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SAR IN SUPPORT OF GEOLOGICAL INVESTIGATIONS OF THE SUDBURY STRUCTURE. V. Singhroy[1], R. Mussakowski[2], B. O. Dressler[3], N. F. Trowell[3], and Richard Grieve[4], [1]Canada Centre for Remote Sensing Department of Energy, Mines and Resources of Energy, Mines and Resources, Canada, [2]Provincial Remote Sensing Office, Ontario Ministry of Natural Resources, Canada, [3]Ontario Geological Survey Ministry of Northern Development and Mines, Canada, [4]Geological Survey of Canada, Department of Energy, Mines and Resources, Canada.

Imaging radar is an important contributing source of information for a range of geological problems and environments. Airborne SAR and ERS-1 data integrated with other geoscience datasets are being used in an attempt to characterize the crustal fracturing associated with the Sudbury structure. This presentation highlights examples of integrated and composite images aimed at facilitating the interpretation of the Sudbury structure. This work is the result of an ongoing cooperative multidisciplinary SAR study of the basin carried out by the Canada Centre for Remote Sensing, Ontario's Provincial Remote Sensing Office, the Ontario Geological Survey, and the Geological Survey of Canada.

VISCOSITY DETERMINATIONS OF SOME FRICTIONALLY GENERATED SILICATE MELTS: IMPLICATIONS FOR SLIP ZONE RHEOLOGY DURING IMPACT-INDUCED FAULTING. John G. Spray, Department of Geology, University of New Brunswick, Fredericton, New Brunswick, Canada.

Analytical scanning electron microscopy, using combined energy dispersive and wavelength dispersive spectrometry, has been used to determine the major-element compositions of some natural and artificial silicate glasses and their crystalline equivalents derived by the frictional melting of acid to intermediate protoliths. The major-element compositions are used to calculate the viscosities of their melt precursors using the model of Shaw [1] at temperatures of 800°–1400°C, with $Fe^{2+}/Fe(tot) = 0.5$ and for 1–3 wt% H_2O. These results are then modified to account for suspension effects (i.e., the presence of mineral and rock clasts) in order to determine effective viscosities.

The critical factors in controlling the viscosities of the silicate melts are SiO_2 and H_2O contents and temperature, as has been well established for silicate melts of magmatic origin. Additionally, for fault-generated melts, the effects of shear thinning can reduce the viscosity to a significant degree. At 1200°C, the viscosities range from 7 p for the more basic melt sample (40 wt% SiO_2) to 1×10^5 p for the more acid melt sample (64 wt% SiO_2). These viscosities are low and indicate that at least the friction melt derived from the more basic protolith would have been highly fluid within the slip zone during displacement. The effects of shear thinning at very high strain rates would reduce these viscosities even further.

Where friction melts are generated during coseismic slip (to form pseudotachylites) this implies that the melt may help to lubricate the sliding interface and dissipate stored strain energy. These results are contrary to the views of earlier workers, who suggested that any melts generated by frictional heating would possess high viscosities and so inhibit slip. Part of this inference was based on the erroneous assumption that pseudotachylite generation involved the bulk fusion of wallrocks. Although a pseudotachylite matrix plus clasts has a very similar chemistry to the wallrock lithology, the matrix typically possesses a more basic chemistry and hence, due to its lower SiO_2 content, a significantly lower viscosity than that of its protolith. On the other hand, smaller entrained clasts (<1 cm diameter) are typically felsic and dominated by quartz.

These results have implications for the generation of pseudotachylitic breccias as seen in the basement lithologies of the Sudbury and Vredefort structures and possibly certain dimict lunar breccias. Many of these breccias show similarities with the more commonly developed pseudotachylite fault and injection veins seen in endogenic fault zones that typically occur in thicknesses of a few centimeters or less. The main difference is one of scale: Impact-induced pseudotachylite breccias can attain several meters in thickness. This would suggest that they were generated under exceptionally high slip rates and hence high strain rates and that the friction melts generated possessed extremely low viscosities.

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THE LARGE IMPACT PROCESS INFERRED FROM THE GEOLOGY OF LUNAR MULTIRING BASINS. Paul D. Spudis, Lunar and Planetary Institute, Houston TX 77058, USA.

