LOW ABUNDANCE OF Sr87 IN ONTARIO CARBONATITES

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INTRODUCTION

The work of Parsons (1961) has demonstrated that the region of Ontario east and north of Lake Superior represents a new carbonatite-alkalic rock petrographic province. Most of these carbonatite complexes intrude the pre-2500 m.y. old gneisses, granites, and greenstones of the Superior Province of the Canadian Shield, and two of them have been dated by the K-Ar method by workers at the Geological Survey of Canada (Lowden *et al.*, 1963). The carbonatite on Newman Island, Lake Nipissing, which unlike the others lies in the Grenville Province, gives an age of 560 m.y. The Lackner Lake or Nemegos Complex has an age of 1090 m.y., which is very close to the value given by Fairbairn *et al.* (1959) for the age of the syenite at Coldwell, Ontario. Most of these complexes are in structural settings similar to those of the Lackner Lake and Coldwell intrusives, and it appears probable that most of them are 1000–1100 m.y. old.

The accepted carbonatites of the world have been found to have Sr^{87}/Sr^{86} ratios which are distinctly lower than those of most limestones and at least as low as those of mafic continental rocks (Powell *et al.*, 1962, 1965; Hamilton and Deans, 1963). No carbonatites from Ontario were included in these studies, and most of the carbonatites which were analyzed were relatively young. In order to compare their Sr^{87} abundances with those of other carbonatites, specimens of 10 Ontario carbonatites have been analyzed for Sr^{87}/Sr^{86}.

EXPERIMENTAL METHOD

Chemical and mass spectrometric procedures were identical to those outlined by Powell (1965a). The laboratory strontium blank was found to be insignificant compared to the amounts of strontium present in carbonatites. The precision of an individual measurement of the Sr^{87}/Sr^{86} ratio, calculated from a series of duplicate analyses of 12 carbonate rocks using the formula of Youden (1951, p. 16), was found to equal ± 0.0004. These 12 carbonate rocks were analyzed in other concurrent investigations (Powell, 1964a, 1964b) and do not include any of the Ontario carbonatites.

Each of the 10 specimens was analyzed once on one of two mass spectrometers. Seven analyses were made on a mass spectrometer which

gave a value of $Sr^{87}/Sr^{86}=0.7081$ for the interlaboratory strontium standard (Eimer and Amend $SrCO_3$, lot 492327). Three analyses were performed on a second instrument which gave a value of $Sr^{87}/Sr^{86}=0.7089$ for the standard. The Sr^{87}/Sr^{86} ratios obtained on the second instrument have been corrected by -0.0008 to express them relative to the value of the standard obtained on the first instrument. All Sr^{87}/Sr^{86} ratios are normalized to $Sr^{86}/Sr^{88}=0.1194$.

DISCUSSION

The data obtained are listed in Table 1. The Sr^{87}/Sr^{86} ratios of these 10 Ontario carbonatites vary between 0.7019 and 0.7037 and average 0.7028 ± 0.0006 (σ). Their Sr^{87}/Sr^{86} ratios are as low as the initial Sr^{87}/Sr^{86} ratios of any except the most ancient rocks. For comparison, Gast (1962) reports that primordial strontium in chondritic meteorites has $Sr^{87}/Sr^{86}=0.698$ (Gast's value has been normalized to $Sr^{86}/Sr^{88}=0.1194$). Mafic continental rocks generally have Sr^{87}/Sr^{86} ratios higher than about 0.704, and limestones in general have Sr^{87}/Sr^{86} ratios greater than about 0.706. The data therefore further strengthen the conclusion that carbonatites are not mobilized limestone xenoliths.

Comparison of the probable age of the Ontario carbonatites with those of the rocks of the Superior Province indicates that the latter were approximately 1500 m.y. old at the time of emplacement of many of the carbonatite-alkalic rock bodies. These volatile-rich carbonatite magmas must have risen many tens of kilometers through ancient sialic rocks

TABLE 1. ISOTOPIC COMPOSITION OF STRONTIUM IN ONTARIO CARBONATITES

Sample Number	Locality	$(Sr^{87}/Sr^{86})^1$	Sr^{86}/Sr^{88}
R22	Lake Nipissing	0.7031[2]	0.1192
R27	Nemegosenda Lake	0.7035[2]	0.1189
R28	Lackner Lake	0.7032	0.1197
R29	Firesand River	0.7024	0.1188
R30	Seabrook Lake	0.7037[2]	0.1192
R49	Cargill Township	0.7019	0.1196
R50	Clay Township	0.7032	0.1190
R51	Prairie Lake	0.7028	0.1187
R52	Chipman Lake	0.7022	0.1195
R53	Twp. 107, Sudbury District	0.7021	0.1187

Average $Sr^{87}/Sr^{86}=0.7028 \pm 0.0006(\sigma)$

[1] Normalized to $Sr^{86}/Sr^{88}=0.1194$.

[2] Analyzed on a second instrument and corrected by -0.0008.

which because of their relatively high Rb/Sr ratios must have been enriched in radiogenic Sr^{87} even at that time. Yet these carbonatites, in view of their very low and rather uniform Sr^{87}/Sr^{86} ratios, cannot have been contaminated with radiogenic Sr^{87} to any appreciable extent. This undoubtedly reflects the high concentration of strontium in carbonatites in general, and particularly in these Ontario carbonatites which may contain from 6,000 to 20,000 ppm (Parsons, 1961). The conclusion that even under the most favorable conditions for contamination with radiogenic Sr^{87}, intrusion into an ancient sialic terrain, carbonatites retain their characteristically low abundance of Sr^{87} lends weight to the suggestion of Powell *et al.* (1965) that the Sr^{87}/Sr^{86} ratio may be used as an empirical criterion for identifying carbonate rocks of uncertain classification as carbonatite.

