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A geological, petrological, and geochronological study of the Grey Gabbro unit of the Podolsky Cu-(Ni)-PGE deposit, Sudbury, Ontario, with a focus on the alteration related to the formation of sharp-walled chalcopyrite veins

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ABSTRACT

An integrated geological, petrological, and geochronological study of the Grey Gabbro (GG) unit of the Podolsky Cu-(Ni)-PGE deposit, which is located in a radial dyke of the 1850 Ma Sudbury Igneous Complex (SIC), indicates it is a dislodged fragment of alkalic gabbroic basement rock with a minimum age of ca. 2714 Ma (U-Pb zircon). Petrographic textures in the GG record both the impact event (e.g. planar deformation features in zircon) and subsequent thermal overprinting from the cooling SIC melt sheet; U-Pb dating of epitaxial zircon overgrowths yielded concordant dates at ca. 1850 Ma. Petrological study of the GG adjacent to sharp-wall chalcopyrite veins provides a number of insights into the origin of mineralization in the high-sulphide Cu-PGE Podolsky deposit. 1) Actinolite fibres (<1-2 cm) occur both at vein margins and within the sulphide veins, indicating that they are synchronous with or pre-date vein injection. 2) Intense alteration with the formation of actinolite-epidote-quartz-chalcopyrite-magnetite assemblages is restricted in the GG to within <1-2 cm of vein margins. The same alteration assemblage does occur <20-30 cm into the GG but as micro-clots (<1 mm) and post-dates the thermal effects of the cooling SIC; hence, this provides a time frame for massive chalcopyrite vein formation. (3) At distances of >1 m from the sulphide veins, geochemical modification from fluid:rock interaction is minimal in the GG, with Cu the only distal indicator of mineralization (i.e. 100s ppm Cu). 4) Isotopic data (Sr, O, S) indicate that S in the Podolsky deposit is similar to that of the Whistle contact Ni-Cu deposit and is sourced from the melt sheet ($\delta^{34}S_{cpv}$ = 4.3%). These observations indicate that alteration within the GG is the result of the equilibration of hightemperature magmatic-derived fluids with the GG and that the GG is part of the pre-impact history of the area. Intense hydrothermal alteration in the GG occurs only adjacent (<10s cm) to the sharp-walled sulphide veins and thus does not provide a significant vector for exploration.

INTRODUCTION

The Podolsky Cu-(Ni)-PGE deposit, located in Norman township ~35 km north-northeast of Sudbury, is hosted by the Whistle-Parkin radial offset dyke that radiates outwards from an embayment structure in the Paleoproterozoic 1850 Ma (Krogh et al., 1984) Sudbury Igneous Complex (SIC; Fig. 1a,b). The Podolsky 2000 deposit (Fig. 1b) was an underground mine that produced ~1.5 M tonnes of 4.29% Cu, 0.38% Ni, 0.051 oz/t Pt, 0.054 oz/t Pd, and 0.024 oz/t Au, between 2007 and 2011 (Courtesy of KGHM International Ltd.). This deposit is a hybrid style deposit that displays aspects of both "sharp-walled" and "low-sulphide" style mineralization in the Sudbury Structure (Farrow et al., 2005). The 2000 deposit is situated ~650 m below the formerly producing Ni-Cu-Co Whistle deposit, which is located at the basal contact of the SIC and the radial Whistle-Parkin offset structure (Fig. 1b,c). This offset, which is host to the Podolsky 2000 deposit, is a northeast-trending structure and is atypical compared to most radial offset structures, which are generally composed of quartz diorite material. Instead, this offset dyke is dominated by metabreccia rock (i.e. metamorphosed breccia rock) that contains small bodies of quartz diorite rock, inclusionbearing quartz diorite, and pods of other intrusive phases that vary in size (i.e. <1 cm to 10s of m; Carter et al., 2009). One such pod in this offset dyke is a large fragment of gabbroic rock, which has been referred to informally as the grey gabbro (GG), that hosts part of

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Figure. 1. a) Simplified geological map of the Sudbury Structure showing the footwall rocks, the Sudbury Igneous Complex (SIC) and related offset and concentric dyke rocks, and basin-fill material, as well as the location of the different types of sulphide deposits (i.e. contact, offset, footwall). Note the location of the Podolsky deposit and Joe Lake gabbro, both in the north part of the map area (red filled circles), which are referred to in the text. The figure is modified from Ames and Farrow (2007). **b)** A schematic plan view of the Whistle embayment structure of the SIC in relation to the Whistle-Parkin offset (modified from Lightfoot et al., 1997). The map shows the relationship between the main rock types of the SIC along with the beginning of the NE-trending Whistle-Parkin offset. Note the presence of SIC units, which include the inclusion-rich sublayer norite that hosted the Ni-rich contact-style mineralization mined from the Whistle Pit by INCO. **c)** A northeast long section (line A and A' in Fig. 1b) of the Whistle embayment that shows, from top down, felsic norite, sublayer norite, Ni-rich mineralization, Whistle-Parkin offset, the Grey Gabbro (GG) unit and the 2000 deposit. The study area was located in the GG fragment which hosts a series of sharp-walled chalcopyrite veins from the 2000 deposit. Figure has been modified from Farrow et al. (2005).



Figure. 2. Images of the Grey Gabbro (GG) unit and sharp-walled sulphide veins. **a)** Scanned rock slab of sample LM-P-007 showing the texture typical of the GG unit with mafic (i.e. pyroxene, amphibole, biotite) and felsic (i.e. plagioclase) domains. **b)** Thin section scan of sample LM-P-007 (in plane polarized light) showing the typical gabbroic-like texture, but note the unusual scalloped outlines of the plagioclase against the mafic domains and the dusty cores of the plagioclase due to alteration. The brown phase is biotite. **c)** Underground photo (1925 level) of a sharp-walled chalcopyrite vein cutting GG. **d)** Cut slab of sample LM-P-060 collected from the 1700 level. The sample shows, from top to bottom, the GG, intensely altered GG (actinolite-epidote), actinolite grains or fibres (Act) and massive chalcopyrite (Ccp) that entrains the actinolite grains. **e)** The GG in contact with a chalcopyrite sharp-walled vein with actinolite along the contact, as seen in drillhole FNX40272. **f)** Thin section photomicrograph (in plane polarized light) of sample LM-P-060 showing rotated actinolite fibres along the contact of a chalcopyrite vein. **g)** A grain of actinolite from a prepared mineral separate from sample LM-P-060 (see Fig. 2d) that was used for ⁴⁰Ar/³⁹Ar dating and isotope analyses (O, Sr).

the "sharp-walled" vein systems of the Podolsky 2000 deposit.

This paper summarizes the results of a graduate thesis project by the second author (L. MacInnis, M.Sc. thesis, in prep.) that documents the nature and extent of alteration in the GG unit (Figs. 2a,b, 3a,b), both proximal and distal to its contained footwall-style mineralization (Fig. 2c). The GG unit is, as noted above, a large (230 m by 270 m) fragment that occurs in the Whistle offset dyke, which hosts thick (<1 m) sharpwalled veins of massive chalcopyrite, many of which contain narrow (i.e. cm-scale) epidote-actinolite-magnetite-bearing alteration halos (Fig. 2d-f). More specifically, the focus of the study was to characterize the mineralogy and geochemistry of the alteration specific to the sharp-walled vein mineralization to further our understanding of footwall-styled ore systems and to see if such data may provide criteria for vectoring towards mineralization in other footwall environments of the SIC. The massive and homogenous nature of the GG unit, combined with underground access to it and the sharp-walled veins in addition to the availability of historic drill core, made this site ideal for such a project. The study was broken into two parts in order to achieve its objectives:

- Characterize the mineralogy and geochemistry of the least altered host rock (i.e. GG) to the mineralization, as this formed the basis for the subsequent alteration study;
- · Assess the nature and origin of the alteration asso-



Figure 3. Remapped vertical (facing northwest) and plan view of the Podolsky Grey Gabbro fragment depicting the relationship of epidote alteration and foliation in relation to the sharp-walled Cu-(Ni)-PGE mineralization trend. Note where A and A' are in relation to the vertical and plan view maps.

ciated with the sharp-walled veins and compare it to the other known alteration present in the footwall environment of the SIC (e.g. Tuba et al., 2014 and references therein). The characterization and chemical fingerprinting of alteration-specific mineralization could provide criteria for targeting mineralization in other footwall environments.

METHODOLOGY

Mapping of the Grey Gabbro

The nature and origin of the GG unit had not previously been addressed, thus its genetic relationship to mineralization was not considered. For example, whether the GG unit was a passive host or active participant to mineralization has not been considered before this study. In order to answer this outstanding problem, the GG was studied to address two possible hypotheses: 1) The GG represented an 1850 Ma impact-generated melt compositionally related to the SIC or another source (i.e. mantle input); or 2) the GG represents a fragment of the pre-existing target area. At the time of this study, the provenance of GG was not known. To further our understanding of the unit, a comprehensive suite of 12 drillholes, which penetrated the GG unit horizontally and vertically, were re-logged using archived photos provided by KGHM International Ltd. and a geological map was produced (Fig. 3a,b). In order to assess the homogeneity of the GG unit, it was logged in 1.5 m intervals based on lithology, grain size, and texture in addition to the presence of alteration, foliation, and mineralization. The intensity of mineralization and alteration were also assessed based on the relative abundances of present phases present (see MacInnis et al., 2014). Information from several drill cores that penetrated the GG unit combined with underground visits were used to verify the maps that been produced from the photo library.

Sampling of Whole-Rock Materials and Geochemical Analysis

Seventy samples of the GG unit and its contained mineralization were collected from both underground workings and archived drill core; these samples provided the basis for petrological studies, including complete major and trace element chemistry, with a subset used for stable (O, S) and radiogenic (Sr) isotopic analysis (see below). The sample suite consisted of 19 least altered GG samples, 30 altered samples of GG, and 21 mineralized samples. The underground samples were collected between the 1700 and 2450 working levels of the deposit and included multiple transects leading up to sharp-walled chalcopyrite veins that were collected by using a diamond air saw. Full details of the sample locations and analytical techniques along with the geochemical data are presented in MacInnis et al. (2014).

