crepida conodont zone, based upon the presence of conodont species *Pa. quadrantinodosalobata, Po. nodocostatus, I. iowaensis, I. cornutus, I. alternatus*, and *Pel. inclinatus* [6], and *Pa. crepida, Pa. minuta minuta, Pa. quadrantinodosalobata, I. iowaensis, I. alternatus helmsi*, and *I. alternatus alternatus* [7]. Petrographic, SEM, XRD, and electron microprobe analyses indicate that the microspherules were like microtektites produced by a bolide impact, on the basis of their "splash form" shapes, inner bubble vesicles, glassy nature, silica glass inclusions (lechatelierite), and chemical compositions that are similar to those of microtektites. The geochemical anomaly in the 3-cm clay is characterized by siderophiles (Ir, Fe, Co, Cr) and chalcophiles (Se, Sb, As) enriched by factors of 1 to several orders of magnitude over their background values, although Ir abundance in the clay is low (38 ppt). The $\delta^{13}C$ maintains constantly positive values in the carbonate samples below the clay, but shifts suddenly to a minimum of −1.97‰ in the clay and above. Although the carbonate rocks we analyzed were altered to some degree by diagenesis (as seen in the thin sections), we believe that the trend of the carbon isotopic change is still preserved. A "strangelove ocean"-like $\delta^{13}C$ excursion of 2.7‰ (PDB) in the Qidong Section is consistent with the paleontological data suggesting that an extinction might have terminated the *Yunnanellina* fauna, which in turn gave rise to the *Yunnanella* fauna. Taihu Lake, a large circular structure, has long been speculated to be a probable impact crater. Recent work, on the basis of shock metamorphism found in the target sediments, has suggested that it is a probable impact crater [2].

Western Australia: A strong iridium anomaly (20 times the background value) was initially reported in the Famennian Upper *triangularis* conodont zone in the Canning Basin, Western Australia [3]. An evaluation of the conodont fauna proved that the Ir anomaly is actually in the Lower *crepida* zone, based upon the occurrence of *Pa. crepida* [8]. This strongly indicates that the Canning Basin Ir anomaly occurs at the same stratigraphic level as the Qidong microspherule and geochemical anomaly horizon. Because the Australian Ir anomaly is associated with a *Frutexites* stromatolite, the interpretation was that the Ir was concentrated biologically by the cyanobacteria. We acknowledge this scenario but further propose that there must have been abundant Ir available in the environment for the biological concentration to take place. The most probable source for Ir is an impact near the region, such as the impact in South China. The presence of *Frutexites* stromatolites is probably the reason why there is a stronger Ir anomaly in the Canning Basin than in the Qidong area, where no *Frutexites* stromatolites are present. A negative $\delta^{13}C$ excursion of about 1.5‰ is coincident with the Ir anomaly in the Canning Basin, and has been suggested to indicate a decrease in biomass [3].

The carbon isotopic excursions, which occur at the same stratigraphic level in both South China and Western Australia cannot be explained as being coincidental. The $\delta^{13}C$ excursions and the brachiopod faunal turnover in South China indicate that there might have been at least a regional (possibly global) extinction in the Lower *crepida* zone. The impact-derived microspherules and geochemical anomalies (especially the Ir) indicate a Lower *crepida* zone impact event on eastern Gondwana. The location, type of target rocks, and possibly age of the Taihu Lake crater qualify as the probable site of this Late Devonian impact.

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ELECTRON PETROGRAPHY OF SILICA POLYMORPHS ASSOCIATED WITH PSEUDOTACHYLITE, VREDEFORT STRUCTURE, SOUTH AFRICA. J. C. White, Center for Deformation Studies in the Earth Sciences, Department of Geology, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 5A3.

High-pressure silica polymorphs (coesite and stishovite) have been described from the Vredefort structure [1,2] in association with pseudotachylite veinlets. In addition to the fundamental significance of the polymorphs to genetic interpretations of the structure, it has been additionally argued that the type of pseudotachylite with which they occur forms during the compressional phase of the shock process, while the larger, classic pseudotachylite occurrences are barren of polymorphs and formed during passage of the rarefaction wave. This identification of temporal relationships among transient shock features at a regional scale is similar to observations from the Manicouagan structure, Quebec [3], where texturally distinct diaplectic plagioclase glasses formed during both compressional and decompressional phases of the shock process. The clarification of such relationships impinges directly on interpretations of natural shock processes and the identification of high probability targets for polymorph searches.

