COULD THE ORIGINAL SUDBURY STRUCTURE HAVE BEEN CIRCULAR?

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The Sudbury Structure (SS) of the Canadian Shield, one of the oldest (1.85 Ga) and largest (~200 km) impact features on earth, encompasses a unique igneous complex with a closed elliptical surface expression (1-3). Uniform paleocurrent trends observed in the Chelmsford turbidite (4), the upper unit of the sediments filling the igneous complex, have been interpreted to mean the structure was never circular (5,6). As an impact origin would require an initially circular structure, Sudbury’s genesis has been controversial for more than a century (7,8). Herein we present new high-resolution seismic images which provide the first evidence for the relative timing of the deformation events that reshaped the initial Sudbury Structure. The seismic images have revealed that the lower unit of the Sudbury basinal fill sediments, the Onwatin argillite, is penetrated by a set of imbricated thrusts, whereas the overlying Chelmsford turbidites are unaffected. By proving that the deposition of the Chelmsford turbidites postdates the major deformation of the SS, our seismic results strongly support the impact origin.

A coordinated geoscience effort, spearheaded by seismic reflection profiling as part of the multidisciplinary Canadian Lithoprobe program was initiated to study the SS during 1991-92. Three high-resolution vibroseis reflection profiles were acquired across the SS. The preliminary results show that the Sudbury Igneous Complex (SIC) is highly deformed and markedly asymmetric at depth, suggesting considerable N-S shortening (9). Intensive reprocessing of the seismic reflection data was rewarded with a substantially enhanced seismic image across the entire SIC to a depth of ~12 km, warranting a new, more detailed, structural interpretation.

Beneath the North Range, most lithologic units are well marked by distinct, south-dipping (20°-30°) seismic reflections, in excellent agreement with borehole logging and geologic data from the vicinity of the seismic profiles. The contact between norite and the Levack gneiss, defining the SIC floor, is the most continuous feature and can be traced to a depth of ~12 km under the South Range, suggesting the original S-W diameter of the SIC could be twice larger.

The South Range is characterized by numerous, steep, south-dipping reflections. Prominent reflectors project up-dip to surface-mapped faults (10). The deepest reflections can be traced upward to the boundary between the Onaping and Onwatin and project into the Cameron Creek fault (CCF). Considering the surface geologic pattern, the subsurface geometry of these south-dipping reflections, and the manner in which they penetrate the contact between the Onaping and Onwatin, we interpret these faults as part of an imbricate thrust system. The CCF was the basal detachment surface along which NW-SE shortening took place. The observed offset of lithologic contacts by up to 5 km at the southwest closure of the SIC, is the surface manifestation of the thrust-faulting. In contrast to the North Range, correlation of reflections with lithologic units under the South Range is more difficult, consistent with the well-established view that the South Range has undergone deformation.

The Sudbury Basin is conspicuous in the seismic section. The contact between the Chelmsford-Onwatin Formations appears continuous with a steep inward dip (~50°) at the south and a shallow dip (~15°) at the north. The Onwatin-Onaping contact is progressively offset in the south with staircase geometry, consistent with the south-dipping thrusting and indicating that the Onwatin Formation deposition predates the thrusting. The southern contact of the Chelmsford with the Onwatin, however, appears to be unaffected by the thrusting, implying that the Chelmsford turbidites were deposited after the thrusting event or during its final stages.
Two main aspects of the seismic image shed new light on the tectonic history of the SS. First, by clearly defining a major imbricated thrust zone, the seismic data establish that brittle thrust-faulting played an important role in NW-SE shortening of the SS. This brittle deformation has economic implications as the Sudbury Sublayer, an important ore-bearing horizon at the base of the norite, may be duplicated at shallow depths at the southwest corner of the SIC. Second, the relatively undeformed nature of the Chelmsford-Onwatin contact, together with the uniform W-SW paleocurrent trend in the Chelmsford, confirms that the Chelmsford turbidites were deposited in an elongate, not circular, basin. Moreover, the seismic image shows that the discrete thrusting must have taken place after ductile deformation of the SIC, but before the deposition of the Chelmsford. Thus, the paleocurrent direction in the Chelmsford is unrelated to the initial shape of the Sudbury Structure. This, combined with the observed extent of the North Range SIC at depth beneath the South Range, provides quantitative evidence that the initial SIC could have been circular.

Based on the new seismic image and the available geologic data, we speculate the following tectonic deformation sequence (Fig. 1) which created the present Sudbury Structure. The basic assumption underlying the sequence is that immediately after the catastrophic impact event, the SS comprised a stack of horizontal tabular units including the Onaping breccia blanket and the molten granophyre, gabbro, and norite of the SIC. Subsequent northwest compression deformed the original SS into a tight fold, probably during the early stages of the poorly understood 1.8 Ga Penokean Orogeny. This large-scale folding caused the first-order NW-SE shortening of the SS and is manifest today by the South Range shear zone (SRSZ). After the folding, the Onwatin argillite, composed of reworked Onaping, was deposited. Discrete NW-SE thrusting took place during the late stages of the Penokean Orogeny, causing further shortening of the SS. The North Range acted as a foreland and largely escaped deformation. The deposition of the Chelmsford turbidite followed the thrusting.

REFERENCES

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