Isotopic Analysis (O, Sr, S) and Geochronology (U-Pb and Ar-Ar dating)

A total of 20 samples, including nineteen whole-rock samples of the GG and one actinolite separate (see Fig. 2g), were analyzed for δ^{18} O at the Queen's University Facility for Isotopic Analysis, Kingston, Ontario. The same actinolite separate, 2 samples of least altered GG, a sample of the Joe Lake gabbro, which is an inferredage equivalent to the GG (see below)), and, for comparison with SIC compositions, 9 North Range offset dyke samples and 1 South Range grey gabbro (Segway), were analysed for 87Sr/86Sr isotopes at the Carleton University Isotope, Geochemistry and Geochronology Research Centre, Ottawa, Ontario. A comprehensive suite of 15 chalcopyrite samples collected from massive chalcopyrite sharp-walled veins in the GG, which included 3 detailed transects from 4 levels of the mine, were analysed for sulphur isotopes (δ^{34} S) at the G.G. Hatch Isotope Laboratories, Ottawa, Ontario. Methods and results for O, Sr, and S isotopic analyses are provided in MacInnis et al. (2014) and MacInnis (M.Sc. thesis, in prep.).

A sample of least altered, medium-grained GG with "salt-and-pepper" texture from the 1700 level of the Podolsky mine was selected for U-Pb zircon geochronology and was processed using conventional methods at the Geological Survey of Canada (sample 11AV-74; lab number z10633). The zircon separates, along with the host rock, were first characterized petrographically, which was followed by scanning electron microscopy (SEM) with backscattered electron (BSE) and catholuminescence (CL) imaging to fully characterize the unusual habit of the zircon (see the more detailed discussion below). The zircon grains were then dated using both isotope dilution-thermal ionization mass spectrometry (ID-TIMS; Mattinson, 2005) and the sensitive high-resolution ion microprobe (SHRIMP; Stern, 1997; Stern and Amelin, 2003). The same sample of actinolite used for O and Sr isotopic analyses, which was collected along the contact of the GG and a massive sulphide vein (see Fig. 2c,f), was selected for Ar-Ar dating. This vein sample was processed using standard methods (i.e. crushing, sieving, heavy liquids, hand picking) to generate a highpurity separate (Fig. 2g), which was subsequently irradiated and analysed at the Geological Survey of Canada; full details and results can be found in MacInnis et al. (2014).

RESULTS AND SUMMARY

Map of the Grey Gabbro Unit

Figure 3 shows a plan (1925 level) and sectional map for the GG unit and highlights the distribution of epidote alteration and mineralization, the latter represented by sharp-walled sulphide veins. The epidote alteration is confined to a portion of the GG and, based on mapping, does not appear to have any significant spatial association with the density of the sulphide mineralization, as might have been expected given the association of epidote with some mineralization in Sudbury area (e.g. Fraser deposit; Farrow and Watkinson, 1996). In addition, a weak foliation in the GG unit was observed at its northern end. This feature is also seen microscopically as an alignment of light and dark domains (a mixture of pyroxene, amphibole, and biotite). Another feature of interest was small leucocratic pegmatite bodies ($\leq 1-2$ m²) that occur rarely in the GG; however, these were too small and rare to portray on this map and, in addition, did not appear to have any obvious spatial distribution within the GG.

Petrology of the Grey Gabbro

The least altered GG is in general a medium- to finegrained, homogeneous unit, with a "salt-and-pepper" texture that is somewhat analogous to ophitic textured gabbro with felsic and mafic domains (Fig. 2a,b). Rare occurrences of possible chilled margins were noted in logging the GG, which was subsequently confirmed by company geologists based on their underground observations. Detailed petrographic studies integrated with imaging and chemical analyses using an SEM coupled to an energy dispersive system (EDS) indicate that the GG records a complex, multi-stage history involving initial crystallization and deuteric alteration, a shock metamorphic event, a thermal overprint, and finally a hydrothermal alteration event, as shown in representative petrographic images in Figure 4 and summarized as follows: 1) Domains of what is inferred to have been originally single grains of magmatic plagioclase now consist of sub-domains of granoblastic-textured plagioclase of 10-50 µm and An₅₀ composition (Fig. 4a,c,d). This feature is considered to reflect dynamic recrystallization due to thermal heat from the melt sheet. 2) Plagioclase is altered along internal grain boundaries and interiors to a quartz-An₂₀ plagioclaseepidote assemblage (Fig. 4d) and also to sericite, due to later fluid-mediated alteration related to the sulphide veins. In rare cases, the plagioclase occurs as patches of a ternary feldspar-like orthoclase phase. Interstitial to the grains are mafic clots consisting of mixed silicates (i.e. pyroxene, amphibole, biotite, Fe-Ti oxides, actinolite; Fig. 4e,f), which have a bulk composition equating to stoichiometric augitic pyroxene. These



Figure 4. Photomicrographs of Grey Gabbro that highlight the two main domains of primary clinopyroxene and plagioclase and also examples of alteration. **a**) Plagioclase grain (in plane polarized light) with a subhedral outline that appears to be largely (?) unaltered. Note the euhedral apatite grains to the right, and biotite and altered pyroxene grains to the left. **b**) Clinopyroxene grain (in plane polarized light) that has a subhedral outline and a fresh interior; **c**) Same plagioclase grains seen in image (a) that in cross-polarized light displays a granoblastic texture due to thermally induced recrystallization. **d**) Backscatter electron image of the granoblastic-textured plagioclase of An₅₀ composition. The bright phases are epidote and the dark phases that are intergranular to plagioclase are quartz and An₂₀ plagioclase. **e**, **f**) Examples (in cross polarized light) of clinopyroxene partially to completely pseudomorphed by actinolite.

clots likely represent the combined effects of shockrelated modification to the primary magmatic augitic pyroxene and later alteration due to fluids. 3) Zircon with planar deformation features (PDFs) and overgrowths of neomorphic zircon (se discussion below). The latter features in the zircons are considered to be related to the impact event. 4) Variable development of sericite, carbonate, and epidote with some sulphides disseminated in the GG as a result of fluid infiltration during sulphide vein formation. Proximal to sharpwalled veins, the GG is enriched in hydrothermal minerals (e.g. sericite, chlorite, quartz, actinolite, calcite, epidote, magnetite) along fractures and within dissolution features; the most intense development occurs <10 cm from the sulphide veins (Fig. 2d).

The volumetrically small pegmatite bodies, which consist of albite and quartz \pm potassium feldspar, are very fresh and notably do not record petrographic evidence of the complex textures seen in the GG unit, hence a different petrogenesis is probable. Further work is required, but we tentatively suggest that they may represent partial melting of the GG due to thermal metamorphism, which would be analogous to the generation of plagiogranite found in ophiolite complexes (e.g. Grimes et al., 2013).

The major element chemistry of the GG is very uniform, which is consistent with our drill-core logging and petrographic study, and equates to a gabbro of 50 wt% SiO₂ with some chemical evidence of a cumulate component (i.e. clinopyroxene accumulation). In addition, a subalkaline character for the GG is indicated from its Zr/TiO₂ ratio. The elemental abundances and mantle-normalized profile for the trace element data show enrichment of the large ion lithophile elements (LILE), depletion of high field strength elements (HFSE: in particular strongly negative Ta-Nb anomalies), a strong fractionation of the rare earth elements (REE) with (La/Lu)N ~40, and only a slightly negative Eu anomaly; these geochemical features are consistent with derivation of the GG from a previously metasomatized subcontinental lithospheric mantle reservoir. When compared to other intrusive rocks in the Sudbury area (e.g. dyke rocks, SIC units), the GG is geochemically most similar to the 2657 ± 9 Ma (Bleeker et al., 2013) Joe Lake intrusion that is located just west of Podolsky (Fig. 1). In broader terms, the trace-element chemistry and extended spider plots compare most favourably to those of ocean island basalts (OIB; Sun and McDonough, 1989).

Petrology of Altered Grey Gabbro

Adjacent to sharp-walled sulphide veins, the GG unit records two features that reflect reaction with a fluid. The first feature, seen immediately against the sulphide veins, is the presence of a thin layer of mono-mineralic actinolite fibres that are <1 to 2 cm in width and are oriented perpendicular to the wall rock GG (Fig. 2d-f). The second feature is intense alteration haloes of actinolite-epidote-quartz-sulphide-magnetite-chalcopyrite. These alteration haloes are <1 to 2 cm wide and are bordered by a zone of variably altered GG that gives way to least altered GG over 10 to 30 cm. The most notable petrographic feature of this alteration as observed in thin section is the presence of a network of connected pores that are commonly lined with epidote-actinolitemagnetite±chalcopyrite: these features are spatially coincident with the sericitic alteration of plagioclase near rare carbonate veins. We also note that quartz nearest the sulphide veins is intergrown with epidote and contains abundant hypersaline fluid inclusions with multi-solid phases that are petrographically similar to those observed in PGE-rich, low-sulphide footwall systems of the Sudbury Structure (e.g. Farrow et al., 1994; Molnár et al., 2001; Péntek et al., 2011; Tuba et al., 2014).

Geochemical analyses of samples collected across these alteration zones did not reveal appreciable chemical or mass change except close to the sharp-walled sulphide veins where the most altered samples show a mass gain relative to least altered samples and minor development of Eu anomalies due to alteration of plagioclase. Absolute changes in metal abundances occurred over only short distances from the veins (<20–30 cm), in particular gains of Cu, Ni, Au, Sn, Pd, Pt, Ag, and Zn. Interestingly, Cu is singularly enriched furthest from the veins without accompanying metal enrichment. In addition, sulphur, ferric iron, and loss on ignition reflected some mass gains relative to all other elements.

Stable and Radiogenic Isotopes

Oxygen isotopes were measured on four samples of least altered samples of GG and for traverses away from the veins into the GG; there was no apparent spatial correlation between δ^{18} O values of the GG unit and the sharp-walled chalcopyrite veins. The δ^{18} O values for the least altered GG of 6.7 to 8.1‰ (average = 7.3‰) compare to values of 6.5 ± 0.5‰ for samples from traverses adjacent the sharp-walled veins (see MacInnis et al. (2014) for data and details of samples). The δ^{18} O data indicate that there was no modification of the δ^{18} O signature of the GG due to vein-related
 Table 1. Sr isotope whole-rock data for mafic rocks in the

 Sudbury mineral district.

