CHARACTERIZATION OF CARBONACEOUS MATERIAL FROM THE SUDBURY IMPACT STRUCTURE USING RAMAN MICROSPECTROSCOPY. A J. Wright[1], J. Parnell[1] and D. E. Ames[2], [1]Dept. of Geology & Petroleum Geology, University of Aberdeen, Kings College Campus, Aberdeen, AB24 3UE, UK (a.j.wright@abdn.ac.uk) [2]Natural Resources Canada, Geological Survey of Canada, 601 Booth Street, Ottawa, ON, K1A 0E8, Canada

Introduction: Samples from the 1.85 Ga Sudbury impact structure have been analyzed using Raman microspectroscopy in order to characterize the carbonaceous material within the structure. Samples analyzed comprised a mixture of thin sections and/or rock chips from (i) the Ni-Cu-PGE massive sulfide deposits associated with the Sudbury Igneous Complex, (ii) the Onaping and Vermilion Formations, and (iii) cross-cutting veins of anthraxolite (a carbon-rich anthracite-like bitumen) in the Onwatin Formation. A sample from the 2.4 Ga Elliot Lake Group was also analyzed (Fig. 1).

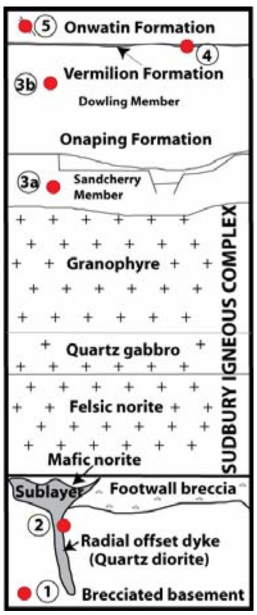


Figure 1. Simplified stratigraphy of the Sudbury impact structure (redrawn from [1]). Numbers refer to sample stratigraphic localities:
1. Elliot Lake Group, basement (?)
2. Ni-Cu-PGE mineralization - McKim Mine
3. Onaping suevite, plume collapse
4. Zn-Pb-Cu hydrothermal mineralization – Errington Mine
5. Anthraxolite veins

The crater-fill suevites of the Onaping Formation [1] contain as much as 4 wt% C. Isotopic data suggests a biological origin for the carbon in both the suevites and the overlying shales of the Onwatin Formation [2]. The suevites also contain numerous carbonaceous clasts, thought to represent target stratigraphy on the southern Laurentian passive margin [3]; these sequences are also a likely source of biogenic carbon [4]. Raman spectroscopy was used to investigate the relationship between carbonaceous strata of the Huronian basement, represented by the Elliot Lake Group, the crater fill, and the mineral deposits associated with the Sudbury impact structure.

Methodology: Raman spectra of the samples were obtained using the 514.5 nm line of an Ar^+ ion laser. A specially adapted Research Grade Leica DMLM microscope was used to focus the laser light, using either a 50x or 100x lens, depending on the sample thickness. This gives a spot size of ~1.5 µm. The scattered light was dispersed and recorded by means of a Renishaw inVia Reflex Spectrometer equipped with a CCD detector. Data were collected between 1100 and 1700 cm^{-1}, with spectral resolution <3 cm^{-1}. Laser output power at the source (50 mW maximum) and integration times were varied to obtain the best possible spectra relative to signal to noise ratio. Between 3 and 6 spectral accumulations were averaged and Renishaw WiRE 2.0 software was used for data processing.

Results: Carbonaceous material was found in all the samples examined:
(i) Carbon in the Ni-Cu-PGE mineralization (Sample 2) occurs as spherules, ~1 µm in diameter, in chalcopyrite crystals and occasionally in pyrrhotite and pentlandite. The spherules may form short inclusion trails or occur as isolated grains (Fig. 2).

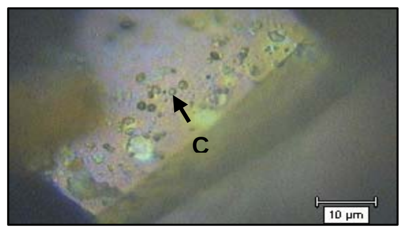


Figure 2. Reflected light image showing carbon spherules in chalcopyrite from the Milnet Mine.

(ii) Carbon in the Onaping Formation (Sample 3) is found as finely disseminated material within the suevite matrix and as anhedral inclusions within melt fragments. The inclusions are <5 µm across and occur in sulfides, which are predominantly pyrite with subsidiary chalcopyrite. The suevites also contain numerous sub-angular carbonaceous clasts.
(iii) Carbon in the Errington deposit (Sample 4) is found as flakes <25 µm long and is associated with calcite and quartz crystals in the Zn-Pb-Cu carbonate-hosted hydrothermal mineralization.

Spectral parameters from the measured data were used to produce cross-plots. Fig. 3 shows G-peak position plotted against full width at half maximum (FWHM). The samples from the Onaping suevite and anthraxolite veins plot in the same field, which overlaps the field of the Errington data. Carbonaceous clasts within the suevite show a higher degree of structural order and consequently plot close to 1580 cm^{-1}, with a narrow peak width. Data for the Ni-Cu-PGE mineralization generally show a wider peak width and lower G-peak position than that for the Errington data. Raman spectroscopy confirms that the included material is a carbonaceous solid, rather than fluid inclusions containing CO_2.

