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DOES THE SEDIMENTOLOGY OF THE CHELMSFORD FORMATION PROVIDE EVIDENCE FOR A METEORITE IMPACT ORIGIN OF THE SUDBURY STRUCTURE?

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The post-"event" fill of the Paleoproterozoic Sudbury Basin consists of at least 600 m of deep-water mudrocks of the Onwatin Formation, overlain by 850 m of lithic-arkosic muddy sandstones in the Chelmsford Formation. While mudstones of the Onwatin reflect deposition in a deep-water, anoxic setting, there is no clear evidence of local breccias, conglomerates, or sand bodies to support the concept that the basin was protected by the steep walls of an impact crater. Carbonates in the basal, Vermillion Member are of sedimentary exhalitive origin and were not derived from a shallow marine shelf. Turbidites in the Chelmsford Formation show no evidence of centripetal fill as might be expected from a restricted, circular basin. They appear to have been emplaced by predominantly southwest-erly flowing turbidity currents, which showed little to no deflection along the depositional axis of an elongate foreland basin that developed in front of the rising Penokean mountain chain.

While the presence of minor sandstone-filled fractures in parts of the Chelmsford Formation suggests the presence of north- or south-directed paleoslopes, no evidence is seen to support the existence of subbasins or a central uplift within the Sudbury Basin. While tilt-corrected paleocurrent orientations are ambiguous, due to postdepositional shortening of strata during cleavage development, strain correction of the observations makes little difference to the net, south-southwest-directed paleoflow.

IMPACT ORIGIN OF THE SUDBURY STRUCTURE: EVOLUTION OF A THEORY.

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This paper reviews the origin, development, and present status of the widely accepted theory, proposed by Robert S. Dietz in 1962 [1], that the Sudbury structure was formed by meteoritic or asteroidal impact. The first publication leading to Dietz's proposal was the suggestion by Hamilton [2] that the Sudbury Igneous Complex (SIC) was an extrusive lopolith, covered by its own silicic differentiates (the Onaping Formation, then considered a welded tuff). Hamilton's interpretation was applied by Lowman [3] to the problem of how parent rocks similar to tektites in composition could be formed on the Moon, tektites assumed to be of lunar origin. Lowman proposed that the lunar maria were extrusive lopoliths, analogous to the Bushveld, Sudbury, and Duluth Complexes, and that tektites were derived by impact from rhyolites surfacing the maria, analogous to the silicic differentiates of lopoliths. The lopolith-mare analogy was interpreted by Dietz to imply that the terrestrial lopoliths, like the circular maria, were large impact craters, and should have associated shatter cones. Dietz then searched for, and found, shatter cones in Huronian metasediments on the south side of the Sudbury structure. It is stressed that this was a predictive discovery, not a chance one. Dietz then proposed that Sudbury was a small terrestrial mare basin. It was shown, however, by B. M. French [4] that the Onaping Formation was a metamorphosed fallback breccia rather than a welded tuff. Although contradicting Dietz's impact-triggered extrusive lopolith hypothesis, French's

convincing demonstration of shock metamorphism put the impact mechanism on firm ground. Detailed field and laboratory studies in following years by Peredery, Dressler, Guy-Bray, Dence, and many others greatly strengthened the impact theory, which is today widely though not universally accepted by geologists familiar with the Sudbury area.

Following publication of the monumental *The Geology and Ore Deposits of the Sudbury Structure* [5], several lines of study have clarified the origin and evolution of the structure and the intrusive complex. Isotopic analyses by Faggart et al. supported the earlier proposal by Dence that much of the SIC might be impact melt rather than internally derived igneous rock. Impact modeling by Grieve et al. [6] also supports this mechanism, showing that the SIC average composition is close to that of local granite-greenstone terrain with a small proportion of Huronian cover rock. The size and shape of the original impact crater remain open to debate. An imaging radar and field study by Lowman [7] supported the interpretation by Rousell that the original crater had been elliptical, though made more so, since its formation, by the Penokean orogeny. However, primary elliptical impact craters do exist on the Moon and Mars, and ellipticity should not be considered an argument against impact. The predeformation shape of the crater was reconstructed by Shanks and Schwerdtner using finite-element modeling methods, which indicate that the predeformation structure was 2 to 3 times wider (northwest-southeast), i.e., nearly circular. A LITHO-PROBE survey carried out in 1991 [8] supported the Shanks-Schwerdtner interpretation to the extent that the South Range Shear Zone, in which the deformation was concentrated, was traced at depth by reflection profiling.

The impact theory for the origin of the Sudbury structure seems supported by a nearly conclusive body of evidence. However, even assuming an impact origin to be correct, at least three major questions require further study: (1) the original size and shape of the crater, before tectonic deformation and erosion, (2) the source of the melt now forming the Sudbury Igneous Complex, and (3) the degree, if any, to which the Ni-Cu-platinum group elements are meteoritic.

The history of the impact theory illustrates several underappreciated aspects of scientific research: (1) the importance of cross-fertilization between space research and terrestrial geology, (2) the role of the outsider in stimulating thinking by insiders, (3) the value of small science, at least in the initial stages of an investigation, Dietz's first field work having been at his own expense, and (4) the value of analogies (here, between the Sudbury Igneous Complex and the maria), which, although incorrect in major aspects, may trigger research on totally new lines. Finally, the Sudbury story illustrates the totally unpredictable and, by implication, unplannable nature of basic research, in that insight to the origin of the world's then-greatest Ni deposit came from the study of tektites and the Moon.

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