Sample	<u>87Sr</u> i	87 <u>Rb</u> 86Sr	87 <u>Sr</u> 86 <u>Sr</u> 1	±SE2	Description of Lithology
^a Podolsky C	Cu-PGE d	leposit			
LM-P-007	0.70183	0.1279	0.70683	0.000024	Least altered Grey Gabbro
LM-P-043G	0.70079	0.1812	0.70787	0.000008	Representative Grey Gabbro
LM-P-060	0.70209	0.0776	0.70512	0.000005	Intensely altered Grey Gabbro (actinolite separate)
^a Levack gno	eiss gabb	ro			(
12-AV-44	0.70167	0.0877	0.70509	0.000019	Joe Lake mafic intrusion
^b Offset dyk	es, SIC				
13-AV-06	0.70577	0.4148	0.71681	0.000020	Hess quartz diorite, margin
13-AV-08	0.70969	0.7164	0.72876	0.000014	Ermatinger quartz diorite, core
13-AV-10	0.69999	0.7157	0.71905	0.000015	Ermatinger quartz diorite, core
13-AV-12	0.71785	0.6991	0.73645	0.000006	Ministic quartz diorite, core
13-AV-13	0.70608	0.1622	0.71040	0.000006	Parkin quartz diorite, margin
13-AV-15	0.70708	0.4763	0.71976	0.000006	Parkin quartz diorite, margin
13-AV-17	0.71042	1.0357	0.73799	0.000012	Pele quartz diorite, margin
05-AV-15	0.71038	0.3218	0.71895	0.000005	Segway grey gabbro
13-AV-04	0.70722	0.4904	0.72027	0.000052	Trill quartz diorite, core
05-AV-33	0.67327	1.1956	0.70509	0.000019	Trill quenched quartz diorite
¹ analyzed wit IGGRC Car	th Thermo rleton Univ	finnigan versity	Triton T1	thermal ion	ization mass spectrometer,

²Uncertainties are presented as ± 2 standard errors (SE)

ainitial Sr (i) calculated at 2700Ma, binitial Sr (i) calculated at 1850 Ma

fluid infiltration and is consistent, which is in agreement with the geochemical data discussed previously. An actinolite separate collected from immediately against the sulphide vein had a δ^{18} O value of 5‰, which equates to a $\delta^{18}O_{H_2O}$ value between 6.1 and 6.9‰ at 400 to 600°C (Zheng, 1993) and is consistent with a fluid of unknown origin equilibrating with the GG unit and generating the actinolite under a low fluid:rock ratio and, hence, inheriting the δ^{18} O value of the GG unit.

Sulphur isotopic data across the sharp-walled veins (<1 m thick) are consistent with an average δ^{34} S value of 4.3 ± 0.3‰ (McInnis et al., 2014). These values are similar to those reported by other workers for the sulphide mineralization related to the SIC (e.g. Ames et al., 2010; Tuba et al., 2014), and therefore indicate a uniform isotopic reservoir for the S. This also suggests that the sulphides were deposited in the Whistle-Podolsky ore system under similar physio-chemical conditions since no variation, which would result from fractionation, is recorded. Furthermore, the data are consistent, as expected, with a dominantly crustal reservoir for the S versus a mantle source (i.e. departure from 0‰; Ohmoto and Rye, 1979).

Strontium isotopic data (i.e. ${}^{87}Sr/{}^{86}Sr$, Table 1) obtained for two samples of least altered GG indicate measured ${}^{87}Sr/{}^{86}Sr$ values of 0.70512, 0.70683, and 0.70787, which give age-corrected initial Sr isotope (Sr_i) values of 0.70079 to 0.70209 at 2700 Ma, the minimum estimated time for crystallization of the GG (see below), and Sr_i values of 0.70305 and 0.703042 at 1850 Ma, the age of the impact event and the sulphide mineralization. The Sr_i values for the GG at 2700 Ma overlaps with a single Sr_i value of 0.70167 for the geo-

chemically similar Joe Lake gabbro (also at 2700 Ma, Table 1) and are much lower than the Sr_i values for the offset dyke component of the radiogenic SIC (6 North Range offset dykes; Table 1). The single actinolite sample analysed yielded an initial 87 Sr/ 86 Sr value of 0.70305, its low Rb content not requiring age-correcting. That the initial 87 Sr/ 86 Sr value for the actinolite is similar to the GG value at 1850 Ma suggests that the actinolite formed due to reaction of a fluid with the GG at this time and is consistent with the 40 Ar/ 39 Ar dating of the actinolite (see below).

Geochronology

40Ar/39Ar Age Dating

The results of 10 out of 14 total fusion analyses of actinolite grains from adjacent a sharped-wall sulphide vein indicate a weighted mean age of 1850 ± 30 Ma (see MacInnis et al. (2014) for full results). This age is interpreted to record cooling of the actinolite below the argon blocking temperature, which is taken to be around 350 to 400°C in this phase (McDougall and Harrison, 1999). Importantly, the age overlaps (within error) the time of the Sudbury impact event (1849.53 \pm 0.21 Ma; Davis, 2008) and indicates, therefore, that in the study area a subsequent reheating to above 350 or 400°C did not occur after 1820 Ma, although we cannot say it did not occur prior to this time and after 1850 Ma. This latter interpretation is further verified based on the results of step-wise heating of actinolite grains from the same sample, which yielded flat age spectra profiles (MacInnis et al., 2014).

Zircon Morphology and U-Pb Thermal Ionization Mass Spectrometry and Sensitive High-Resolution Ion Microprobe Dating

Zircon Morphology

Examination of the zircon hosted by the GG unit indicated two distinct morphological types which, based on their proportions in the mineral separate prepared for dating, appear to be in roughly equal proportion. One of these zircon sub-populations consists of clear, colourless, euhedral, prismatic (elongate to stubby), well faceted, and terminated crystals with few fractures and rare clear inclusions (Fig. 5a). When examined in CL (Fig. 5b), the euhedral zircon grains are strongly luminescent and exhibit sharp oscillatory and sector zoning, which are features most commonly ascribed to growth from a silicate melt (Corfu et al., 2003). This morphological type of clear zircon was analysed for U-Pb dating by isotope dilution - thermal ionization mass spectrometry (ID-TIMS).

The second zircon sub-population consists of highly fractured, anhedral, pale brown to reddish brown, cloudy fragments (Fig. 5c) that occur as cores to the overgrowths of the clear, colourless zircon, which is tentatively linked to the euhedral morphology described above. The fractured zircon has relatively poor CL response, appearing as medium to dark grey (Fig. 5d), whereas the clear overgrowths luminesce strongly (Fig. 5d). Corresponding back scatter electron (BSE) images faintly mimic the zoning in the CL images, but more clearly illustrate the presence of fractures and inclusions (Fig. 5d). The BSE images clearly show that anhedral zircon is characterized by the presence of crystallographically oriented features, including short fractures or small pits. These features have been noted in zircons elsewhere and were attributed to planar deformation features resulting from shock impact (Krogh et al., 1984; Bohor et al, 1993; Krogh et al., 1993a, b; Pidgeon et al., 2011). Anhedral zircon, both with and without the euhedral overgrowths, was analysed for U-Pb dating by sensitive high-resolution ion microprobe (SHRIMP).

U-Pb Age Dating

Six single-grain fractions of euhedral zircon were analysed using ID-TIMS with five of the most concordant analyses (0.1–0.3%) yielding a mean ²⁰⁷Pb/²⁰⁶Pb age of 1849.9 ± 1.0 Ma; the sixth zircon analysed was more discordant (0.7%) and gave an age of 1854 Ma (Fig. 6, Table 2). The 1849.9 ± 1.0 Ma age is considered to represent the time at which these euhedral zircon grains grew, which is equate to the Sudbury impact event. Twenty-one U-Pb SHRIMP analyses were carried out on fifteen anhedral zircon grains, with a few analyses also hitting the euhedral overgrowths on these grains. These zircon analyses yielded a range of ²⁰⁷Pb/²⁰⁶Pb ages between 2606 Ma and 1706 Ma and were typically 3-10% discordant. Examination of the data in a concordia diagram (Fig. 6b) indicate that a linear array is defined with an upper intercept of ca. 2714 \pm 52 Ma, which is derived by anchoring the lower intercept at 1850 Ma, the inferred time of impact and resetting of the zircons (Fig. 6b, Table 3). The upper intercept is considered the best approximation of a minimum age for the GG, whereas the lower intercept is considered to reflect a resetting event and when the PDF in the zircon formed, which equates to the time of the Sudbury impact event.

SUMMARY OF THE FINDINGS AND IMPLICATIONS FOR EXPLORATION

1. The GG unit represents a large dislodged fragment of a previously crystallized alkali gabbro rock that formed at or before ca. 2714 Ma. This unit is correlated with its petrologically equivalent unit in the North Range footwall environment, the Joe Lake Gabbro, which has a minimum age of ca. 2657 ± 9 Ma based on U-Pb dating of inferred metamorphic



Figure 5. Photographs summarizing the various textures of zircon extracted from a sample of Grey Gabbro. **a**) Transmitted light photomicrograph of euhedral, prismatic zircon grains, after annealing for 48 h at 1000°C; photograph includes zircon grains analysed by TIMS. **b**) Cathodolumi-nescence (CL) images of euhedral, prismatic zircon. **c**) Transmitted light photomicrograph of anhedral zircon inferred to record shock metamorphic textures; some of these grains were selected for SHRIMP analysis. The arrows indicate the presence of overgrowths of euhedral zircon on the earlier, shocked zircon. **d**) Complementary CL (top) and BSE (bottom) images of shocked zircon with the grey arrow indicating an area of zircon overgrowth. Note the enhanced brightness of the euhedral zircon overgrowth relative to the anhedral shocked zircon. The crystallographically oriented features seen in the BSE (indicated by pairs of small, white arrows) are interpreted as impact-related planar deformation features. SHRIMP analysis sites are shown by black ellipses labelled with corresponding spot name shown in Table 3.

zircons (Bleeker et al., 2013). The geochemistry of the GG, and also the age and geochemically equivalent Joe Lake gabbro, indicates it was sourced from a previously metasomatised subcontinental lithospheric mantle and is unrelated to the SIC.