Detailed analytical scanning (SEM) and transmission electron microscopy (TEM) has been utilized to further establish the nature of both the pseudotachylite and the silica polymorph occurrences in

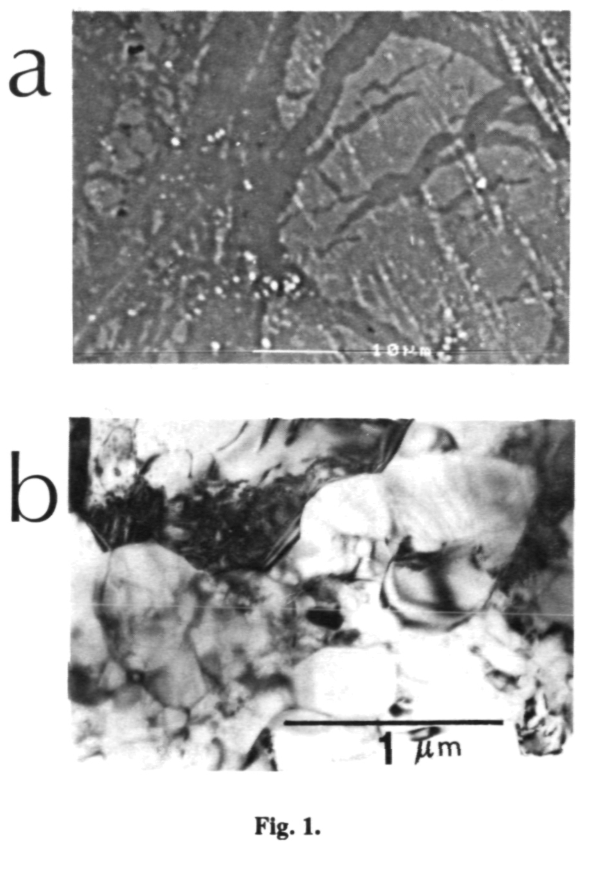

Fig. 1.

the Vredefort rocks. This methodology enables the maintenance of strict control over the spatial, compositional, and crystallographic relationships of the deformed material. The brown, optically isotropic nature of the pseudotachylite belies an essentially pure silica composition. As has been previously noted [2], minor K-feldspar, aluminosilicate (kyanite?) and primary mica are the significant nonsilica mineral phases. Backscattered electron imaging demonstrates complex relationships among the silica phases. Stishovite replacement by quartz (Fig. 1) often takes the form of tensile veinlets suggesting reconversion during shock wave relaxation. Coesite most commonly occurs as acicular grains and is widely dispersed at a fine scale throughout quartz. Reconverted quartz (Fig. 2) from both presumed melt and polymorphs can be remarkably fine-grained, e.g., ≤200 nm grain diameters. Preservation of crystalline material of such small grain size would appear to preclude significant postformation thermal anneals, or otherwise requires extremely sluggish transformation kinetics.

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FLOOR-FRACTURED CRATER MODELS OF THE SUDBURY STRUCTURE, CANADA.

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Introduction: The Sudbury structure in Ontario, Canada, is one of the oldest and largest impact structures recognized in the geological record [1]. It is also one of the most extensively deformed and volcanically modified impact structures on Earth [2–4]. Although few other terrestrial craters are recognized as volcanically modified, numerous impact craters on the Moon have been volcanically and tectonically modified [5] and provide possible analogs for the observed pattern of modification at Sudbury. In this study, we correlate the pattern of early deformation at Sudbury to fracture patterns in two alternative lunar analogs and then use these analogs both to estimate the initial size of the Sudbury structure and to model the nature of early crater modification at Sudbury.

