be essentially that of the host rock. It is apparent from grain
deformation that transport distances were on the order of millime-
ters to centimeters along the veins.

The textures of fláide, quartz breccia, and pseudotachylite are
fundamentally different when viewed petrographically. Although
each of the rock types appear darkly opaque (dark gray or black) in
hand specimen, the only sample with a matrix that is truly opaque
in thin section is the fláide. No clasts representing compositions and
textures of the other impactites have been observed in the
pseudotachylite thus far. Present work is directed at determining
what textural and compositional changes were involved during
formation and whether the pseudotachylite represents material
comparable to associated impactites.


SUDBURY PROJECT (UNIVERSITY OF MÜNSTER–
ONTARIO GEOLOGICAL SURVEY): (4) ISOTOPE SYST-
EMATICS SUPPORT THE IMPACT ORIGIN. A. Deutsch*,
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Introduction: Within the framework of the Sudbury project
[1–3] a considerable number of Sr-Nd isotopic analyses were carried
out on petrographically well-defined samples of different breccia
units [4–7]. Together with isotopic data from the literature these
data are reviewed in this abstract under the aspect of a self-consistent
impact model [5,8–10]. The crucial point of this model is that the
Sudbury Igneous Complex (SIC) is interpreted as differentiated
impact melt sheet [5,8–11] without any need for an endogenic
"magmatic" component such as "impact-triggered" magmatism or
"partial" impact melting of the crust and mixing with a mantle-
derived magma [e.g., 12]. For the terminology used here we refer to
the companion abstracts in this volume [1–3].

Strontium and Neodymium Isotopes: Impact melt rocks
such as the sublayer [12], the SIC [11,12], and the clast-rich melt
breccia on its top [5,6], as well as melt breccia bodies, matrix,
and melt particles from the Onaping breccias [5,6], are characterized by
€Nd between -5 and -12 with Onaping lithologies tending toward
lower €Nd values (Fig. 1). Their Nd-model ages TDM relative to
a depleted mantle [13] cluster around 2.7 Ga, which agrees well with
the time of the last major crust-forming event in the Archean
Superior Province northwest of the Sudbury structure [e.g., 14,15].
It is important to note that ultramafic inclusions in the sublayer
plot among other SIC rocks with negative €Nd and positive €Sr [12].
Figure 1 shows that the SIC has highly radiogenic and variable Ia.
All those findings fit with the proposed total melting of the crust in
the Sudbury region by the impact event that leads to $1.5 \times 10^6$ km$^3$
of impact melt [10], namely the SIC and the melt breccia, and
the melt in the suevitic Onaping breccias [3]. In contrast, the data are
incompatible with the input of fresh mantle magma as up to 75%
contamination by upper crustal material would be required [12] to
explain the Nd-Sr isotope systematics of these units, but an endo-
genic melt cannot assimilate such a high fraction of relatively cold
material.

Neodymium isotope ratios of the impact melt concur with Nd
characteristics of the target lithologies in the Sudbury region, for
example, the Levack gneiss [12]. The observed spread in €Nd reflects
the widely varying ($^{186}$Sr/$^{86}$Sr)$^\text{t} = 1.85$ Ga for the Archean basement
[4,15], Proterozoic Intrusives [16,17], and the Huronian Supergroup
[16,18] that were mixed into the melt. Distinct fields for the sublayer
from different localities [12,19] in Fig. 1 show that the impact melt
sheet (SIC) assimilated local bedrocks after its emplacement in the
final modified crater. Strongly deviating Sr isotope ratios for some
Onaping rocks in Fig. 1 with ($^{186}$Sr/$^{86}$Sr)$^\text{t} = 1.85$ Ga as low as 0.700 [6,7]
or 0.67 [20] are due to a reopening of the Rb-Sr system during the
Penokean orogeny [4, see also 7]. This is demonstrated with selected
growth curves in Fig. 2: Some recrystallized melt particles and
devitrified glass have enhanced Rb/Sr ratios but the majority of the
material has Ia identical to the granophyre. Together with their €Nd,
this fact supports our view that the melt-breccia on top of the
granophyre and the melt material in the suevitic Onaping breccias
and in the Green Member originated from the same source as the
SIC, namely impact-melted crustal material.

Oxygen isotope data [21] support our findings. The norite,
the granophyre, and the matrix of Onaping breccias all show a consid-
erable spread in δ18O, but typical trends as known from differenti-
ated layered intrusions are absent. The δ18O values of these lithologies
are bracketed by oxygen isotopic compositions observed for local
Archean and Proterozoic bedrocks with the Onaping breccias
reflecting a higher input of Huronian greywackes. To explain the Os
isotope ratios for the Sudbury ores [22] by mixing between a mantle
magma and crust would need up to 90% crustal material. Therefore
these data are also in line with a derivation of the ores exclusively
from ancient crustal sources by impact melting followed by segre-
gation of a sulfide liquid out of the melt sheet.

