characteristics indicate that it is derived almost exclusively from the local Levack gneisses [7,8]. (3) Breccia dikes, collectively named Sudbury Breccia, which are irregularly distributed in the basement up to a radial distance of at least 55 km from the SIC [6]. They have a random orientation and range in thickness from millimeters to some 300 m. Four generations of dikes have been identified [6] that differ in matrix characteristics (crystalline to clastic), thickness, clast content, and contact relationships. The composition of the matrix typically resembles the composition of the country rock and the clasts are derived from the local rocks except for very large dikes where clasts were moved over distances of up to 800 m. Shocked clasts (stage I) within the dikes occur only up to a radial distance of 10 km from the SIC.

SIC and Basal Member of Onaping (Fig. 1): The SIC has been studied only in its contact zones to the Basal Member and to the Footwall Breccia. The Sublayer is a heterolithic breccia with a crystalline melt matrix of mafic composition and abundant mafic to ultramafic lithic clasts. It contains also clasts of FB as the latter carries clasts of the norite and Sublayer. The contacts of the FB to the norite are sharp whereas to the Sublayer they are either sharp or gradational [8,9]. Similarly, the uppermost section of the SIC (granophyre) shows sharp and gradational transitions to the Basal Member, which is a clast-rich impact melt breccia. Abundant clasts (up to 80 vol%), mainly from the Proterozoic Huronian metasediments, are embedded in a crystalline matrix with granophyric to variolitic texture [10]. There is a chemical similarity between the SIC, especially the granophyre, and the melt breccia of the Basal Member confirming that both units represent a whole rock melt of Precambrian target rocks. There is some indication for an increasing proportion of Proterozoic Huronian rocks toward the top of the melt system [4].

Gray, Green, and Black Members of Onaping (Fig. 1) [10,11]: The Gray Member is a polymict clastic matrix breccia composed of lithic clasts of variable degree of shock and irregularly shaped melt inclusions that have a fine-grained crystalline texture and show flow structures. Texturally, this breccia layer is similar to the suevitic breccias found in the crater fill of many complex impact craters. The clastic breccia constituents are derived predominantly from rocks of the Huronian Supergroup and, more rarely, from Archean basement rocks. The Gray Member is covered by a thin layer of a rather uniform, strongly chloritized breccia (Green Member, formerly called chloritized shard horizon). The contact varies from sharp to gradational. This breccia contains relatively fine-grained clastic material in a microcrystalline matrix characterized by concavely shaped vugs filled with chlorite. Green Member is topped by the clastic matrix breccia layer of the Black Member, which, as a whole, is characterized by a carbonaceous matrix. In its lower unit it shows similarities to the Gray Member. The upper unit displays textural features of reworking and sedimentation under aquatic conditions. A major fraction of the carbon is derived from organic matter and formed under euxinic conditions. The bulk chemical composition of the whole sequence of clastic matrix breccias (Gray Member to Black Member) is less siliceous and richer in Fe, Mg, K, and Na than the melt breccia of the Black Member [10,11]. It is not clear whether this is due to secondary alteration processes or whether it reflects a primary change in the composition of the source rocks of the clastic matrix breccias. The REE patterns of all breccia units of the Onaping Formation are quite similar and are well within the range of the potential source rocks from the Proterozoic and Archean basement.

The data obtained from the petrographic and chemical investigations of the breccia formations at the SS are compatible with the impact basin model summarized in [2]. The interpretation of our results with regard to the origin and emplacement of these formations are therefore different from most of the previous views as expressed mainly in [5]. The present interpretation is as follows: The Sudbury Breccias (dike compression of the crater basement by *in situ* frictional melting and by shearing processes during the gravity-induced breccias) were formed during shock collapse of the transient cavity. The Footwall and Sublayer Breccias including the offset dikes were formed in the late stage of the transient cavity (TC) formation as crater floor breccias before the collapse of the cavity. This holds also for the impact melt system and the suevitic breccias of the Gray Member that covered the central part and the upper walls of the TC. As a consequence of its collapse the innermost, clast-free part of the melt layer within the TC pooled to a melt sheet filling the central depression as well as the depressions outside the now eroded peak ring and, immediately afterward, became covered by clast-rich melt slumping in from higher regions of the TC wall. Similarly, the suevitic material slumped into the depression from even higher portions of the TC wall. It was then covered by airborne fallback material (Green Member) deposited from the ejecta plume. The Black Member breccias are interpreted as material that was transported into the central depression by turbulent slumping from the walls of the peak ring and by aquatic sedimentation of ejecta material covering the ring region.

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"BRONZITE" GRANOPHYRE: NEW INSIGHT ON VREDEFORT. A. M. Therriault and A. M Reid, University of Houston, Department of Geosciences, Houston TX 77204, USA.

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The Vredefort Dome is located near the center of the Witwatersrand Basin, about 120 km southeast of Johannesburg, South Africa. Its origin is enigmatic, ranging from a major impact event [1–3] to endogenous processes, either igneous [4–6] or tectonic [7]. A unique melt rock, the "Bronzite" Granophyr, occurs in the Vredefort structure as vertical ring dikes along the contact between sedimentary collar and core of Archaean granites, and as vertical dikes extending northwest-southeast and northeast-southwest in the granitic core. The granophyre rocks have an unusual composition and high content of recrystallized sedimentary inclusions compared to common intrusive igneous rocks with similar SiO_2 content (61 to 70% by weight). The unique nature of the granophyre has been underlined in previous studies and origin hypotheses as an impact melt or as a highly contaminated intrusive mafic magma have also been discussed [e.g., 8–10]. We present new results obtained from a recent detailed petrographic and geochemical study of a very large and texturally diverse suite of "Bronzite" Granophyre, representing all dikes occurring at Vredefort.

