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Indications of Late Holocene Climate Change from Stable Isotope Variations in Soil Organic Carbon, Pedogenic Calcite and Land Snails from the Southern Great Lakes Region, Canada

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Late Holocene climate change in the southern Great Lakes region of Canada has been investigated for a sand-dune chronosequence located along the southeastern shore of Lake Huron. As the lake regressed over at least the last 5,000 years, a series of dunes were developed parallel to the shoreline. We sampled organic carbon, pedogenic calcite and land snails from soils that formed at various stages of this regression. Stabilized younger dunes are covered presently by open vegetation, mostly grasses and some shrubs; older dunes are vegetated mostly by trees. Mean monthly temperatures are 13-21ºC in the summer and -6 to 0ºC in the winter. Precipitation is spread evenly throughout the year at 70-100mm per month. Soil samples were taken from pits at four sites, which represent conditions at about 5,000 (Site V), 3,000 (Sites III [slack] and IIIB [crest]) and 1,000 years before present (Site I). In all cases, the top 0-10cm have organic carbon contents of 0.2-2%; the highest values occur in forested areas, where the contribution of modern leaf litter is highest. The organic matter content drops sharply with depth to <0.05%, except for charcoal-rich horizons at Site I, in which much higher values are encountered.

The stable carbon-isotope values of organic matter exhibit a wide range, -27 to -18 per mil (VPDB) that is distributed systematically within each soil profile. At <30cm, the compositions trend towards lower values that increasingly reflect the addition of modern organic matter to the top soil (-26.5 per mil at the C3-dominated forested sites [V, III, IIIB] and -21.5 per mil at the mixed C3-C4 grass-dominated site [I]). At >90 cm, the stable carbon-isotope compositions of organic matter at each site again begin to decrease, with the lowest values (-25 to -23.5 per mil) occurring at or near the bottom of each pit (120-150cm). These compositions reflect a strong bias towards preservation of roots from C3 vegetation at such depths. At each site, the samples most enriched in carbon-13 occur within the 30-90cm interval of the soil profile. At these depths, the influence of modern roots on organic matter content is minimized. The maximum stable carbon-isotope values in any one profile, generally at ~60-70cm depth, range from -23.5 per mil at Site V, to -22.5 to -21.5 per mil at Sites III and IIIB, to -19.5 per mil at Site I. We interpret this behaviour to indicate an increase in the abundance of C4 vegetation from 5,000 to 1,000 years before present, and propose that the climate changed from wetter (and perhaps cooler) to drier (and perhaps warmer) over this time.

The coarse-grained nature of the sandy soils allows rapid percolation of water, and the uppermost portions of all profiles have been decalcified, generally to greater depths with increasing age. Nevertheless, biomineralization of calcite has occurred in localized microenvironments, particularly at >80cm. Its crystallization was facilitated by cyanobacteria and the presence of organic matter. The pedogenic calcite generally has stable carbon-isotope compositions (-6 to 0 per mil) that are higher than predicted to be in equilibrium with the soil organic matter. Instead, this calcite has utilized carbon derived from both organic matter and detrital carbonate, with contributions from the latter source increasing as the soil profiles become younger. The oxygen-isotope compositions of the pedogenic calcite increase systematically from about -9 per mil (VPDB) at Site V to -6 per mil at Site I. This change is consistent with the shift expected in the oxygen isotopic composition of local precipitation (and the soil water derived from it), as the climate evolved from wetter to drier. This conclusion is supported by oxygen-isotope data for the aragonitic shells of land snails. Snails from Site V have compositions of -9 to -7 per mil. The range extends to higher values at Sites III and I (-9 to -4.5 per mil), with the average values most enriched in oxygen-18 being obtained for snail shells from Site I. Such isotopic behaviour is best explained by decreasing relative humidity from 5,000 to 1,000 years before present time.