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). L. Bischoff, P. Brockmeyer, U. Jenchen, and R.-M. Swietlik, Institute of Geology, University of Münster, Germany.

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.

The granite, which is shocked to stage I, often shows in its upper part *in situ* melting, which gradually increases toward the top. This partly molten granite is not part of the allochthonous coherent melt sheet [3] that covered the granite and induced its melting. Except for some relics this layer of molten target rock was eroded like most of the ground-surge and fall-back breccias.

The original bedding of the Paleozoic formations is deformed by impact-induced fracturing and folding. The concentric arrangement with increasing younger formations from the center to the margin of the structure give the structure the apparent domelike appearence. This is due to the combination of a central uplift and the peripheral graben structure. But, in fact, most contacts between the different formations are of tectonic origin and each ring consists of a multitude of fault blocks. Bedding in these blocks has a steep dipping in the central ring, but has moderate to gentle dipping in the outer parts of the structure. Folds are best developed in the sandstones of the Devonian Furnas Formation of the interior hills. The axis of the steeply outward plunging open folds scatter remarkably in different directions. They are sometimes arranged in a complex fanlike pattern. From the analysis of the fault pattern and the geometry of the folds, the principal stress components can roughly be estimated with σ_1 radial to the center.

Pebbles of some target rocks are heavily sheared. Shear plane analysis may be used to reconstruct stress distribution during the cratering process if the original position of the pebble-containing beds is known.

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SUDBURY PROJECT (UNIVERSITY OF MÜNSTER–ONTARIO GEOLOGICAL SURVEY): (2) FIELD STUDIES 1984–1989—SUMMARY OF RESULTS. L. Bischoff[1], B. O. Dressler[2], M. E. Avermann[1,3], P. Brockmeyer[1,3], R. Lakomy[1,3], and V. Müller-Mohr[1,3], [1]Geologisch-Paläontologisches Institut, University of Münster, Corrensstr. 24, W-4400 Münster, Germany, [2]Ontario Geological Survey, 77 Grenville Street, Toronto, Ontario, M7A 1W4, Canada, [3]Institut für Planetologie, University of Münster, WilhelmKlemm-Str. 10, W-4400 Münster, Germany.

In cooperation between the Ontario Geological Survey (B. O. Dressler) and the Institute of Geology and Institute of Planetology, both of Westfälische Wilhelms-Universität, Münster, geological, petrological, and geochemical studies were carried out on impact-related phenomena of the Sudbury structure during the last decade. The main results of the field studies are briefly reviewed (see also [1–5]). As shown in Fig. 1, Footwall rocks, sublayer, and lower sections of the Sudbury Igneous Complex (SIC) were mainly mapped and sampled in the northern (Levack Township) and western (Trillabelle and Sultana Properties) parts of the north range. Within these mapping areas Sudbury Breccias (SB) and Footwall Breccias (FB) have been studied; SB have also been investigated along extended profiles beyond the north and south ranges up to 55 km from the SIC [5]. The Onaping Formation (OF) and the upper section of the SIC were studied both in the north range (Morgan and Dowling Townships) and in the southern east range (Capreol and McLennan Townships) (see Fig. 1).

The Footwall rocks [6–12] exhibit shock metamorphic phenomena of shock stage I, which is characteristic of an impact crater floor. Shock metamorphism, including especially planar elements in quartz and shatter cones, can be observed up to a radial distance of 9 km from the lower SIC contact or up to 17 km (shatter cones). The Footwall rocks were subjected to a thermal overprint by the SIC up to a distance of 1 km [8,12].

The FB [3,6,10,12,13] is the remnant of a clastic matrix crater floor breccia. It occurs as irregularly or lenticularly shaped bodies at the contact between the Footwall and the SIC. Further on FB dikes intrude into the brecciated crystalline basement rocks up to 250 m away from the FB layer [10,12,13]. The contacts between FB and the underlying Footwall rocks are always sharp, even on a microscale. The fragment content reflects a local origin. Fragments of FB occur enclosed in the sublayer and norite. The crystalline matrix was formed after localized melting of the originally clastic matrix due to the thermal overprint by the SIC. Locally megaclasts (>25 m) adjacent to the country rock are embedded in huge intercalations of FB matrix.

The SB [5,7,9,11,12,14] occur as various types of clastic or crystalline matrix breccia forming irregular dikes whose orientations appear not to be controlled by the geometry of the Sudbury structure. In the north range dikes have been observed up to a distance of at least 55 km from the lower contact of the SIC, but are abundant within a zone of 10 km adjacent to the SIC and a second zone located approximately between 20 and 33 km north of the SIC. The thickness of the dikes ranges from centimeters to several hundred meters. Most of the dikes exhibit sharp contacts to the wall rock. Several phases of brecciation can be distinguished by breccia fragments in SB, whereas crosscutting of different breccia types is extremely rare. Most of the fragments of the SB are directly derived from the country rock, but in large dikes relative movements of clasts over several hundred meters can be found. The SB were formed by shearing and friction of Footwall rocks.

The breccias of the OF [4,15–17] can be divided from bottom to top into Basal Member, Gray Member, Green Member, and lower and upper Black Member according to their lithological composition, matrix, clast population, contacts, and texture. The term "Basal Member" comprises a clast-rich melt breccia on top of the SIC and the "melt bodies" [18], as they were formerly called, whereas the term "Green Member" implies the former "chlorite shard horizon" [18]. The Black Member was subdivided due to obvious changes upward in fragment content, size, matrix texture, grade of foliation, and occurrence of both carbonaceous material and sedimentary features. The lower part of the polymict allochthonous breccias of the OF are interpreted as impact-melt breccias, the overlying breccias as ground-surge breccias, and the uppermost as original or resedimented fall-back breccias [see 1,2,4].

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