Fig. 4 shows the R1 value (peak height D1/peak height G) plotted against FWHM, allowing the components of the suevite to be separated into carbon occurring in the matrix and that within melt fragments.

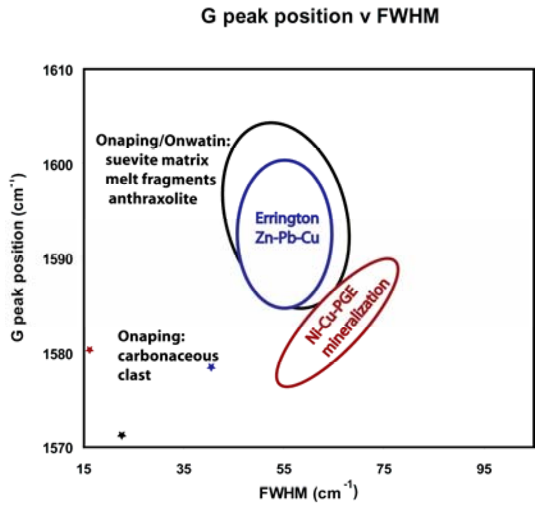
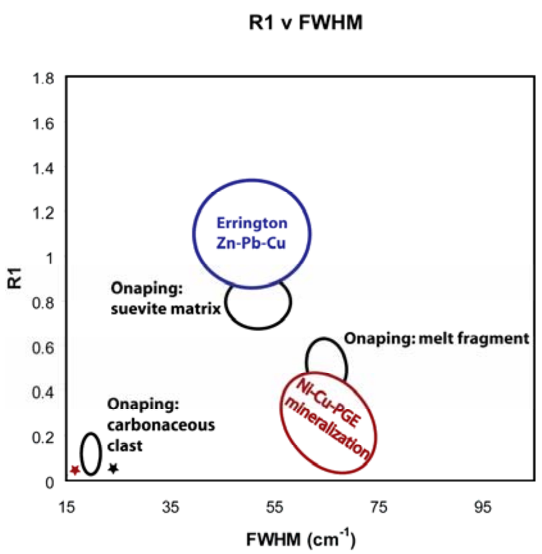


Figure 3: Cross-plot of G peak position (cm^{-1}) against FWHM (cm^{-1}). Data points lie within the areas shown, with the exception of a single outlier in each group, indicated by a star.

(Onaping/Onwatin suevite matrix n = 10, anthraxolite n = 10; Onaping carbonaceous clast, n = 10; Errington Zn-Pb-Cu n = 9; Ni-Cu-PGE n = 6).



The R1 data field from the suevite melt fragments overlaps that of the Elliot Lake data (not shown).

Interpretation: The model of [3] envisages that a large meteorite or comet excavated an impact crater in a shallow marine basin in the Sudbury region, generating shock-melting of the underlying upper and lower crustal material, which included carbonaceous mudstones. The Raman data for the suevite matrix is consistent with disordered carbon being redeposited from a plume, with some of the carbon in the high-temperature melt being graphitized. The R1 data for the Elliot Lake Group is consistent with rocks from this group being fragmented to form the constituent elements of the suevite. However, further work on other possible target rocks is necessary to confirm that the Elliot Lake Group is the only probable source of carbon in the Onaping suevites. Sulphur-rich target rocks are the likely source of the crustal component necessary for the development of the Ni-Cu-PGE deposits [5]. Prolonged hydrothermal alteration of the Sudbury impact derived rocks is recorded both above and below the melt sheet [1] and the occurrence of carbon within the Ni-Cu-PGE sulfides indicates that at least some of these fluids were carbonic.

Conclusions: The occurrence of carbon in the Ni-Cu-PGE massive sulfide deposits at Sudbury suggests that either carbon from the target rocks played a hitherto unrecognised role in the mineralization process or the hydrothermal systems above and below the melt sheet shared a common carbonic fluid phase, which also contributed to the Errington and Vermilion sulfide deposits. Isotopic data is required to determine whether the solid carbonaceous phase is magmatic or biogenic in origin. It is not known whether sulfides in the igneous rocks of the Sudbury Igneous Complex or offset dykes also contain carbonaceous inclusions; this information may also help constrain the source of the carbon.

Raman data supports a generic link between the different carbonaceous components of the Sudbury crater-fill sediments. It is considered that carbonaceous material was preferentially scavenged from the suevite matrix, confirming the importance of hydrothermal fluids in the redistribution of elements within the base metal endowed impact structure.

References: [1] Ames, D.E. et al., (2006) *In*: Cockell, C., Koeberl, C. and Gilmour, I. (eds) *Biological processes associated with impact events*. Springer: Berlin. [2] Heymann, D. and Dressler, B. (1997). *LPS XXVIII* Abstract #1268. [3] Mungall, J.E. et al., (2004) *Nature*, *429*, 546-548. [4] Erikkson, P.G. et al., (2001) *Sed. Geology*, *141*-142 1-135. [5] Naldrett, A.J. (2005) *Can. Min. 43*, 2069-2098.