Petrography: The major mineral phases observed in the granophyre are hypersthene, plagioclase, orthoclase, quartz, pigeonite, augite, biotite, magnetite, and ilmenite. Only rare bronzite grains are observed and they occur exclusively as xenoliths. None of the bronzite grains are in equilibrium with the granophyre melt.

Two major types of granophyre are observed: (1) fine-grained, clast-rich dikes, confined to the central core of the structure that are dominated by a spherulitic texture and textural heterogeneity occur over distances ranging from millimeters to tens of meters produced by four spherulitic subtypes and an ophitic subtype texture; and (2) medium- to fine-grained clast-rich granophyre core-collar dikes dominated by hypidiomorphic textures [11]. Grain size of the granophyre matrix minerals ranges up to 5 mm. The mineralogy of all dikes is similar with the exception of the higher modal abundance of biotite in the core dikes relative to the core-collar dikes. The spherulitic texture with skeletal crystal morphologies observed in the core dikes is indicative of extreme undercooling conditions [12], while increased textural homogeneity characterizing the core-collar granophyre dikes indicates more uniform and slower cooling histories.

Numerous monomineralic and lithic fragments, up to 80 cm long, compose up to 20% of the rock volume [11]. All the major country rocks are represented as inclusions in every dike examined. Granite, gneiss, and quartzite are the most abundant, mafic rock fragments and metasediments other than quartzite are less abundant, and shale inclusions are rare [10,11]. These abundant inclusions show intense recrystallization, reactions with the granophyre melt, and melting. Rare shock features are observed in quartz grains and are restricted to remnants of decorated planar elements occurring as one set parallel to the c axis of individual quartz grains.

Chemistry: Chemical homogeneity, on a regional scale, is a major characteristic of the granophyre dikes of the Vredefort structure. Homogenization was achieved early in the melt's history and was maintained as the melt intruded the fractured country rocks where it underwent cooling and crystallization under relatively undisturbed conditions.

Although no gross differences in major- and most trace-element compositions were detected that could be ascribed to regional position within the structure, minor chemical variations are present. The granophyre dikes of the central core have higher SiO_2, TiO_2, Al_2O_3, and K_2O contents than the core-collar dike, while core-collar dikes have higher FeO + Fe_2O_3, MgO, CaO, and Na_2O contents. These differences are thought to be due to differences in the composition and amount of local materials assimilated. Although the granophyre melt is weakly differentiated, this is a minor factor in the evolution of the granophyre melt and differential assimilation is the major cause of the chemical variability observed.

Discussion: Metasediments and shale inclusions, from lithologies occurring within units stratigraphically higher than the present emplacement level of the granophyre dikes, are regionally distributed within all these dikes. This observation is hard to reconcile with the processes involved in the intrusion of a magma from the mantle or upper crust and indicates that the granophyre melt must have been efficiently and dynamically mixed before being injected into major fractures. Highly heterogeneous clast populations from widely different stratigraphic levels, a complex thermal history, and injection of melt/clast mixtures into dikes are in agreement with processes related to impact melt formation. The first report of rare shock features in xenolithic quartz grains supports the melt origin by impact. Two reasons explain why shock planar features, observed in the source rocks [13], are rarely seen in inclusions of the granophyre: (1) they have been annealed [13,14] and (2) shocked fragments are preferentially assimilated in the melt because they attained a higher temperature during the initial shock event [15,16].

Conclusions: The matrix textures, the variable thermal effects in the inclusions, and the chemical variations presented for the granophyre dikes of Vredefort are compatible with an impact melt [15,16]. Our observations and results indicate that the granophyre dikes best represent remnants of an impact melt that intruded fractures of the transient crater floor of Vredefort. We thus favor the Vredefort structure as a deeply eroded multiring impact basin.

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A COMPARISON OF THE CHEMISTRY OF PSEUDOTACHYLYTE BRECCIAS IN THE ARCHEAN LEVACK GNEISSES OF THE SUDBURY STRUCTURE, ONTARIO.

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The Archean Levack Gneisses of the North Range host millimeter-thick veins and centimeter-thick lenses of pseudotachylyte, as well as substantially larger meter-wide, dykelike bodies of pseudotachylytic "breccia." The "breccia" occurs up to several tens of kilometers away from the Sudbury Igneous Complex and is commonly sited within or near joints and other natural weaknesses such as bedding, dyke contacts, and lithological boundaries.

The larger "breccia" dykes comprise a generally dark matrix containing rounded to subrounded and occasionally angular rock fragments derived predominantly from Levack Gneiss. The matrix may exhibit flow features and typically appears aphanitic, although in certain exposures it possesses a fine-grained crystalline texture. The "breccia" fragments can be as large as 2–3 m in their long dimension and are typically chaotically arranged within the matrix, showing evidence of both rotation and internal fracturing. More exotic rock fragments, such as amphibolite, also occur and these appear to have been transported for some distance (i.e., at least tens of meters). The origin of the so-called Sudbury Breccias is a subject of controversy, but is generally believed to be related to the 1.85-Ga Sudbury event. Field evidence indicates that they are fault-related and frictionally induced and are therefore not the direct products of shock melting.

Selected samples of bulk Sudbury Breccia and Sudbury Breccia matrices have been chemically analyzed and compared to existing data on the Levack Gneisses and Sudbury Breccia. The matrices are apparently enriched in Fe and, to a lesser extent, Mg, Ti, and Ca compared to the wallrocks and the majority of clasts. This enrichment can be partly explained by the preferential cataclasis and/or frictional melting of hydrous ferromagnesian wallrock minerals, but also appears to require contamination by more basic exotic