The nature of the impact process has been inferred through the study of the geology of a wide variety of impact crater types and sizes. Some of the largest craters known are the multiring basins found in ancient terrains of the terrestrial planets [e.g., 1]. Of these features, those found on the Moon possess the most extensive and diverse data coverage, including morphological, geochemical, geophysical, and sample data. The study of the geology of lunar basins over the past 10 years [2–4] has given us a rudimentary understanding of how these large structures have formed and evolved.

Basin Morphology: Basins on the Moon begin to form at diameters of about 300 km, the 320-km-diameter Schrodinger being an example [5,6]. At these diameter ranges, only two distinct rings are apparent; the transition diameter at which multiple rings appear is uncertain, but appears to be between 400 and 500 km in diameter [6]. Above these diameters, basins possess multiple rings, as few as three and as many as seven [1,5,6]. In every basin, one ring appears to be very prominent and is believed to correspond structurally to the topographic rim of complex craters. This ring has various names (basin rim of [5], Ring IV of [6], MOR of [7]), but corresponds to the Cordillera ring of the Orientale Basin. Rings inside and outside this ring are recognized, each having distinct morphology. Basin inner rings tend to be clusters or aligned segments of massifs, arranged into a crudely concentric pattern; scarplike elements may or may not be present. Basin outer rings tend to be much more scarplike and massifs are rare to absent. Within a certain subset of basins on the Moon (e.g., Crisium [8], Humorum [9]), the main topographic rim is not evident. These basins appear to have undergone a different style of postimpact modification, possibly related to rapidly changing thermal conditions within the Moon 3.9 Ga ago [8,9].

Basin Ejecta: Basins display textured ejecta deposits, extending roughly an apparent crater radius beyond the main topographic rim. Ejecta may display various morphologies, ranging from wormy to hummocky deposits (e.g., Hevelius Formation of Orientale, Fra Mauro Formation of Imbrium [5]) to knobby textured material (e.g., Alpes Formation of Imbrium [5]). The cause of these variations in ejecta morphology are not known. At Orientale, knobby material is largely confined within the Cordillera scarp while hummocky materials appear to be mostly restricted beyond this boundary [5,10]. However, at Imbrium, both units are restricted beyond the topographic rim (Apennine ring) and display a curious "bilateral" double symmetry [1,3]; this relation remains unexplained. Outside the limits of the basin textured ejecta are found both fields of satellitic craters (secondaries [5,11]) and light plains deposits (Cayley Formation [5]). These materials contain both primary basin ejecta and local materials, the local materials being predominant [12].

Impact melt sheets are observed on the floors of relatively unflooded basins, such as Orientale [1,5,10]. A class of impact melts in the Apollo sample collections possess basaltic major-element chemistry, have a KREEP trace-element pattern of varying concentration, and all have ages of about 3.8–3.9 Ga [1,13]. These rocks, collectively called "low-K Fra Mauro" basalts, are probably related to basin impact melts [13–15]. Although the exact number is contentious, at least three major compositional subdivisions of the LKFM melt group can be recognized; each may correspond to a different multiring basin, the Imbrium [13,15], Serentitatis [15], and Nectaris Basins [16]. A curious fact about lunar LKFM melts is that they cannot be produced through the fusion of known lunar pristine rock types [13,14], suggesting the occurrence of unknown crustal lithologies on the Moon. The LKFM melts were probably generated at middle to lower crustal levels [13,15].

Basin Excavation: The preservation of preexisting topography within the main topographic rim provides some constraints on the size of the excavation cavity of multiring basins. At Orientale, pre-existing craters and basins can be mapped [2,17,18] within the Cordillera scarp (950 km diameter) and some structures [17] may extend inside the outer Rook ring (620 km diameter). These observations suggest that the excavation cavity for Orientale must have been less than about 600 km in diameter [2]. The minimum size is difficult to constrain; the innermost ring (400 km diameter) may provide a lower limit to cavity size [2]. These constraints observed at the Orientale Basin are paralleled by similar relations of prebasin topography preserved within the Imbrium Basin (1160-km main rim diameter), where the prominence of the Apennine Bench indicates that the excavation cavity for the Imbrium Basin must be less than about 800 km in diameter [3]. These data indicate that the excavation cavity of multiring basins is between about 0.4 and 0.6 times the diameter of the apparent crater diameter [2–4,17].