Summary and Outlook: While in the original contributions
SIC isotope systematics were discussed preferentially in terms of a
possible mixing between a hypothetical mantle component with up
to 75% crustal material, the impact melt model does not have any
problem explaining the crustal signatures of the SIC, the Onaping
breccias, and the Sudbury ores—total melting of basement and
supracrustal lithologies can only produce crustal signatures. Future
studies on Sudbury should concentrate on combined analyses of

![Fig. 1. €Nd-$\bar{e}$Sr diagram for different lithologies of the structure with data recalculated to 1.85 Ga, the time of the impact event [14]; data sources [4–6,11,12,15–17,19].](https://ntrs.nasa.gov/search.jsp?R=19930000943)
The triggering of plateau basalts by super-large impacts is a modicum of respectability. Also, the recent apparent successful tying in of the K/T extinctions to the Chicxulub asteroid bale in Yucatan encourages the search for an impact event that may have caused the other two major post-Paleozoic extinctions (P/Tr, Tr/J). This gives us heart to offer two further outrageous hypotheses.

Noril'sk Ores/Siberian Basalts: The cosmogenic concept for the Sudbury ore deposit remains viable because it is giant, nonultramafic, and unique (except for Noril'sk). It also has telling geologic relationships; for example, the ore-hosting sublayer appears to be a splash-emplaced target/bolide melt lining the Sudbury Basin cavity like spackle on a bowl that was also injected centrifugally into tensoidal cracks (offsets) (see [3] for further evidence). At Sudbury, endogenic scenarios usually have been assumed, especially the concept of the ring-dike sublayer fed from a deep magma reservoir [5]. This view has recently been seriously challenged by Grieve and Stöffler [6], who explain the Sudbury Intrusive Complex as an impact melt sheet. Although the geologic relationships between the ore and the country rock at Noril'sk remain enigmatic, it seems a remarkable Sudbury look-alike. Their ore mineralogy is similar, including platinum group metals, and they are both large scale (one Noril'sk sulfide body covers 2 sq km and is 20 m thick.) Naldrett et al. [7] believe that the Noril'sk ores and adjacent Siberian plateau basalts are intimately related and consanguineous. A similar view was offered by several other authors at the 1991 American Geophysical Union Fall Meeting symposium (Noril'sk Siberia: Basalts, Intrusions, and Ores). Using argon/argon laser fusions, Dalrymple et al. [8] assigned a date for the ores and flood basalts of 249 ± 1 Ma, indistinguishable from the Permian/Triassic boundary. We therefore suggest that the Noril'sk ores may be of cosmogenic parenthood and that this impact also triggered the Siberian plateau basalts. An associated event then might be the great extinction of life forms at the P/Tr boundary, all tied together as an event horizon.

Bahama Nexxus: Olsen [9] has attributed the Triassic/Jurassic boundary catastrophic extinctions to the Manicouagan asteroidal impact, but recent radiometric dating [10] indicates these events are diachronous (Manicouagan asteroid bale 212 ± 2 Ma and Tr/J boundary 200 Ma). This boundary is also marked by extensive theolitic basalts (flows, sills, and dikes) of the rapidly extruded Newark Supergroup. Radially emplaced dikes on Pangaea (now broken up into Africa, North America, and South America) focus toward the Bahamas [11]. Dietz [12] has previously termed this presumed hidden hot spot (now buried beneath 6 km of shallow water coral reef limestone) as the Bahama Nexxus (a great triple junction connection) that marked the birth of the Atlantic rift ocean. The Bahama Platform might then be a mega coral reef laid down diachronically on a subsiding plateau basin. The floor spreading processes for symmetrical repaving of the ocean floor by dke splitting. This clearly applies to the North Atlantic continental drift (North America/Africa) from Nova Scotia southward until the Bahama platform is reached. Then the conjugate point between North America and Africa jumps to the eastern tip of the Bahama crescentic platform rather than being at the tip of Florida. Clearly the seafloor spreading (dikesplitting) was overprinted by the hot spot, causing newly fragmented Gondwana (Africa/South America) to remain fixed (relative to the Earth’s spin axis) while North America drifted away. (We can observe a modern example by the eastward offsetting of the Mid-Atlantic ridge as it transsects Iceland hot spot.) Eventual death of the hot spot allowed the Mid-Atlantic Ridge to pave the ocean floor symmetrically. Thus almost the entire Bahama platform was stranded on the North American plate, leaving a very small conjugate volcanic exoscrescence attached to Africa—the Bijagos Plateau off Portuguese Guinea. This great magmatic event