- 2. The GG is a macroscopically homogeneous unit, but detailed petrographic and SEM-EDS imaging studies indicate a complex textural history that involved extensive mineral re-equilibration. The latter feature is interpreted to reflect shock-induced metamorphism at ca. 1850 Ma due to the Sudbury impact event (e.g., zircon PDF features and overgrowths), then shortly thereafter thermal annealing related to the cooling melt sheet that overlay the site (e.g. plagioclase textures), and then superimposed hydrothermal alteration related to the emplacement of sharp-walled sulphide veins.
- ⁴⁰Ar/³⁹Ar age-dating of actinolite found along the contact of GG and sharp-walled sulphide veins records cooling of the area below ~350–400°C at ca. 1850 Ma and, furthermore, its flat age spectra indicates the area did not subsequently experience heating above this temperature.
- 4. Hydrothermal alteration of the GG adjacent to the sharp-walled sulphide veins is most intense nearest the veins (i.e. $\leq 10-20$ cm) with formation of a quartz-epidote-actinolite-magnetite-chalcopyrite zone that quickly becomes cryptic into the wall rock. Geochemically, the most distal indicator of the mineralization is elevated Cu (to 100s ppm up to 1 m away) without enrichment of other metals.
- 5. Isotopic analyses (Sr, O, S) indicate that the GG retains its primary isotopic signal for Sr and O despite alteration, whereas the O data for actinolite records $\delta^{18}O_{H_{2}O}$ values of 6.1 to 6.9‰ at 400 to



Figure 6. U-Pb concordia diagrams for zircon from the Grey Gabbro unit. a) Results for six zircon grains analysed by ID-TIMS with error ellipses plotted at 2σ . The calculated age of 1849.9 Ma excluded the most discordant sample, which is shown by the dashed ellipse. b) Results of SHRIMP analyses with error ellipses plotted at 2σ . Note the following: (1) pairs of analyses on a single grain are shown by colours other than light grey, (2) analyses of shocked zircon grains are shown by solid outlines and cluster towards 2400 Ma, (3) euhedral overgrowths are shown by dashed outlines and cluster at 1800 to 2000 Ma, and (4) the analysis excluded from regression (ellipse at 2200 Ma) is shown with no outline. Note that the regression line shown (dashed line) is anchored at 1850 Ma, the time of the impact event at Sudbury.

⁷ ract. ¹ Description ²	Wt.	D	Pb ³	206Pb4	Pb5	^{208}Pb	207Pb	±1SE	206Pb	±1SE	Corr. ⁷	207Pb	±1SE	206Pb =	±2SE	²⁰⁷ Pb ∃	±2SE	F qd ∠03	=2SE	%
	ng	mqq	nqq 1	1 204 Pb	pg	²⁰⁶ Pb	235U	Abs	238U	Abs	Coeff.	^{206}Pb	Abs	238U		235U		06Pb	Ι	Disc
Sample 11AV-74 (Z10633)																				
A16-1 Clr, Co, El, Pr, NM0	4	51	29	1781	7	0.87	5.1789	0.0075 (0.33207	0.00037	0.857111505	0.11311	0.00009	1848.4	3.6	1849.1	2.5 1	850.0	2.7	0.1
A16-2 Clr, Co, El, Pr, NM0	5	78	45	3977	7	0.90	5.1652	0.0061 (.33128	0.00030	0.908397397	0.11308	0.00006	1844.6	2.9	1846.9	2.0 1	849.5	1.9	0.3
A16-3 Clr, Co, St, Pr, nln, NN.	0 12	21	12	1190	4	0.84	5.1745	0.0080 (.33104	0.00034	0.800901953	0.11337	0.00011	1843.4	3.3	1848.4	2.6 1	854.1	3.4	0.7
C16-1 Clr, Co, El, Pr, M1	9	59	35	7873		0.98	5.1758	0.0061 ().33186	0.00031	0.926939444	0.11311	0.00005	1847.4	3.0	1848.6	2.0 1	850.0	1.7	0.2
C16-2 Clr, Co, El, Pr, M1	9	33	19	3776	0	0.92	5.1821	0.0069 (.33216	0.00037	0.908311575	0.11315	0.00006	1848.8	3.5	1849.7	2.3 1	850.6	2.1	0.1
C16-3 Clr, Co, El, Pr, M1	4	4	24	975	4	0.93	5.1826	0.0086 (0.33252	0.00034	0.800641518	0.11304	0.00012	1850.6	3.3	1849.8	2.8 1	848.8	3.7 -	0.1
All zircon fractions are com	posed	of sir	ngle g	grains an	iaw bi	re chen	nically a	braded 1	using a m	nodified p	rocedure fro	m Mattins	on (2005); all fra	ctions	compos	sed of	single g	rains	
Zircon descriptions: Co=coli M1=magnetic @ 1.8A 1oSS	ourless S.	s, Clr	=cle	ar, El=e	longa	te, Eu⁼	=euhedr:	ıl, nIn≕	numerou	s inclusio	ns, Pr=prism	atic, St=st	ubby pris	sm, NMC)=non	-magnet	tic @1	8A 00S	Š	
Radiogenic Pb																				
Measured ratio, corrected fo	r spik	e and	l frac	tionation	u															
Total common Pb in analysi:	s corre	scted	for f	fractiona	tion a	and spil	ke													
Corrected for blank Pb and	U and	com	mon	Pb, erro.	rs quc	oted are	e 1 sigme	absolu	te; proce	dural bla	nk values for	this study	/ are 0.1	pg U and	l 1 pg	\mathbf{Pb}				
Pb blank isotopic composit:	ion is l	basec	d on 1	the analy	ysis o	f proce	dural bla	inks; coi	rrections	for com	non Pb were	made usi	ng Stacey	and Kra	umers	(1975) (compo	sitions		
Correlation Coefficient																				
Corrected for blank and con	l nom	Pb, e.	rrors	quoted	are 2(σ in Ma	1													
The error on the calibration	of the	GSC	3 205F	•b-233U-	235U (spike u	tilized in	this stu	dy is 0.2	2% (2s)										

Table 2. U-Pb TIMS analytical data of six grain fractions of a euhedral zircon found in sample 11AV-74 (Z10633).