Basin depths of excavation can be inferred from the composition of basin ejecta. At Orientale, basin ejecta are very feldspathic, having normative composition of noritic anorthosite, and mafic (basaltic) components cannot be present in quantities greater than a few percent [2]. Because evidence from other basins [16,20] and impact melts from Imbrium and Serentitatis [15] suggest a more mafic crustal composition at depth, this basin ejecta composition strongly suggests that basin excavation was limited to upper crustal levels [2]. At Orientale, the crust may be as thick as 100 ± 10 km [21]; thus, the maximum depth of excavation is on the order of about 50 km, suggesting an effective depth of excavation of about 0.1 ± 0.02 times the diameter of the excavation cavity [2–4]. Data from well-studied complex craters on the Earth suggest that the excavation cavity of complex craters is on the order of 0.5 to 0.65 times the diameter of the apparent crater [19]; the maximum depths of excavation are on the order of 0.09–0.12 times the excavation cavity diameter [19]. These numbers compare favorably with the admittedly poorly resolved lunar values [1–3], a conclusion substantiated by certain analytical methods [22]. The relatively shallow effective depths of excavation predicted by these various models account for the relative paucity of very deep crustal or mantle materials within the returned Apollo lunar samples [5,23].

Basin Ring Formation: A wide variety of mechanisms has been proposed to account for the formation of basin rings (see review in [1,5,7]). In my opinion, none of them are entirely plausible and the formation of rings constitutes the last great unsolved puzzle of multiring basin formation. Ring-forming mechanisms can be divided into two broad groups (see [1,6]): (1) forcible uplift due to fluidization of the target [5,24]; (2) concentric, brittle fracturing and failure of the target on regional (megaterraces [25]) to global scales (lithospheric fracturing [27]). Geological evidence supports portions of all of these models, but none of them completely or unequivocally. One constraint that has emerged from the examination of a variety of basins on a number of terrestrial planets is that basin rings are spaced at a constant factor, namely the famous $\sqrt{2}$ relation observed between adjacent rings [1,6,27]. Originally proposed only for the Orientale Basin [27,28], it has been found to be valid for all of the terrestrial planets and some icy satellites [1,6]. Because geological evidence supports divergent ring-forming models, it may be that the ring-locating mechanism is different from the ring-forming mechanism [6]. Thus, large-scale crustal foundering (megaterracing) could occur along concentric zones of weakness created by some type of resonant wave mechanism (fluidization and uplift); such immediate crustal adjustment could then be followed by long-term adjustment due to lithospheric fracturing. If the conundrum of ring genesis can be resolved, we will possess a good understanding of all of the principal phases of formation of multiring basins.

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SUDBURY PROJECT (UNIVERSITY OF MÜNSTER–ONTARIO GEOLOGICAL SURVEY): (3) PETROLOGY, CHEMISTRY, AND ORIGIN OF BRECCIA FORMATIONS.

D. Stöffler[1], A. Deutsch[1], M. Avermann[1,2], P. Brockmeyer[1,2], R. Lakomy[1,2], and V. Müller-Mohr[1,2], [1]Institut für Planetologie and [2]Geologisch-Paläontologisches Institut, Universität Münster, Wilhelm-Klemm-Str. 10 and Correnstr. 24, W-4400 Münster, Germany.

Within the Sudbury Project of the University of Münster and the Ontario Geological Survey [1] special emphasis has been put on the breccia formations exposed at the Sudbury structure (SS) because of their crucial role for the impact hypothesis [2]. They were mapped and sampled in selected areas of the North, East, and South Ranges of the SS ([3] and Fig. 1 of [2]). The relative stratigraphic positions of these units are summarized in Fig. 1. Selected samples were analyzed by optical microscopy, SEM, microprobe, XRF and INAA, Rb-Sr and Sm-Nd-isotope geochemistry [4], and carbon isotope analysis.

This abstract summarizes the results of petrographic and chemical analyses for those stratigraphic units that were considered the main structural elements of a large impact basin (see [1]).