An example of the application of this criterion is provided by specimen R53. This carbonate rock outcrops in Township 107 in the Sudbury District of Ontario. It is described as marble by Guillet (1962). G. E. Parsons (personal communication, 1963) classifies it as a "possible carbonatite." The Sr^{87}/Sr^{86} ratio of this rock, 0.7021 ± 0.0004, is similar to those of accepted carbonatites and distinctly lower than those of most sedimentary and metamorphic carbonate rocks, including Grenville limestone. Therefore the strontium isotope data strongly support the conclusion that this rock is carbonatite, not marble.

Faure (1963) in a preliminary report lists initial Sr^{87}/Sr^{86} ratios for the Columbia River and Deccan basalts, the Skaergaard, Duluth, Sudbury, Bushveld, and Stillwater intrusives, the Endion sill, and the Great Dyke of Southern Rhodesia. Excluding the Stillwater intrusive, which may be as old as 3 b.y., the initial Sr^{87}/Sr^{86} ratios of these rocks range from 0.7028 to 0.7059 and average 0.7042. The Duluth gabbro, the Endion sill, and the Sudbury irruptive, which are closer in age and geographic location to the Ontario carbonatites than any of the others analyzed by Faure, have ratios of 0.7044, 0.7036, and 0.7040, respectively. Although Faure emphasizes the tentative nature of his data, it appears that the Sr^{87}/Sr^{86} ratios of the Ontario carbonatites are in general lower than those of the mafic continental rocks which he analyzed.

Powell *et al.* (1962, 1965) interpreted the low Sr^{87}/Sr^{86} ratios of carbonatites to indicate that they were derived from a subsialic source. Hamilton (1964) stated that he did not necessarily agree with this conclusion and suggested that "deeper parts of the sial . . . " having a lower Rb/Sr ratio might represent the source regions of carbonatites and alkalic rocks. Heier (1964) stated his opinion that the low Sr^{87}/Sr^{86} ratios in some igneous rocks might " . . . be consistent with a derivation from deep crustal material." It is generally agreed that large masses of basalt

magma such as those which gave rise to the intrusives analyzed by Faure originate at levels at least as deep as the lower subsialic part of the crust and quite possibly are derived from the upper mantle. It is also accepted that these deep regions have lower Rb/Sr and Sr^{87}/Sr^{86} ratios than the more sialic portions of the crust. It is difficult to understand how the Ontario carbonatites could have lower Sr^{87}/Sr^{86} ratios than rocks of un-doubted subsialic origin, such as the mafic intrusives analyzed by Faure, and yet themselves be derived from the sial. It is believed that, on the contrary, the results of this study confirm the conclusion of Powell *et al.* (1962, 1965) that carbonatites are derived from below the sial and pos-sibly from the mantle.

Rocks which are derived from basalt magma by differentiation should have Sr^{87}/Sr^{86} ratios identical to those of basalts. Rocks derived from basalt magma by a process of contamination, such as assimilation of limestone, should have Sr^{87}/Sr^{86} ratios which are either equal to or higher than those of basalts. The fact that the Sr^{87}/Sr^{86} ratios of the Ontario carbonatites appear to be lower than those of the mafic rocks analyzed by Faure therefore suggests that carbonatites are generated independently of basalt magma. However, the rocks studied by Faure are considered to have been derived from tholeiitic magmas (Turner and Verhoogen, 1960, p. 302–303). Precise Sr^{87}/Sr^{86} analyses of rocks of the alkali olivine basalt type from the continents are required before strontium isotopic data can provide further information concerning possible genetic relations be-tween carbonatite and basalt.

ACKNOWLEDGMENTS

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THE IDENTITY OF PATERNOITE WITH KALIBORITE
$(K_2O \cdot 4MgO \cdot 11B_2O_3 \cdot 18H_2O)$[1]
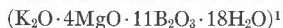
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Paternoite was named and described by Millosevich (1920) as a new hydrous magnesium borate mineral $(MgO \cdot 4B_2O_3 \cdot 4H_2O)$ from Monte Sambuco, Calascibetta, Sicily. Although intensive studies of magnesium borates and other borates from Korea, Japan, eastern Siberia, Inder region of USSR, Argentina, Alaska and California have been conducted in recent years, no mineral with the composition suggested for paternoite has been reported from any other locality.

Doubts as to the validity of paternoite as a distinct mineral species with the formula assigned to it by Millosevich (1920) were raised by Schaller (1942) when he noted that the indices of refraction reported by Barth and Berman (1930) for "sicherlich authentisch" paternoite (HMM 89270) were identical, within the errors of measurement, to those of kaliborite, $K_2O \cdot 4MgO \cdot 11B_2O_3 \cdot 18H_2O$, originally described by Feit (1889), thirty-one years before Millosevich's paper. A subsequent test for potash on the Harvard specimen of paternoite (HMM 89270) indicated the presence of from 5 to 10 per cent K_2O, comparable to that reported in the literature for kaliborite; this convinced Schaller (1942) that "the supposed paternoite described by Barth and Berman is kaliborite."

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