	Spot name	þ	Тh	ЧТ	٩X	Ŧ	²⁰⁴ Pb	%	²⁰⁶ Pb*	f(206) ²⁰⁴	^{208*} Pb	%	^{207*} Pb	%	^{206*} Pb	%	Corr	^{207*} Pb	%	^{206*} Pb	^{207*} Pb		Disc.
10633-82 11 20 194 61 27 10633-82 11 20 134 61 22 134 23 55 23 63 21 0335 174 64 7091 34-5 25 61 0331 156 033 63 0315 01128 113 63 134-5 13 54 135 13 54 0333 15 0315 01128 21 131 131 131 131 131 131 131 131 131 131 131 131 132 131 131 131 131 131 132 131 131 131 132 131 131 132 131 131 131 131 132 131 131 131 132 131 131 131 131 132 131 131 131 131 131 131 131 131 131 131 131 131 131 <th></th> <th>(mqq)</th> <th>(mdd)</th> <th> ></th> <th>(mdd)</th> <th>(mdd)</th> <th>²⁰⁶Pb</th> <th>+I</th> <th>(mdd)</th> <th>%</th> <th>^{206*}Pb</th> <th>+I</th> <th>²³⁵U</th> <th>+1</th> <th>²³⁸U</th> <th>+1</th> <th>Coeff</th> <th>^{206*}Pb</th> <th>+1</th> <th>²³⁸U ±</th> <th>^{206*}Pb</th> <th>+1</th> <th>%</th>		(mqq)	(mdd)	>	(mdd)	(mdd)	²⁰⁶ Pb	+I	(mdd)	%	^{206*} Pb	+I	²³⁵ U	+1	²³⁸ U	+1	Coeff	^{206*} Pb	+1	²³⁸ U ±	^{206*} Pb	+1	%
10633-562 29 51 186 70 716 64 711 1816 60 138 50 111 1816 60 138 60 136 136 0137 1575 20 1174 64 7001 34E3 20 3 5821 0.476 38 525 116 533 1530 0.148 0.53 0.234 0.1491 0.5 2167 221 1033 0.235 0.1491 0.5 2176 221 1033 0.231 0.1491 0.5 2176 221 1033 0.231 0.1491 0.5 2176 221 1033 0.231 1033 0.231 0.1491 0.5 2176 231 231 233 111 226 317 230 136 316 317 230 136 317 230 137 230 137 230 137 230 231 231 231 231 231 231 231 231 </th <th>10633-8.2</th> <th>11</th> <th>20</th> <th>1.94</th> <th>61</th> <th>7870</th> <th>3.2E-3</th> <th>20</th> <th>ю</th> <th>5.587</th> <th>0.547</th> <th>4.2</th> <th>4.60</th> <th>9.3</th> <th>0.319</th> <th>1.75</th> <th>0.188</th> <th>0.1046</th> <th>9.2</th> <th>1784 27</th> <th>1707</th> <th>169</th> <th>-5.2</th>	10633-8.2	11	20	1.94	61	7870	3.2E-3	20	ю	5.587	0.547	4.2	4.60	9.3	0.319	1.75	0.188	0.1046	9.2	1784 27	1707	169	-5.2
10633-12 12 20 1/4 64 7091 3.4E-3 20 5 4.154 0.552 30 5.29 6.1 0.333 3.67 0.315 0.1158 110 1876 60 10633-21 18 3 12 1.22 1.42 127 9667 8.94 153 0.55 1.16 0.333 1.15 0.2927 0.1491 0.5 2167 25 10633 2.16 3.33 3.57 0.135 1.10 1356 2.0 1439 10.5 2167 25 10633 2.31 11 22 1.22 1.42 127 9667 8.94 4.2 0.337 1.5 2.24 1.2 19 667 8.94 2.0 0.337 1.5 0.537 1.10 6.0 0.150 0.155 0.053 0.153 0.153 1.0 1053 1.1 11 25 2.1 10 0.13 0.5 1.1 0.033 0.15 0.1 11 0.2 16 2.1 0.33 0.15 0.016 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15	10633-36.2	29	51	1.85	79	9640	7.9E-5	46	œ	0.137	0.575	2.9	5.03	2.1	0.325	1.74	0.845	0.1121	1.1	1816 28	1834	20	1.1
10633-22 19 34 136 73 716 24F-3 20 5 4154 0.552 30 52.9 61 0.331 156 59 61 0.331 156 50 167 22 10633-71 128 122 142 120 88 12 144 0.39 0.553 0.491 0.553 0.557 110 0.915 0.1491 0.5 1149 0.5 1149 0.5 1149 0.5 1149 0.5 0.554 116 0.392 0.1491 0.5 1149 0.5 1149 0.5 1149 0.5 1149 0.5 1149 0.5 1149 0.5 1149 0.5 1149 0.5 1149 0.5 1149 0.5 1149 15 0.49 1149 0.5 1149 15 0.49 1147 1149 0.55 1147 0.55 1147 0.55 1149 1145 0.416 1147 0.55	10633-1.2	12	20	1.74	64	7091	3.4E-3	20	ო	5.821	0.476	3.8	5.25	11.6	0.338	3.67	0.315	0.1128	11.0	1876 60	1845	200	-1.9
10633-21 189 122 142 124 124 124 124 124 124 124 124	10633-2.2	19	34	1.86	73	7716	2.4E-3	20	2	4.154	0.552	3.0	5.29	6.1	0.331	1.56	0.254	0.1160	5.9	1843 25	1896	107	3.2
10633-7.1 126 24 198 182 9100 30E5 85 44 0.052 0.574 11 8.39 11 0.400 103 0.0149 10.4 2206 15 0.0533 0.155.5 18 1 87 1.10 67 515 2.77 55 15 10 0.533 0.155.5 19 20 0.539 0.155.6 10.4 2261 20 0.533 0.155.5 11 226 2.10 231 2.17 2281 22 10633-11 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.11 2281 22 10633-101 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 11 226 2.10 231 21 0.033 0.1594 0.9 231 21 0.033 0.1594 0.9 231 21 0.033 0.1594 0.9 231 21 0.033 1.19 0.01 12 0.432 1.10 0.857 1.12 2364 2.10 233 2.11 139 2.57 1.91 2.11 185 10034 2.65 51 0.117 0.548 1.10 249 1.10 0.423 1.14 0.789 0.1605 0.9 2275 2.16 333 1.1 339 2.21 22 0.03 0.1594 0.9 231 2.10 2.033 1.1 39 2.57 1.19 2.21 2.2 0.033 2.1 9 37 1.4 0.729 0.160 0.9 2275 2.10 0.53 2.1 139 2.57 1.139 2.57 1.91 2.11 874 6.8E-5 65 51 0.117 0.548 1.0 9.49 1.1 0.428 1.00 2.0 231 2.10 2.033 2.1 0.37 1.4 0.771 0.035 0.150 0.5 2298 2.0 0.033 2.1 11 22 2.2 2.12 0.96 1.125 2.2 2.15 0.033 2.1 9 3.7 1.4 0.971 0.166 0.5 229 2.0 0.53 1.0 2.33 2.1 139 2.57 1.1 139 2.57 1.91 2.11 874 6.8E-5 65 51 0.117 0.548 1.0 0.157 1.10 0.422 1.14 0.971 0.1665 0.5 2298 2.0 0.53 1.0 2.33 2.1 32 2.2 0.95 1.10 0.17 2.348 2.1 0.53 1.0 2.33 2.10 2.33 2.1 132 2.2 0.95 1.1 10.92 2.1 0.00 1.5 0.442 1.17 0.201 0.5 2.2 0.053 2.1 0.533 1.1 22 0.53 1.1 22 2.1 10.00 1.5 0.448 1.26 0.50 0.1655 0.0 2.200 2.053 1.0 0.00 0.00 0.00 0.00 0.00 0.00 0.00	10633-2.1	89	122	1.42	121	9867	8.9E-4	20	30	1.536	0.418	2.4	7.31	2.4	0.399	1.23	0.518	0.1326	2.0	2167 23	2133	36	-1.8
10633-15.1 81 87 1.10 67 9579 -2.7E5 37 27 0.047 0.330 1.8 8.03 1.1 0.330 1.4 0.915 0.1491 0.5 2179 28 10633-35.1 11 226 2.10 204 8823 3.5E5 41 38 0.533 0.549 0.545 0.4 2187 219 28 10633-411 1 226 2.10 204 8823 3.5E5 41 38 0.563 0.553 2.1 8.81 1.2 0.404 1.14 0.930 0.1545 0.4 2187 23 10533-41 11 11 226 2.10 204 8823 3.5E5 41 38 0.053 0.553 1.7 0.431 1.2 0.404 1.14 0.930 0.1555 1.7 2281 28 10633-41 11 1 226 2.10 204 182 3.5E5 41 38 0.059 0.546 2.2 9.15 2.3 0.425 1.51 0.668 0.1562 1.7 2281 28 10633-41 11 1 226 2.10 204 182 1033 2.15 2.3 0.432 1.2 0.404 1.14 0.930 0.1562 1.7 2281 29 1053-41 11 68 146 2.19 153 6941 1.7E4 33 26 0.298 0.643 1.3 9.40 1.2 0.432 1.27 0.867 0.157 0.12 2364 22 10633-311 105 207 1.21 185 10034 2.5E4 28 63 0.448 0.365 1.1 0.422 1.2 0.432 1.12 0.809 0.1605 0.9 2313 21 0633-11 1 105 207 1.21 185 10034 2.5E4 28 63 0.448 0.356 1.1 0.423 1.4 0.423 1.4 0.799 0.165 0.9 2313 21 0533-11 1 105 207 2.04 209 8.7E5 1.1 10.19 1.2 0.447 1.17 0.842 0.166 0.05 2.298 21 0533-11 1 105 207 2.04 209 8.7E5 51 0.0033 0.275 1.1 0.19 1.2 0.447 1.17 0.842 0.166 0.05 2.298 21 0533-11 1 105 207 2.04 209 1126 0.033 0.175 0.15 2.300 2.75 1.1 0.19 1.2 0.452 1.14 0.971 0.1635 0.3 2405 21 0633-11 1 105 207 2.04 209 8.7E5 51 0.0033 0.277 1.9 0.001 1.2 0.445 1.14 0.971 0.1635 0.3 2405 21 0633-11 1 105 207 2.04 209 1120 0.05 2.340 22 10633-11 2 204 1.10 0.827 1.10 0.12 2.331 2.10 2.331 2.10 2.331 2.10 2.343 2.10 0.55 2.448 2.10 0.033 0.477 1.10 0.827 0.160 0.05 2.390 2.10 0.333-11 0.05 2.1 224 2.5 1053-112 0.205 0.165 2.1053-2.1 226 2.10 0.053 0.175 0.05 2.133 2.10 0.55 2.448 2.10 0.053 2.11 0.10 1.2 0.465 1.16 0.01 2.2 0.35 0.12 2.10 2.10 2.331 2.10 2.243 2.10 0.053 0.175 0.05 2.1333-11 0.053 1.2 204 2.11 0.10 1.2 0.465 1.10 0.37 2.130 2.10 2.243 2.10 0.053 2.140 2.11 0.053 2.11 0.10 1.2 0.465 0.10 2.124 2.5 1066 0.165 2.1340 0.17 2.048 1.10 0.050 0.175 0.05 2.433 2.10053 0.175 0.125 0.05 2.05 0.002 0.55 2.448 2.10 0.050 0.175 0.05 2.243 2.100 0.053 0.175 0.105 0.05 2.048 0.106 0.05 2.243 2.100 0.053 0.177 1.9 0.051 1.10 0	10633-7.1	126	242	1.98	182	9100	3.0E-5	85	44	0.052	0.574		8.39		0.408	1.03	0.927	0.1491	0.4	2206 19	2335	7	6.6