Basement and Related Breccias (Fig. 1): The crystalline rocks underlying the Sudbury Igneous Complex (SIC), collectively called footwall rocks [5], display three types of impact-induced effects: (1) An 8–10-km-wide zone with planar deformation features in quartz immediately below the SIC indicating peak shock pressure up to about 20 GPa [6]. (2) An irregular, mostly lens-shaped, discontinuous heterolithic breccia zone along the contact of the SIC (Footwall Breccia = FB) that occasionally occurs in dikelike "intrusions" in the footwall rocks. The breccia matrix is crystalline with a dioritic composition and intersertal texture in an upper zone near to the SIC and a tonalitic-to-granitic composition and poikilitic to granular texture in a lower zone. The matrix texture is caused by thermal annealing and partial melting due to the overlying melt complex [7–9]. The clast lithologies in this breccia and its chemical

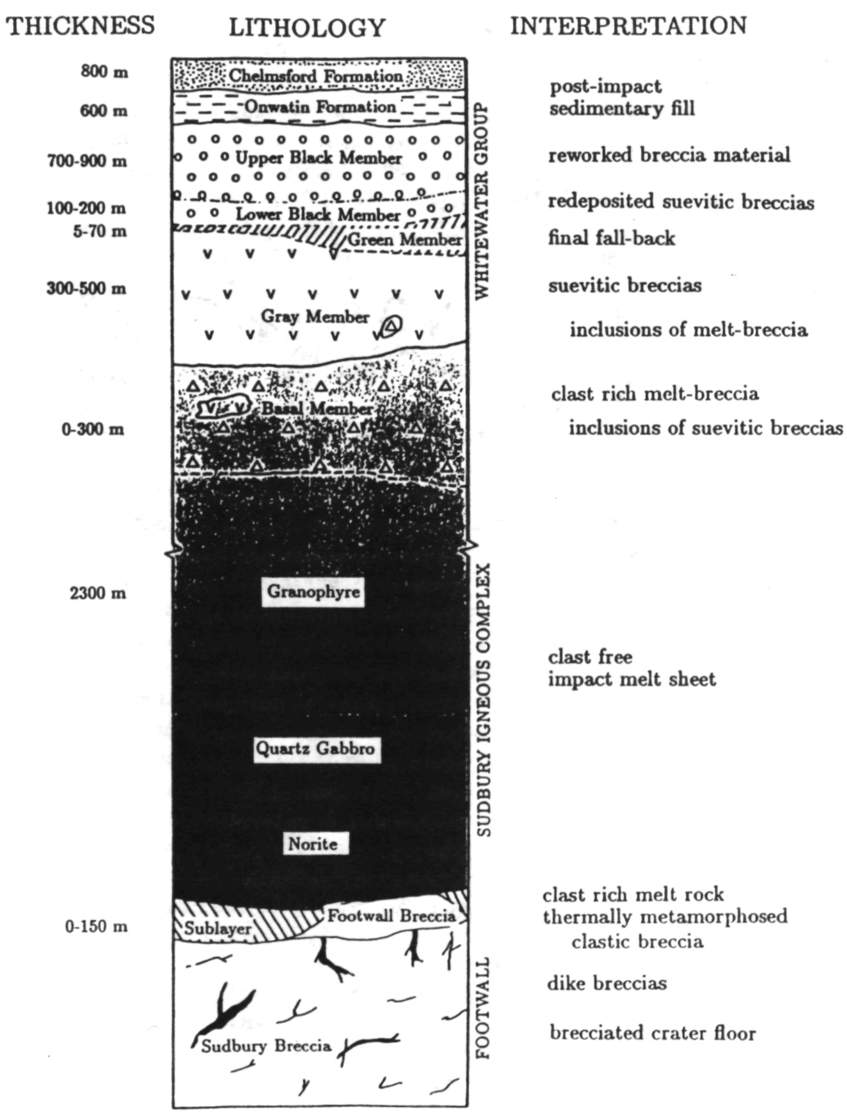

Fig. 1. Stratigraphic sequence at the Sudbury structure with the present genetic interpretation of the lithological units (modified from [12]).