"Sudbury Igneous Complex" (SIC). From bottom to top the OF can be divided into Basal, Gray, Green, and lower and upper Black Members [3,4]. The breccias were mapped in detail in the east range of the structure. The SIC and the lower part of the OF (Basal Member) are interpreted as the impact melt system [1,3,5; compare also 6].

The *Basal Member* occurs as a fragment-laden polymict melt-breccia on top of the granophyre of the SIC and as isolated bodies (formerly called melt bodies [7]) in the Gray and Black Members. The Basal Member contains abundant rock fragments that consist of metasediments of the Huronian Supergroup and minor amounts of Archean crystalline basement. In the upper part of the granophyre a similar fragment population is observed. Therefore, these rocks must have been present in the target area at the time of the impact. Geochemical investigations of the main elements and rare earth elements underline the close genetic relationship of the SIC and the Basal Member and their formation of crustal rocks.

The overlying *Gray Member* is a breccia unit with a clastic matrix and has a sharp contact to the Basal Member. The polymict, allochthonous breccias of the Gray Member are characterized as a suevitic breccia by a high amount of melt particles and fragments with shock metamorphic features. Signs of multiple brecciation and internal contacts found during the mapping provide evidence for turbulent movements during the emplacement of the Gray Member [4,8]. Based on its petrographic character, the lower part of the Gray Member is interpreted as a ground-surge deposit, which grades into fall-back breccias.

The *Green Member* is considered as a continuous uniform breccia layer on top of the Gray Member and comprises the former "chlorite shard horizon" [7]. This breccia layer is characterized by a microcrystalline matrix, chloritized "glassy" particles, and a high content of small mineral clasts. The Green Member is regarded as gradational and fine-grained fall-back material, which was affected by high temperatures during the deposition. The Green Member and the chloritized particles originated by early excavation to high atmospheric regimes, condensation out of a vapor phase, and deposition with the final fall-back material.

The uppermost unit of the OF (*Black Member*) can be subdivided into a lower and an upper Black Member unit. The lower part (100–150 m thick) still shows petrographic features of suevitic breccias, small fragments of basement rocks, melt particles, chloritized particles, and breccia fragments in a dark, clastic matrix. These signs indicate that the lower unit has been transported from its original position outside the crater into the central depression of the crater. The upward increase of sedimentary features, signs of multiple brecciation in the upper part of the Black Member, and the gradational contact to the overlying Onwatin slates of the Whitewater Group indicate the subsequent change in the depositional environment. Investigations of the carbonaceous material in the matrix of the Black Members and the Onwatin slates suggest an origin by biogenetic material deposited at a slow rate lasting into a local, euxinic basin, which was created by the Sudbury event.

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SUDBURY PROJECT (UNIVERSITY OF MÜNSTER–ONTARIO GEOLOGICAL SURVEY): (1) SUMMARY OF RESULTS—AN UPDATED IMPACT MODEL.

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In 1984 the Ontario Geological Survey initiated a research project on the Sudbury structure (SS) in cooperation with the University of Münster. The project included field mapping (1984–1989) and petrographic, chemical, and isotope analyses of the major stratigraphic units of the SS. Four diploma theses and four doctoral theses (Avermann, Brockmeyer, Lakomy, Müller-Mohr) were performed during the project (1984–1992). Specific results of the various investigations are reported in five accompanying abstracts [1–5]. As shown in Fig. 1 of [1], selected areas of the SS were mapped and sampled: Footwall rocks, Footwall Breccia and parts of the sublayer and lower section of the Sudbury Igneous Complex (SIC), Onaping Formation and the upper section of the SIC, and Sudbury breccia and adjacent Footwall rocks along extended profiles up to 55 km from the SIC. All these stratigraphic units of the SS had been studied in substantial detail by previous workers [6,7]. The most important characteristic of the previous research is that it was based either on a volcanic model or on a mixed volcanic-impact model for the origin of the SS. The present project has been clearly directed toward a test of the impact origin of the SS without invoking an endogenic component. In general, our results confirm the most widely accepted stratigraphic division [6] of the SS. However, our interpretation of some of the major stratigraphic units is different from most views expressed in [6]. The stratigraphy of the SS and its new interpretation is given in [3] as a basis for the following discussion.

The main conclusion to be drawn from our results is that (1) the SS is the erosional remnant of a peak- or multiring impact basin with an original diameter in the 200- to 240-km range and (2) the SIC is no endogenic intrusion but rather the main part of an impact melt sheet that occupies the central depression of the basin and has been produced by shock-induced total melting of crustal rocks [8–12]. Independently, R. A. F. Grieve of the Geological Survey of Canada has come to quite identical conclusions [9]. The individual stratigraphic units or impact-related rocks can be characterized and interpreted as follows.

Footwall Rocks and Related Breccias: The Archean and Proterozoic crystalline basement of the SIC displays impact-induced features up to a radial distance of at least 55 km, possibly 80 km [6], from the SIC. At the contact to the SIC it forms a (mega)breccia that is thermally metamorphosed and partially molten by the SIC (Footwall Breccia). This breccia grades into a weakly shocked (and, further out, into unshocked) brecciated basement. All basement units contain at least three generations of breccia dikes (Sudbury breccias) formed by frictional melting and shearing during the compression, excavation, and modification stages of the crater formation—a feature typical of all complex terrestrial craters (e.g., [13]).