10633-61 38 55 152 81 7516 3.1E4 64 13 0.531 0.429 2.3 8.34 2.4 0.402 1.50 0.632 0.1564 1.8 2187 21 0.033-51 18 18 1.14 0.390 0.1545 0.4 2187 21 0.533-51 18 197 1.90 197 1.90 181 10033 0.1552 1.7 2281 22 0.533 0.1533-51 186 1.97 1.90 197 1.90 181 10033 0.1552 1.7 2281 22 0.533 0.1533-51 186 1.97 1.90 181 10033 0.1562 1.7 2281 22 0.533 0.1333-51 186 1.97 1.90 195 0.167 1.2 2364 25 0.0533-51 186 191 7683 1.86 1.86 1.16 4.04 2.58 306 7629 5.4E5 2.34 61 0.094 0.746 1.4 9.63 1.7 0.443 1.24 0.718 0.1576 1.2 2364 25 0.0533-51 186 191 7685 1.8E 4 3 3 24 0.071 1.9 9.49 1.6 0.422 1.7 0.803 0.1569 0.6 231 2 236 2.0533-51 173 202 1.21 185 10034 2.6E4 28 63 0.448 0.336 2.1 9.37 14 0.422 1.17 0.802 0.1606 0.9 2275 2 0.0533-51 133 257 1.91 2.11 712 0.242 1.14 0.977 0.166 0.05 2298 20 0.653-51 132 201 193 2.07 2.04 2.05 191 2.043 1.17 0.842 0.160 0.5 2298 20 0.653-51 132 201 1003 3.5 2.2E5 41 90 0.0130 0.572 1.9 9.92 1.4 0.427 1.17 0.842 0.160 0.5 2298 20 0.653-51 132 201 2.095 149 122 0.427 1.17 0.842 0.166 0.9 2275 2 0.053-51 132 221 2095 1.91 2.034 8.7E5 2.1 0.013 0.577 1.9 0.100 1.5 0.440 1.31 0.842 0.165 0.8 236 2.1063 0.5 236 2 0.053-51 132 240 5.2 1003 3.5 2.2E5 41 90 0.033 0.777 1.9 0.100 1.5 0.440 1.24 0.842 0.165 0.8 236 2 0.053-51 132 2405 2.163 0.15 2.045 1.11 0.053-51 85 166 0.15 2.013 0.773 1.0 0.15 0.440 1.24 0.842 0.166 0.9 233 2.265 2 0.033 0.557 1.1 0.100 1.5 0.440 1.24 0.865 0.1653 0.8 236 2 0.053 0.553 1.0 0.55 2.445 2 0.033 0.557 1.1 10.17 1.2 0.435 1.0 0.903 0.1750 0.5 2.439 25 10633-51 82 10633-51 82 0.033 0.5751 1.000 1.5 0.440 1.24 0.861 0.1663 0.1 242 22 10633-51 2.0569 0.663 0.122 0.366 0.1653 0.8 233 2.65 2.003 0.5566 0.1650 0.9 2.538 2.1 0.653 0.8 2.0360 0.1750 0.5 2.439 25 10633-51 2.0103 0.55 2.648 2.100 0.500 0.0500 0.1750 0.5 2.439 25 10633-51 2.0103 0.5500 0.6500 0.9000 0.1750 0.5 2.439 25 106300 0.962 0.9000 0.0500 0.0500 0.0500 0.1750 0.5 2.439 25 106300 0.962 0.132 0.0600 0.9000 0.1750 0.5 2.439 25 106300 0.962 0.132 0.0600 0.9000 0.1750 0.5 2.439 25 106300 0.122 0.0600 0.9000 0.1760 0.0	10633-15.1	81	87	1.10	67	9579	-2.7E-5	37	27	-0.047	0.330	1.8	8.03		0.390	1.04	0.915	0.1491	0.5	2125 19	2336	œ	10.6
10633-19.1 111 226 2.10 204 6823 3.6E-5 41 38 0.063 0.623 1.1 8.61 1.2 0.401 0.155 0.490 0.156 0.157 0.15 0.417 0.251 221 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.443 1.2 0.433 0.157 0.157 0.157 0.15 233 231 <t< th=""><th>10633-36.1</th><th>38</th><th>55</th><th>1.52</th><th>81</th><th>7516</th><th>3.1E-4</th><th>64</th><th>13</th><th>0.531</th><th>0.429</th><th>2.3</th><th>8.34</th><th>2.4</th><th>0.402</th><th>1.50</th><th>0.632</th><th>0.1504</th><th>1.8</th><th>2179 28</th><th>2351</th><th>32</th><th>8.6</th></t<>	10633-36.1	38	55	1.52	81	7516	3.1E-4	64	13	0.531	0.429	2.3	8.34	2.4	0.402	1.50	0.632	0.1504	1.8	2179 28	2351	32	8.6
10633-61 108 197 1.90 181 10083 2.8E4 62 39 0.490 0.546 2.2 9.15 2.3 0.425 1.51 0.668 0.1562 1.7 2281 22 10633-101 161 404 2.58 306 7829 5.4E-5 234 61 0.094 0.746 1.4 9.63 1.7 0.433 1.24 0.718 0.1576 1.2 2364 22 10633-3.11 163 2.12 189 153 6941 1.7E4 33 2.6 0.299 0.643 1.3 9.40 1.5 0.422 1.27 0.803 0.1594 0.9 2275 22 10633-3.11 173 2.02 1.21 187 18 7.16 8.5 1 0.117 0.548 1.0 9.49 1.1 0.423 1.14 0.789 0.1605 0.9 2275 22 10533-3.11 139 257 1.91 1874 6.8E-5 65 51 0.117 0.548 1.0 9.49 1.1 0.423 1.14 0.789 0.1605 0.9 2275 22 10533-3.11 155 207 2.04 2.058 8.716 5.2 14 0.0 0.572 1.9 9.39 1.1 0.423 1.14 0.789 0.1605 0.9 2275 22 10533-3.11 155 207 2.04 2.58 83 0.344 8.7E-5 21 40 0.150 0.572 1.9 9.39 1.1 0.423 1.14 0.789 0.1605 0.9 2275 2 10533-3.11 105 207 2.04 2.18 874 6.8E-5 65 51 0.117 0.548 1.0 9.49 1.1 0.423 1.14 0.797 0.1633 0.3 2405 2 10533-4.1 64 1.06 1.71 108 823 4.8E-5 71 40 0.0572 1.9 10.00 1.5 0.440 1.31 0.865 0.1650 0.8 2350 26 10633-3.1 132 249 1.95 221 8729 5.3E-5 41 90 0.038 0.257 1.9 10.00 1.5 0.440 1.31 0.865 0.1650 0.8 2350 26 10633-3.1 122 249 1.95 221 8729 5.3E-5 71 20.019 0.577 1.9 10.07 714 0.460 1.24 0.861 0.1633 0.3 7 2493 2 10633-3.1 122 249 1.95 221 8729 5.3E-5 50 0.092 0.577 1.9 10.07 1.2 0.455 1.17 0.370 0.153 0.3 2405 2 10633-3.1 122 157 1.20 1.885 0.1650 0.18 2233 4.16 2.105 0.165 0.18 200 0.155 0.1057 0.10 1.5 0.440 1.31 0.865 0.1650 0.8 2350 2 10633-3.1 122 157 1.20 1.38 835 -1.1E-5 39 22 0.0139 0.577 1.9 10.07 1.1 0.040 1.24 0.861 0.1683 0.7 2439 2 10633-3.1 201631 2.21 371 2.21 371 2.21 371 2.20 1.85 0.1650 0.1 220 188 2.00 0.1650 0.1 20000 0.557 1.9 10.00 1.5 0.448 1.6 0.423 1.0 0.903 0.1750 0.5 2340 2 2 10633-3.1 2065 0.8 2350 2 10633-3.1 2065 0.8 2230 2 10633-3.1 2065 0.8 2230 2 10633-4.1 20000 0.15 0.0440 1.24 0.861 0.1688 0.1 24 0.861 0.1688 0.1 2406 0.1 2000 0.0500 0.1 20000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0000 0.1 0.0	10633-19.1	111	226	2.10	204	6823	3.6E-5	4	38	0.063	0.623		8.61	1.2	0.404	1.14	0.930	0.1545	0.4	2187 21	2396	œ	10.3
10633-10.1 161 404 2.58 306 7629 5.4E-5 234 61 0.094 0.746 14 9.16 0.176 1.2 2364 25 10633-11.1 69 148 2.16 135 0.163 0.843 13 9.40 12 0.432 1.77 0.833 0.159 0.633 1.14 0.789 0.165 0.933 2.17 0.803 0.159 0.93 0.153 0.133 2.17 0.803 0.159 0.93 2.17 0.833 0.153 0.133 2.17 0.803 0.159 0.93 0.215 0.117 0.548 1.9 0.60 0.15 0.447 1.17 0.848 1.1 0.447 1.17 0.848 1.9 0.66 0.1 0.949 1.17 0.837 0.1605 0.9 2.305 2.16 0.0 0.235 1.1 0.19 0.447 1.17 0.843 2.16 0.0 0.233 2.405 2.5 1.0 <t< th=""><th>10633-6.1</th><th>108</th><th>197</th><th>1.90</th><th>181</th><th>10083</th><th>2.8E-4</th><th>62</th><th>39</th><th>0.490</th><th>0.546</th><th>2.2</th><th>9.15</th><th>2.3</th><th>0.425</th><th>1.51</th><th>0.668</th><th>0.1562</th><th>1.7</th><th>2281 29</th><th>2415</th><th>28</th><th>6.6</th></t<>	10633-6.1	108	197	1.90	181	10083	2.8E-4	62	39	0.490	0.546	2.2	9.15	2.3	0.425	1.51	0.668	0.1562	1.7	2281 29	2415	28	6.6
10633-11 69 146 2.19 153 6941 1.7E-4 33 26 0.298 0.643 1.3 9.40 1.2 0.432 1.07 0.857 0.1579 0.6 2313 251 10633-211 139 2.16 191 7885 1.8E-4 33 26 0.310 0.601 1.9 9.49 1.6 0.789 0.1650 0.9 2275 221 10633-211 105 207 1.204 205 8034 8.7E-5 21 40 0.150 0.572 1.9 9.49 1.6 0.47 1.17 0.842 0.1650 0.9 2313 251 1.91 211 874 6.8E-5 51 0.117 0.63 1.02 1.46 0.17 0.875 1.0 0.31 0.44 1.0 0.93 0.1650 0.9 231 240 2.3 240 2.3 2405 2.1 8.7E-5 50 0.003 0.577 1.001 1.0<	10633-10.1	161	404	2.58	306	7629	5.4E-5	234	61	0.094	0.746	4. 4	9.63	1.7	0.443	1.24	0.718	0.1576	1.2	2364 25	2430	20	3.2
10633-2.1 90 189 2.16 191 7685 1.8E-4 34 34 0.310 0.601 1.9 9.49 1.6 0.432 1.27 0.803 0.1594 0.9 2313 25 10633-9.1 173 202 1.21 185 10034 2.6E-4 28 6.3 0.448 0.336 2.1 9.37 1.4 0.789 0.1605 0.9 2275 22 165 203 2.127 0.803 0.1616 0.7 2381 25 10533-11 105 207 2.04 2051 1.9 10.17 0.548 1.0 9.99 1.1 0.428 1.17 0.842 0.1610 0.7 2381 25 1653-13 132 232 212 0.95 149 11253 2.2E-5 41 90 0.038 0.575 1.1 10.19 1.2 0.452 1.14 0.971 0.1635 0.3 2405 25 10533-1.1 32 249 1.95 221 8729 5.3E-5 50 0.092 0.527 1.9 10.01 1.5 0.440 1.31 0.865 0.1650 0.8 236 240 5.31 6.4 106 1.71 108 8233 4.8E-5 71 25 0.033 0.474 2.6 10.44 1.6 0.458 1.24 0.86 0.1650 0.8 2360 2 10633-2.1 132 249 1.95 221 8729 5.3E-5 50 0.092 0.577 1.9 10.67 1.4 0.451 1.3 0.865 0.1650 0.8 2350 2 10633-4.1 6.4 106 1.71 108 8233 4.8E-5 71 25 0.033 0.474 2.6 10.44 1.6 0.458 1.28 0.793 0.1653 1.0 2432 25 10633-4.1 6.4 106 1.71 108 8233 4.8E-5 71 25 0.019 0.577 1.9 10.67 1.4 0.450 1.24 0.861 0.1683 0.7 2432 25 10633-4.1 221 571 2.67 376 7 7.31 0.057 1.4 0.450 1.24 0.861 0.1683 0.7 2432 25 10633-4.1 2.0 0.895 0.965 0.1650 0.8 2360 2.7 10633-2.1 10.170 1.2 0.485 1.068 0.1653 0.3 0.7 2432 25 10633-4.1 6.4 106 1.71 108 8233 4.8E-5 71 25 0.019 0.577 1.9 10.67 1.4 0.450 1.24 0.861 0.1683 0.7 2432 25 10633-4.1 647 1.6 0.865 0.1650 0.8 236 2.1 16630 0.8 236 2.1 16630 0.8 236 2.1 16030 0.577 1.9 10.67 1.4 0.450 1.24 0.861 0.1683 0.7 2432 25 10633-4.1 efters to radiogenic Pic convention x-y.z; where x = sample number, y = grain number and z = spot number 12 0.68 0.163 0.050 0.15 2.48 20 1.063 0.15 0.500 0.15 2.64 20 1.71 0.063 0.15 0.5 2.54 8 20 1.003 0.1750 0.5 2.54 8 20 1.003 0.1750 0.5 2.54 8 20 10630 0.16 0.700 0.15 0.80500; 0.8 0.203 0.1750 0.5 2.54 8 20 1.000 1.5 0.80500; 0.8 0.203 0.1750 0.5 2.54 8 20 10630 0.8 0.500 0.9 0.557 1.1 11.70 1.2 0.486 1.04 0.0180 0.100 0.15 0.163 0.105 0.105 0.10 7 1.0 0.160 0.100 0.15 0.160 0.100 0.15 0.105 0.	10633-1.1	69	146	2.19	153	6941	1.7E-4	33	26	0.298	0.643	1.3	9.40	1.2	0.432	1.07	0.857	0.1579	0.6	2313 21	2434	5	5.9
