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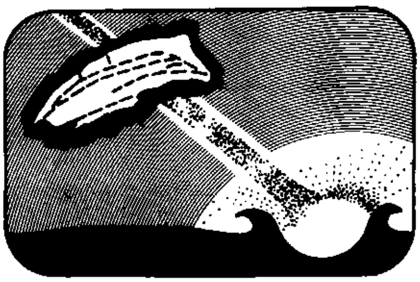
Discussions

Editor's Note

In previous issues, discussions were confined to "Letters" to the Editor. However, as the two printed in this issue are not suitable to the letter format, I have created a new section. I welcome others to submit discussions on articles that have already been published in *Geoscience Canada*, but I will exercise my editorial prerogative to publish as a letter or in this section.



Sudbury and the Meteorite Theory

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' "No data yet" he replied. "It's a capital mistake to theorize before you have all the evidence. It biases the judgement" '. Spoken by Sherlock Holmes to Dr. Watson in a hansom cab on the Brixton Road.

Investigators of Sudbury geology have not followed the injunction of the consulting detective and whether all the evidence is now at hand, or ever will be, seems unlikely. Almost every aspect of Sudbury Geology has been disputed and there exists a massive, scattered, and conflicting literature the comprehension of which is a formidable task in itself. The student of Sudbury geology is hampered by the lack of an up-to-date compilation. Existing published maps, on a reasonably large scale, lack many known features.

A fundamental conflict is the origin of the basin. There are two rival hypotheses: the classical volcanic theory first suggested by Bonney (1888) and the astrobleme theory proposed by Dietz (1962). Adherents to the volcanic theory are mainly field geologists who were impressed by the apparent volcanic nature of the Onaping Formation. Supporters of the astrobleme theory include specialists in lunar and terrestrial impact studies as well as some geologists in the mining industry. The proponents of the astrobleme theory were in a majority during the symposium on Sudbury geology held a decade ago (Guy-Bray, 1972). Since that time, apart from Pattison (1979), little fresh information on the origin of the basin has appeared. The volcanic school has made occasional attacks on data supporting the astrobleme theory (Fleet, 1979; Stevenson and Stevenson, 1980) while the astrobleme school has maintained a rear-guard action (Pattison, 1980).

This discussion is in response to a paper by Stevenson and Stevenson (1980) who argue that the proof of the origin of the Sudbury Basin by meteorite impact depends largely on two features, namely planar lamellae in quartz and shatter cones. They suggest that these features may be formed by processes other than shock metamorphism. Several other aspects of Sudbury geology, which must be considered in the formulation of any theory of basin origin, are omitted from the paper.

Planar lamellae in quartz, formed by strain rates slower than hypervelocity impact, are known as Böhm lamellae. These differ appreciably from planar features formed by shock metamorphism and the two types can be distinguished on the basis of multiplicity, orientation, distribution and fabric (French, 1967). Moreover, microstructures present in the Onaping Formation, considered indicative of shock metamorphism, are not limited to planar features in quartz (French, 1967, 1972). They also include: multiple sets of decorated planar lamellae in feldspar; glassy veins in granite fragments and attributed to sudden fusion; single feldspar crystals which appear as a deformed mosaic of disoriented crystallites and which contains veins considered to represent localized melting; and feldspar grains that are bent or distorted through large angles "looking as though they had been squeezed out of a toothpaste tube" (French, 1967, p. 31).

According to Dietz (1968) the intensity of shock-waves which form shatter cones ($\sim 35 \times 10^5$ kPa) are of a magnitude seldom, if ever, produced by volcanic explosions ($3\text{-}5 \times 10^5$ kPa). Explosions of enormous magnitude took place at Krakotoa (1883) and Thera (circa 1500 B.C.) but to the writer's knowledge shatter cones were not formed. Stevenson and Stevenson (1980) note that conical fractures have been found at settings other than meteorite craters and they refer to conical fractures formed by deformation of concrete in laboratory tests. The latter lack the horse-tail patterns characteristic of shatter cones.

Theories of basin origin are strongly influenced by the interpretation of the enigmatic Onaping Formation (Table I). A felsic breccia, as much as 100 m in thickness, occurs at the base of the formation. Felsic fragments are up to 80 m in length (Peredery, 1972; Stevenson, 1972). This unit has been interpreted as conglomerate, a volcanic rock, tectonically brecciated quartzite and breccia produced by meteorite impact. Above the basal unit there is a massive upward-fining breccia, approximately 1500 m in thickness, containing fragments which include devitrified glasses, quartzite, quartz, granite, gneiss and gabbro. A number of investigators favour a volcanic origin for this breccia. Burrows and Rickaby (1929) and Thomson (1956) describe spherulitic andesite and pillows from the South Range. Peredery (pers. commun.) examined these rocks but found no evidence of pillows. Stevenson (1972) interpreted the glassy fragments as pumice and shards and considered the upper Onaping to be a vast ash flow sheet of rhyodacite to dacite composition. Other investigators interpret the breccia as fall-back material from meteorite impact. Evidence for this includes the striking similarity between these rocks and those from known meteorite craters such as the Ries crater, structures indicative of shock metamorphism in country rock fragments and the chemical composition of recrystallized glass fragments. Peredery (1972) recognized several different types of glasses. They display sperulitic and feathery textures, mafic crystallites, vesicles, flow-lines and shard-like shapes. Some glass fragments contain xenocrysts with planar elements, an indication of shock metamorphism. Homogeneous-looking glass is alkaline and has a range of chemical composition that is much greater than that of alkaline volcanic rocks from a single vent or field. Peredery (1972) interpreted these glasses as country rock that was either melted or shocked to glass in the solid state. The fragments were thrown into the air, chilled, then fell back. The material is pyroclastic, but it is not volcanic in origin.