Structure Descriptions: Two patterns of deformation can be distinguished at Sudbury: (1) an early sequence centered on the Sudbury Igneous Complex [6] and (2) several later episodes of regional deformation that cut basin-controlled features, i.e., are insensitive to the impact structure. The Main Igneous Complex presently defines an elliptical ring about 60 km long and 27 km across. This norite/micropegmatite layered intrusion has a crystallization age of ~1850 Ma, which is commonly assigned to the time of impact [7]. It also feeds an extensive sequence of offset dikes in the surrounding basement rocks radial and concentric to the undeformed structure [6]. The radial dikes are the most evenly distributed and, although disrupted by later deformation, they can extend up to 30 km from the edge of the Main Igneous Complex. The less extensive concentric dikes mostly occur south of the structure where they are typically about 3–10 km from the Main Complex [6]. Lastly, basin-centered concentric lineaments can be identified in satellite images 20–30 km north and west of the structure [8]. Unfortunately, deformation along the Grenville front to the south and at the Wanapitae Impact to the east masks any similar trends elsewhere around the basin.

Similar patterns of crater-centered radial and concentric fractures are observed in lunar floor-fractured craters. Since these patterns appear to be partly controlled by the original impact structures, however, two alternative lunar analogs (i.e., complex craters and two-ring basins) can be identified for the Sudbury dike pattern. The first compares Sudbury to the central peak crater Haldane in Mare Smythii. Haldane is a multiringed structure with an outer rim diameter of 40 km and an uplifted central "floor plate" separated from this rim by a wide (~5 km) moat structure [5,9]. Concentric fractures occur near the edge of the floor plate, in the moat and in a well-defined annulus 9–16 km beyond the crater rim. Radial fractures are typically restricted to the central plate and moat regions, but one set east of the crater extends over 10 km beyond the crater rim in association with additional concentric fracturing. Crater counts indicate that both the crater and the superposed fracture systems formed at nearly the same time, whereas volcanism in Haldane appears to be coeval with other basalt units in Mare Smythii. These volcanic units are primarily located along the outer fracture ring and in the crater moat structure [9].

The alternative analogy compares Sudbury with the lunar two-ring basin Schrodinger. Schrodinger is ~300 km in diameter with a broad interior ring surrounding a central floor region ~100 km in diameter. Roughly concentric fractures occur along the interior ring structure, whereas radial fractures typically extend from the inner ring toward the outer crater wall. Volcanic activity within the basin is limited, but a dark-haloed pit on one of the innermost concentric fractures indicates minor pyroclastic activity.

Comparison: The dike patterns at Sudbury thus can be interpreted in three ways. First, if the Sudbury Igneous Complex marks the location of the crater rim, the radial offset dikes might correspond to the fractures extending beyond the eastern rim of Haldane. The even distribution of these dikes around Sudbury, however, then requires a uniformly tensile regional stress field, which is inconsistent with the onset of the Penokean Orogeny shortly after the impact [10]. Further, since the Igneous Complex probably represents an impact melt unit [11], the edge of this unit is more likely to reflect the edge of the basin floor than the crater rim.

In the second interpretation, the radial offset dikes correspond to radial fractures observed in the Haldane moat. In this case, the concentric dikes and the Sudbury Igneous Complex would mark the edge of an uplifted floor plate, while floor uplift could produce a uniformly tensile stress field within the crater rim [12]. In addition, the absence of an uplifted central peak complex at Sudbury requires detachment of the impact melt from the central peaks during uplift. Although rare, such detachments are observed on the Moon, where a few craters (e.g., Billy, Camoens) show evidence for a "foundered central peak complex" [5,12].

Third, the Sudbury dike pattern also matches the pattern of fracturing in the two-ring basin Schrodinger. The radial offset dikes are identified with the pattern of radial fractures occurring in the outer floor region at Schrodinger, whereas the concentric offset dikes correlate with the inner sequence of concentric fractures along the interior peak ring. Due to the close proximity of the Igneous Complex to the concentric offset dikes, this interpretation suggests that the Sudbury basin may preserve much of the original central impact melt sheet consistent with [11].

Discussion: The comparison of Sudbury to lunar floor-fractured craters thus provides two alternative models for the initial Sudbury structure. Further, the apparent correlation of crater floor fractures to specific elements of the original crater structure allows estimation of crater sizes for these two models. For the Haldane analogy, since radial fractures are confined to the crater interior, the extent of the radial offset dikes from the original basin center indicates a minimum Sudbury diameter of ~100–120 km. If the Sudbury basin contains a down-dropped central peak complex, the