10633-9.1 173 202 1.21 185 10034 2.6E-4 28 63 0.448 0.336 2.1 9.37 1.4 0.423 1.14 0.789 0.1605 0.9 2275 22 10633-21.1 105 207 2.04 205 8024 8.7E-5 21 40 0.117 0.548 1.0 9.49 1.1 0.428 1.03 0.897 0.1610 0.7 2381 23 10633-21.1 105 207 2.04 205 8024 8.7E-5 21 40 0.150 0.572 1.9 9.92 1.4 0.447 1.17 0.842 0.1610 0.7 2381 23 10633-21.1 212 0.95 1.9 1.95 21 8729 5.2E-5 41 90 0.032 0.577 1.9 10.01 1.5 0.440 1.31 0.665 0.8 2365 25 10633-2.1 10.19 1.2 0.452 1.14 0.971 0.1635 0.3 2360 25 10633-2.1 132 249 1.95 221 8729 5.3E-5 50 50 0.092 0.577 1.9 10.01 1.5 0.440 1.31 0.665 0.1650 0.8 2350 25 10633-2.1 85 167 2.02 184 8385 -1.1E-5 38 34 -0.019 0.577 1.9 10.67 1.4 0.460 1.24 0.861 0.1683 0.7 2439 25 10633-2.1 85 167 2.02 184 8385 -1.1E-5 38 34 -0.019 0.577 1.9 10.67 1.4 0.460 1.24 0.861 0.1683 0.7 2439 25 10633-2.1 85 0.085 0.1652 1.0 233 2.0 0.392 0.577 1.9 10.67 1.4 0.460 1.24 0.861 0.1683 0.7 2439 25 10633-2.1 85 0.69 0.903 0.775 1.9 10.67 1.4 0.460 1.24 0.861 0.1683 0.7 2439 2.6 0.053-2.1 0.633-2.1 22.0 0.65 2.0 0.992 0.577 1.9 10.67 1.4 0.460 1.24 0.861 0.1683 0.7 2439 2.6 0.053-2.1 0.633-2.1 20.038 0.775 1.0 10.67 1.4 0.460 1.24 0.861 0.1683 0.7 2439 2.7 0.053-2.1 0.633-2.1 22.0 2.85 5.7 2.5 2.3 9 92 0.133 0.757 1.1 11.70 1.2 0.485 1.28 0.793 0.1653 1.0 2432 2.7 0.033-2.1 0.633-2.1 22.0 2.950 2.0 0.525 2.5 39 92 0.133 0.757 1.1 11.70 1.2 0.486 1.24 0.861 0.1683 0.7 2439 2.7 0.053-2.1 0.633-2.1 22.0 2.950 2.7 2.2 10633-2.1 22.0 2.950 2.5 2548 2.7 10033-2.1 10633-2.1 22.0 2.950 2.5 2548 2.7 10633-2.1 10633-2.1 22.0 2.5 2548 2.7 10633-2.1 10633-2.1 22.0 2.0 2.5 2.5 28 2000 9.5 2.2 2.1 2.0 2.0 2.1 2.2 2.0 2.2 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5	10633-23.2	06	189	2.16	191	7685	1.8E-4	34	34	0.310	0.601	1.9	9.49	1.6	0.432	1.27	0.803	0.1594	0.9	2313 25	2449	16	6.6
10633-21.1 139 257 1.91 211 8744 6.8E-5 65 51 0.117 0.548 1.0 9.49 1.1 0.428 1.03 0.897 0.1608 0.5 2298 20 10633-11.1 105 207 2.04 205 8034 $8.7E-5$ 21 40 0.150 0.572 1.9 9.92 1.4 0.47 1.17 0.842 0.1610 0.7 2381 23 10533-1.1 32 249 1.95 221 8729 5.3E-5 41 90 0.038 0.275 1.1 10.19 1.2 0.452 1.14 0.971 0.1635 0.3 2405 23 10533-23.1 64 167 1.17 108 8233 4.8E-5 71 2.6 0.002 0.521 1.9 10.00 1.5 0.440 1.31 0.865 0.1650 0.8 2350 25 10533-3.1 64 167 1.2 0.2 18 8 326 0.1653 0.0 3 2474 2.6 10.44 1.6 0.458 1.28 0.793 0.1653 1.0 2432 25 10533-3.1 85 167 2.0 128 8 338 1.1E-5 39 9.2 0.133 0.757 1.1 11.0 1.2 0.486 1.24 0.861 0.1683 0.7 2439 25 10633-3.1 221 571 2.67 376 7531 7.7E-5 39 9.2 0.133 0.757 1.1 11.7 1.2 0.486 1.24 0.861 0.1683 0.7 2439 25 10633-3.1 221 571 2.67 376 7531 7.7E-5 39 9.2 0.133 0.757 1.1 11.7 1.2 0.486 1.24 0.861 0.1683 0.7 2439 25 10633-3.1 221 571 2.67 376 7531 7.7E-5 39 9.2 0.133 0.757 1.1 11.7 1.2 0.486 1.24 0.861 0.1683 0.7 2439 25 10633-3.1 221 571 2.67 376 7531 7.7E-5 39 9.2 0.133 0.757 1.1 11.7 1.2 0.486 1.24 0.861 0.1683 0.7 2439 25 10633-3.1 221 571 2.67 376 7531 7.7E-5 39 9.2 0.133 0.757 1.1 11.7 1.2 0.486 1.24 0.861 0.1683 0.5 2548 25 10633-3.1 2063 0.8/5 2.13840) * refers to mole percent of total 2069 that is due to common Pb, calculated using the 204 Pb-method; common Pb composition used is the surface bit 7/6. 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb, calculated using the 204 Pb-method; common Pb composition used is the surface bit 7/6: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb) Calculated using the 204 Pb-method; common Pb composition used is the surface bit 7/6: 0.89500; 8/6: 2.13840) Korter to the meter 1.0% (included) * 0.865 25 µm spot; 5 or 6 scans; ~9nA O- primary beam intensity, U-Pb calibration error 1.0% (included)	10633-9.1	173	202	1.21	185	10034	2.6E-4	28	63	0.448	0.336	2.1	9.37	4. 4	0.423	1.14	0.789	0.1605	0.9	2275 22	2461	15	8.9
10633-11.1 105 207 2.04 205 8034 8.7E-5 21 40 0.150 0.572 1.9 9.92 1.4 0.447 1.17 0.842 0.1610 0.7 2381 23 10633-9.2 232 212 0.95 149 11253 2.2E-5 41 90 0.038 0.275 1.1 10.19 1.2 0.452 1.14 0.971 0.1635 0.3 2405 23 10633-4.1 64 1.6 1.71 108 1.2 0.452 1.14 0.971 0.1635 0.8 2350 26 10633-4.1 64 1.6 1.71 108 1.2 0.458 1.28 0.793 0.1653 0.8 2352 21 10633-4.1 21 117 0.845 1.17 10.845 0.1650 0.8 2332 21 10633-4.1 21 117 0.845 1.17 10.845 0.1650 0.8 2352 21 10633-4.1 21 117 0.845 1.16 0.7 2381 22 10633-4.1 21 17 1 102 1.2 0.458 1.28 0.793 0.1653 1.0 2432 25 10633-4.1 2053-4.1 21 571 2.02 184 8335 -1.1E-5 38 3 24 -0.019 0.577 1.9 10.67 1.2 0.485 1.28 0.793 0.1763 0.7 2439 25 10633-8.1 221 571 2.67 730 0.1755 0.0.1 20.7 739 2.1 202 184 8335 -1.1E-5 39 92 0.013 0.577 1.9 10.67 1.2 0.485 1.08 0.903 0.1750 0.5 2548 25 10633-8.1 2 202 184 8335 -1.1E-5 39 92 0.013 0.577 1.9 10.67 1.2 0.485 1.08 0.903 0.1750 0.5 2548 25 10633-8.1 2 201 286 that is due to common Pb, calculated using the $^{204Pb-method}$; common Pb composition used is the surface bit 7/16: 0.89500; 8/6: 2.13840) * refers to mole percent of total ^{206Pb} that is due to common Pb, calculated using the $^{204Pb-method}$; common Pb composition used is the surface bit 7/16: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb, calculated using the $^{204Pb-method}$; common Pb composition used is the surface bit 7/16: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb) calculated using the $^{204Pb-method}$; common Pb composition used is the surface bit 7/16: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb) calculated using the $^{204Pb-method}$; common Pb composition used is the surface bit 7/16: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb) calculated using the $^{204Pb-method}$; common Pb composition used is the surface bit 7/16: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb) * refers to radiogenic Pb (corrected for common Pb) * refers	10633-21.1	139	257	1.91	211	8744	6.8E-5	65	51	0.117	0.548	1.0	9.49		0.428	1.03	0.897	0.1608	0.5	2298 20	2464	ი	8.0
10633-9.2 232 212 0.95 149 11253 2.2E-5 41 90 0.038 0.275 1.1 10.19 1.2 0.452 1.14 0.971 0.1653 0.3 2405 23 10633-23.1 132 249 1.95 221 8729 5.3E-5 50 50032 0.521 1.9 1.0 1.5 0.440 1.31 0.865 0.1650 0.8 233 2405 233 2405 233 2405 233 2405 20 2032 0.521 1.9 10.00 1.5 0.440 1.31 0.865 0.1650 0.8 233 24.8 233 4.8E-5 71 25 0.0032 0.577 1.9 10.67 1.4 0.460 1.24 0.861 0.1653 0.7 233 0.7 1033 0.757 1.1 11.70 1.2 0.861 0.1683 0.7 23 26 27 106 7.30 0.903 0.17560 0.5 2548 27 16 0.456 1.6 0.750 0.5 2548	10633-11.1	105	207	2.04	205	8034	8.7E-5	21	40	0.150	0.572	1.9	9.92	4. 4	0.447	1.17	0.842	0.1610	0.7	2381 23	2466	13	4.1