SIC and Basal Member of the Onaping Formation: This unit represents a layered complex of rocks that crystallized from an impact melt. It comprises from bottom to top (1) the sublayer, including the offset dikes, a noritic to quartz-dioritic, clast-rich melt breccia that covers the floor of what is considered the transient cavity of the impact basin; (2) the norite, quartz gabbro, and granophyre units that are interpreted as clast-free, differentiated impact melt; and (3) the Basal Member of the Onaping Formation, a clast-rich melt breccia. The complete melt sequence has the chemical and isotope signatures of a mixture of upper and lower crustal rocks [12,14,15].

Gray, Green, and Black Members of the Onaping Formation: The rocks of these units form a layered sequence of polymict, melt-bearing, clastic matrix breccias showing strong similarities to suevitic breccias. The lithic fragments of these breccias are derived mainly from the Huronian Supergroup and more rarely from the Archean basement. The melt particles appear to represent whole-rock melts of a mixture of such basement rocks [14,15]. The lower unit (Gray Member), which is interpreted as a ground-surge-type suevite, is affected by thermal metamorphism induced by the underlying melt complex. It is topped by a thin layer of melt-rich clastic fall-back material (Green Member, formerly called the chloritized shard horizon) that might have temporarily formed the impact basin floor before the suevitic breccia material of the Black Member was deposited by slumping during the gravity-induced modification stage of the basin formation [16]. We believe that the lower part of the Black Member formed in this way whereas the upper part was deposited aquatically under euxinic conditions. These conditions are responsible for the carbonaceous matter (derived from organic material according to the C isotopes) in the matrix of these breccias.

The distribution and stratigraphic relation as well as the petrographic, chemical, isotope, and shock metamorphic characteristics of the rock units of the SS are clearly compatible with its interpretation as an impact basin whose transient cavity had a diameter D_{tc} in the 100- to 140-km range. These figures are derived from the radial extension of shock effects in quartz, of shatter cones, and of the Sudbury breccias, and from the position of the down-faulted "megablocks" of Huronian rocks within the Archean basement north of the structure [9]. They translate into a diameter of the apparent basin D_a of at least 150 km [9], more probably of 200 to 240 km [8,10], depending on what empirical relation between D_{tc} and D_a is used. A major uncertainty in determing these dimensions is caused by the postimpact deformation of the basin during the Penokean Orogeny. Recent geophysical and structural data [17,18] have removed previous objections against a primary circularity of the SS. The present interpretation of the subbasin structure [17] indicates a minimum diameter of the outer margin of the SIC of 60 km. Taking the deformation of the east range by the Wanapitei impact structure into account [6], we believe that this diameter was at least 65 km although the curvature of the north range would allow a diameter of up to 80 km. In the latter case, D_a could exceed even 250 km.

From the present interpretation of the SS additional conclusions can be drawn: (1) The depth of the transient cavity was in the order of 30 to 40 km and the depth of excavation near 12 to 20 km [8,10]. According to current models for melt zones in impact craters [16], the melt zone at Sudbury probably reached a depth of about 30 km, which is the base of the transient cavity [8,10]. This may explain why the Sudbury basin never had a morphologically expressed central uplift [9] but instead a had a central depression bordered by a peak ring with a diameter of 80 to 90 km. (2) The Sudbury impact occurred during an active orogeny (Penokean), 1.85 b.y. ago [19], during which the southeastern part of the basin and peak ring was deformed by thrust faulting to the northwest. This deformation took place while the central part of the melt complex had not yet been cooled and fully crystallized [20] and is therefore not foliated, whereas the rocks above and below were deformed [6]. It is highly probable that the section of the SIC exposed in the south range is from a deeper position of the impact basin than the section of the north range. (3) As the SS is not only the largest impact structure and the only peak- or multiring basin on Earth but also the largest Cu-Ni deposit, it has gained considerable importance as a model for the study of large impact basins on the terrestrial planets and as a pathway for exploring the geological processes and the genesis of crustal ore deposits in the early history of the Earth. The recognition of a nearly 3-km-thick differentiated impact melt sheet at Sudbury has far-reaching consequences for the interpretation of the >4-b.y.-old "plutonic" pristine rocks of the lunar highland crust.

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STRUCTURAL ASPECTS OF THE ARAGUAINHA IMPACT STRUCTURE (BRAZIL).

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A report is given on the results of two months' field studies carried out in 1988. During that time the northeast segment was mapped and the structural setting of the central area was studied in detail. In addition, the structure of outer zones of the Araguainha Crater was investigated along three radial sections.

The Araguainha impact occurred 243 ± 19 Ma ago [1] under shallow marine conditions on a mixed target consisting of Devonian, Carboniferous, and Permian mainly clastic sediments overlying a Precambrian phyllitic and granitic basement. The intrusion of the granite probably took place 449 ± 9 Ma ago [1]. A peripheral ring-fault system, 40 km in diameter, forms the outer boundary of the complex structure [2]. The central part of the structure, 6–6.5 km in diameter, consists of a ring of steep hills rising 150 m above the surrounding plain. The ring is made up of large uplifted blocks of Devonian sandstone, which surround a central 2.5–3-km-wide depression. The interior of the central depression consists of uplifted alkaligranitic basement. The outer limit of the granite is mostly covered by polymict suevitic breccias forming another ring of hills.