Peredery (1972), in a local area in the North Range, mapped irregular bodies that occur on top of the basal quartzite breccia and which project into the overlying Onaping rocks. These bodies are fine-grained and consist of albite laths, quartz, altered pyroxene and some granophyre. Inclusions are abundant and display features of shock metamorphism. The margins of the bodies are chilled, brecciated, possess flow banding, and contain attenuated vesicles. The bodies are alkaline with chemical compositions similar to the fluidal glass fragments in the Onaping Formation. Peredery (1972 p. 57) interprets these bodies as melt rocks formed by impact and implaced as follows: "As the fallback accumulated rapidly, the lithostatic load may have caused the underlying melt to force its way up, especially along the crater wall, with resulting overflow whenever it reached the depositional surface. . . . the melt bodies are intrusive in character and have closely associated lava-like fluidal glass apophyses". These bodies are apparently equivalent to those described by Burrows and Rickaby (1929) as volcanic breccia and lavas. Stevenson (1963) noted that the quartzite breccia in the East Range and locally in the South Range is interspersed with inclusion-bearing rocks that project downward into the micropegmatite and upward into the overlying "tuff". Stevenson (1963) concluded that these rocks represent a phase of the micropegmatite that intruded the quartzite breccia. According to Peredery and Naldrett (1975) the melt rocks may also be equivalent, in part, to the inclusion-bearing micropegmatite of Stevenson (1963).

The nickel-copper ores at Sudbury are associated with a distinctive xenolith-bearing unit known as the sublayer (Souch *et al.*, 1969; Naldrett *et al.*, 1972; Pattison, 1979). It occurs as a discontinuous sheet between the Irruptive and the footwall and as outward-radiating dikes. There are two major facies: igneous (gabbro, norite and diorite); and Leucocratic breccia. Quartzite and granite xenoliths were apparently derived from the footwall whereas xenoliths of anorthosite and ultramafic rocks may have been derived from depth. Pattison (1979, p. 272) believes that the sublayer is older than the Irruptive and that the sublayer formed by meteorite impact. "The igneous sublayer is visualized as a mixture of sulphide-rich impact melt and brecciated basic and ultrabasic footwall rocks derived from the deeper levels of the crater structure to a maximum depth of 30 km". The leucrocratic breccia was formed by attrition of the shocked and brecciated rocks (the migmatitic and granitoid rocks of the Levack complex and Cartier granite) as the igneous sublayer (melt) moved rapidly up the wall of the crater". Prior to impact, sulphide mineralization presumably occurred in basic to ultrabasic rocks at depth. The sulphides were incorporated into the melt rocks and later separated from associated silicate material due to density differences.

Card and Hutchinson (1972) stress the unique location of the Sudbury Basin: near the junction of the Superior, Southern and Grenville Structural Provinces; straddling the contact between Archean and Proterozoic rocks; and at the junction of two regional fault systems. Based on paleocurrent data, they further suggest that the site of the basin was a positive element during Huronian deposition. They consider that the Sudbury Basin represents a eugeosynclinal volcanic-sedimentary basin.

The writer suggests that it is necessary to consider the paleogeology of the site just prior to basin formation. At that time the basin site was probably covered by a veneer of Huronian rocks that extended well to the northwest of the basin. The Grenville Province, as such, did not exist. The two regional fault systems intersect at several other locations and some of these faults may be post-basin in age. Paleocurrents in the Huronian Mississagi Formation south of the basin trend to the southwest parallel to the axis of the basin (Long 1978); northeast of the basin they trend south-southeast toward the basin; east of the basin some paleocurrents trend to the west, also toward the basin. Accordingly, paleocurrents do not radiate away from the basin and therefore these data do not uphold the contention that the basin site was a dome during the deposition of the Mississagi Formation.

In conclusion, the available evidence does not support a conventional endogenic origin for the Sudbury Basin. Ratter, the events were apparently triggered by meteorite impact. Some of the features of the basin, unusual even for an astrobleme (Guy-Bray, 1972), suggest that the meteorite struck a zone of crustal weakness (Sims *et al.*, 1980).

Table I *Interpretation of the Onaping Formation*

Investigator	Basal felsic breccia	Upper units
Coleman (1905)	Trout Lake conglomerate	tuff
Burrows and Rickaby (1929)	Volcanic breccia and agglomerate	tuff
Yates (1948)	Volcanic breccia and agglomerate	tuff
Thomson (1956, 1969) Williams (1956)	Rhyolite and rhyolite breccia	tuff, breccia, andesite
Stevenson (1961, 1972)	Tectonically brecciated quartzite	pyroclastic rocks with some sediments
Card and Hutchinson (1972)	- tuff and breccia -	
Dence (1972)	quartzite - slumped from crater wall?	fall-back breccia
Peredery (1972)	fallback or brecciated in place; some slumped material?	fall-back breccia and washed-in material
Dietz (1972), French (1972), Pattison (1979)	- fall-back breccia -	

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