10633-23.1 132 249 1.95 221 8729 5.3E-5 50 0.092 0.521 1.9 10.00 1.5 0.440 1.31 0.865 0.1653 0.3 2322 26 10633-5.1 85 167 1.06 1.71 108 8233 4.8E-5 71 25 0.083 0.474 2.6 10.47 1.6 0.773 0.1653 1.0 2432 28 2432 26 10.633-5.1 85 1.165 31 7.7E-5 39 92 0.019 0.577 1.9 10.67 1.4 0.60 0.1683 0.7 233 21 27.7E-5 39 92 0.133 0.757 1.1 11.70 1.2 0.861 0.1683 0.7 2432 26 10.635 0.168 0.365 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.1750 0.15 1.1760 1.1750 1.1750	10633-9.2	232	212	0.95	149	11253	2.2E-5	4	06	0.038	0.275		10.19	, 1	0.452	1.14	0.971	0.1635	0.3	2405 23	2492	ŝ	4.2
10633-4.1 64 106 1.71 108 8233 4.8E-5 71 25 0.083 0.474 2.6 10.44 1.6 0.793 0.1653 1.0 2432 26 10633-5.1 85 167 2.02 184 8385 -1.1E-5 38 34 -0.019 0.577 1.9 10.67 1.4 0.460 1.24 0.861 0.1683 0.7 2439 25 10633-5.1 85 167 2.67 376 7531 7.7E-5 39 92 0.113 0.577 1.1 11.70 1.2 0.861 0.1683 0.7 2439 25 Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number 1.2 0.476 1.4 0.460 1.24 0.861 0.1750 0.5 2348 25 Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number 20.4Pb-method; common Pb composition used is the surface bls 7(6: 0.89500; 8/6: 2.13840) 0.5134 26 2548 25 2548 25 2548 25 25 254P 26	10633-23.1	132	249	1.95	221	8729	5.3E-5	50	50	0.092	0.521	1.9	10.00	1.5	0.440	1.31	0.865	0.1650	0.8	2350 26	2507	13	7.5
10633-5.1 85 167 2.02 184 8385 -1.1E-5 38 34 -0.019 0.577 1.9 10.67 1.4 0.460 1.24 0.861 0.1683 0.7 2439 25 10633-8.1 221 571 2.67 376 7531 7.7E-5 39 92 0.113 0.577 1.1 11.70 1.2 0.485 1.08 0.903 0.1750 0.5 2348 23 Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number 11 11.70 1.2 0.485 1.08 0.903 0.1750 0.5 2348 23 Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number 11 11.70 1.2 0.485 1.08 0.903 0.1750 0.5 2348 23 7(6: 0.89500; 8/6: 2.13840) 5.13840) . 36 2.2 0.494 1.170 1.2 0.485 1.08 0.903 0.1750 0.5 2348 23	10633-4.1	64	106	1.71	108	8233	4.8E-5	7	25	0.083	0.474	2.6	10.44	1.6	0.458	1.28	0.793	0.1653	1.0	2432 26	2511	17	3.8
10633-8:1 221 571 2.67 376 7.531 7.7E-5 39 92 0.133 0.757 1.1 11.70 1.2 0.485 1.08 0.903 0.1750 0.5 2348 233 Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number z spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number 0.69550; 8/6: 2.13840) 0.903 0.1750 0.5 2348 23 7/6: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb) calculated using the ²⁰⁴ Pb-method; common Pb composition used is the surface bk 7/6: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb) the surface bk 204Pb-method; common Pb composition used is the surface bk 7/6: 0.89500; 8/6: 2.13840) the surface bk 7/6: 0.89500; 8/6: 2.13840) the surface bk 7/6: 0.89500; 8/6: 2.13840) the surface bk 7/6: 0.89500; 8/6: 2.13840) the surface bk 7/6: 0.89500; 8/6: 2.13840) the surface bk 7/6: 0.89500; 8/6: 2.13840) the surface bk 7/6: 0.89500; 8/6: 2.13840) the surface bk 1/6: 0.89500; 8/6: 2.13840)	10633-5.1	85	167	2.02	184	8385	-1.1E-5	38	34	-0.019	0.577	1.9	10.67	1. 4	0.460	1.24	0.861	0.1683	0.7	2439 25	2541	42	4.8
Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number f(206) ²⁰⁴ refers to mole percent of total ²⁰⁶ Pb that is due to common Pb, calculated using the ²⁰⁴ Pb-method; common Pb composition used is the surface bls 7/6: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb) Errors are reported at 10 uncertainty level unless otherwise noted Analytical details: IP665: 25 µm spot; 5 or 6 scans; ~9nA O- primary beam intensity, U-Pb calibration error 1.0% (included) No mass fractionation correction applied	10633-8.1	221	571	2.67	376	7531	7.7E-5	39	92	0.133	0.757	. .	11.70	1.2	0.485	1.08	0.903	0.1750	0.5	2548 23	2606	ი	2.7
f(206) ²⁰⁴ refers to mole percent of total ²⁰⁶ Pb that is due to common Pb, calculated using the ²⁰⁴ Pb-method; common Pb composition used is the surface ble 7/6: 0.89500; 8/6: 2.13840) * refers to radiogenic Pb (corrected for common Pb) Errors are reported at 1σ uncertainty level unless otherwise noted Analytical details: P6655 : 25 µm spot; 5 or 6 scans; ~9nA O- primary beam intensity, U-Pb calibration error 1.0% (included) No mass fractionation correction applied	Spot name 1	ollows th	Je conve	ntion	x-y.z; /	where x =	: sample r	βdmbr	эг, y = g	ırain numb	er and z	= spc	ot numb	er									
r/o. 0.03000, 000. 2.1.0040) * refers to radiogenic Pb (corrected for common Pb) Errors are reported at 1σ uncertainty level unless otherwise noted Analytical details: IP665: 25 µm spot; 5 or 6 scans; ~9nA O- primary beam intensity, U-Pb calibration error 1.0% (included) No mass fractionation correction applied	f(206) ²⁰⁴ rei	ers to m	ole perc	ent of	total ²⁰	⁾⁶ Pb that	is due to c	comm	ion Pb,	calculated	using th	ie ²⁰⁴	⊃b-meth	od; o	ommon	Pb co	mpositic	in used i	is the	surface bla	nk (4/6: (0.057	70;
Errors are reported at 10 uncertainty level unless otherwise noted Analytical details: IP665: 25 µm spot; 5 or 6 scans; ~9nA O- primary beam intensity, U-Pb calibration error 1.0% (included) No mass fractionation correction applied	* rafare to ra	dingenic		ractar		d nomm																	
Analytical details: IP665: 25 µm spot; 5 or 6 scans; ~9nA O- primary beam intensity, U-Pb calibration error 1.0% (included) No mass fractionation correction applied	Errors are re	ported ¿	it 10 une	certain	ity level	l unless c	vtherwise I	noted															
IP665: 25 μm spot; 5 or 6 scans; ~9nA O- primary beam intensity, U-Pb calibration error 1.0% (included) No mass fractionation correction applied	Analvtical c	letails:																					
No mass fractionation correction applied	IP665: 25 µ	m spot;	5 or 6 sc	ans; -	-9nA O	- primary	beam inte	ensity	U-Pb	calibration	error 1.()% (in	cluded)										
	No mass fra	ctionatio	n correc	tion a	pplied	-		•					-										

600°C, which suggests isotopic equilibration with the GFG unit at low fluid:rock interaction. The S isotopic data for the sharped-wall vein sulphides, with average δ^{34} S value of 4.3‰, is consistent with a single homogeneous crustal reservoir, which was likely sourced from the melt sheet.

In summary, this study has shown that the GG is part of the pre-impact history at 1850 Ma and although there is an intense hydrothermal alteration adjacent to the sharp-walled sulphide veins, its extent is limited to 10s cm and thus does not provide a significant vector for exploration.

FORTHCOMING PRODUCTS

A petrological and geochronological study of the grey gabbro unit of the Podolsky Cu-Ni-PGE deposit, Sudbury, Ontario: A 2.6 Ga Gabbro Hosting 1.85 Ga impact-related mineralization. Authors: Linette M. MacInnis, Daniel J. Kontak, Doreen E. Ames, and Nicole Rayner, January, 2015, CJES.

The chemical fingerprint of alteration marginal to a sharp-walled Cu(-Ni)-PGE vein setting: Podolsky deposit, Sudbury, Ontario. Authors: Linette M. MacInnis, Daniel J. Kontak, Doreen E. Ames, and Nancy Joyce, January 2015, SEG.

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