 1976; Rabenhorst et al. 1984). In the present paper, we review studies of stable isotopes in soil carbonates and offer some preliminary data from our current studies of how biotic processes may affect the formation of caliche and its stable isotope content.

Stable Isotope Content

Talma and Netterberg (1983) compiled many of the available data on $^{13}\text{C}/^{12}\text{C}$ and $^{18}\text{O}/^{16}\text{O}$ ratios in soil carbonates. Stable carbon isotopes average -4‰ (vs. PDB) with a range of -12 to $+4\text{‰}$ among 303 samples. Thus, soil carbonate is typically depleted in ^{13}C compared to marine limestones that average $\pm 0\text{‰}$ vs. PDB. Stable oxygen isotopes range from $+21.6$ to $+34.0\text{‰}$ (vs. SMOW), averaging $+26\text{‰}$ over 155 samples. This range spans that of marine carbonates, in which variations in the ratio of oxygen isotopes are strongly dependent upon the temperature at the time of precipitation.

Comparisons among samples from different areas suggest some broad correlations between the ratio of stable isotopes in soil carbonate and the environmental conditions at the time of deposition. Talma and Netterberg (1983) reported a tendency for greater $\delta^{18}\text{O}$ in soil carbonate from regions of low mean annual rainfall. Cerling (1984) showed a strong correlation ($r = 0.98$) between

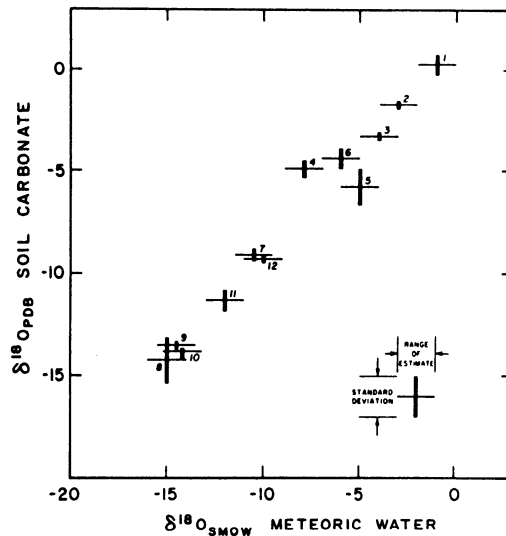


Figure 18.1. Oxygen isotope composition of modern soil carbonate as a function of the estimated isotopic composition of meteoric water in each locality. From Cerling (1984). For conversion to SMOW, add approximately $+31$ to PDB values.