Sm/Nd evidence for a major 1.5 Ga crust-forming event in the central Grenville province

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ABSTRACT

The majority of gray gneisses from an 80 000 km^2 area in the central (Quebec) Grenville province define a Sm-Nd isochron that yields an age of 1.53 ±0.07 Ga. Major element, trace element, and initial Nd isotopic data all point to a subduction-related (orogenic) source for this terrane. It is attributed to a major crustal extraction event that formed a mid-Proterozoic island arc. The age of the terrane agrees with published data from the eastern and western Grenville province in Newfoundland and Ontario, respectively. We suggest that 1.5 Ga arc fragments were accreted along much of the length of the Laurentian foreland within 100 m.y. of their formation, in an event marked by widespread granitoid plutonism.

INTRODUCTION

The Grenville province is characterized by high-grade metamorphism attributed to a ca. 1.1 Ga collisional orogeny. However, recent geochronological work in the eastern and western parts of the province has shown that it is actually a mosaic of much older terranes with an accretionary history that may reach back through much of the Proterozoic (e.g., Gower, 1990; Dickin and McNutt, 1990).

The central part of the Grenville province has received remarkably little attention from geochronologists, yet an understanding of this vast area is critical in order to integrate tectonic models for the eastern and western parts of the province. Sm-Nd geochronology is able to make a unique contribution to this problem by mapping out the formation age of the crustal basement over large regions of high-grade metamorphic terrane. This study presents reconnaissance Sm-Nd analyses for an 80 000 km^2 area in central Quebec bounded by the Saguenay, St. Lawrence, and Manicouagan rivers. The data are indicative of a major crust-forming event during the mid-Proterozoic evolution of the central Grenville province.

GEOLOGICAL CONTEXT

Wynne-Edwards (1972) divided the central part of the Grenville province, on the basis of metamorphic petrology, into the "Central Granulite Terrane" in the west and the "Baie Comeau Segment" in the east. The boundary between these two subdivisions trends north-northeast from near Quebec City to Gagnon and, roughly speaking, separates charnockitic rocks ("green gneisses") to the west from gray gneisses to the east. Figure 1 shows a simplified geologic map of the study area and surrounding regions. Three petrologic types are distinguished: anorthosites, gray gneisses (and their migmatized equivalents), and all others.

The gray gneisses of the Baie Comeau segment are a promising target to begin a study of crustal formation ages in the central Grenville province because their petrology is typical of basement rather than supracrustal rocks, yet they have not been unrecognizably overprinted by younger plutonism. However, remnants of such material are also present, to a limited extent, in slightly lower grade "islands" within the Central Granulite terrane (Fig. 1). The protoliths of these gray gneisses are good candidates for juvenile subduction-related arc terranes, which are generally believed to be the prime sites of crustal formation.

METHODOLOGY

Sampling in this study was focused, as far as possible, on gray gneisses within areas mapped as such (units G1 and G20) on 1:250 000 scale maps of the Ministère des Ressources Naturelles du Québec. Where samples did not come from such units as mapped, they probably represent rafts or tectonic slivers of gray gneisses within other units. In all other respects, sampling and analytical techniques used in this study are identical to those employed by Dickin and McNutt (1989).

Nd isotopic analyses were performed on a VG isomass 354 mass spectrometer at McMaster University. Double filaments and a four-collector peak switching algorithm were used, and the analyses were normalized to a $^{146}Nd/^{144}Nd$ ratio of 0.7219. An average value of 0.51185 ±0.00002 (2σ population) was determined for the La Jolla standard. Average within-run precision on the samples was ±0.000012 (2σ). Sm/Nd ratios were determined by isotope dilution; a ^{149}Sm-^{150}Nd mixed spike was used. Reproducibility of replicate Sm/Nd analyses over the study period has averaged about 0.2% (2σ). Other trace and major element analyses were performed by X-ray fluorescence spectrometry on pressed pellets and fused discs, respectively; calibration lines based on international reference standards were used.

RESULTS

Isotopic results (Table 1) are shown as depleted-mantle model ages in Figure 1, and on a Sm-Nd isochron diagram in Figure 2. Most of the data points define an isochron of surprisingly good quality whose slope corresponds to an age of 1.53 ±0.07 Ga (2σ mean), mean squared weighted deviates = 0.98. Most of the other

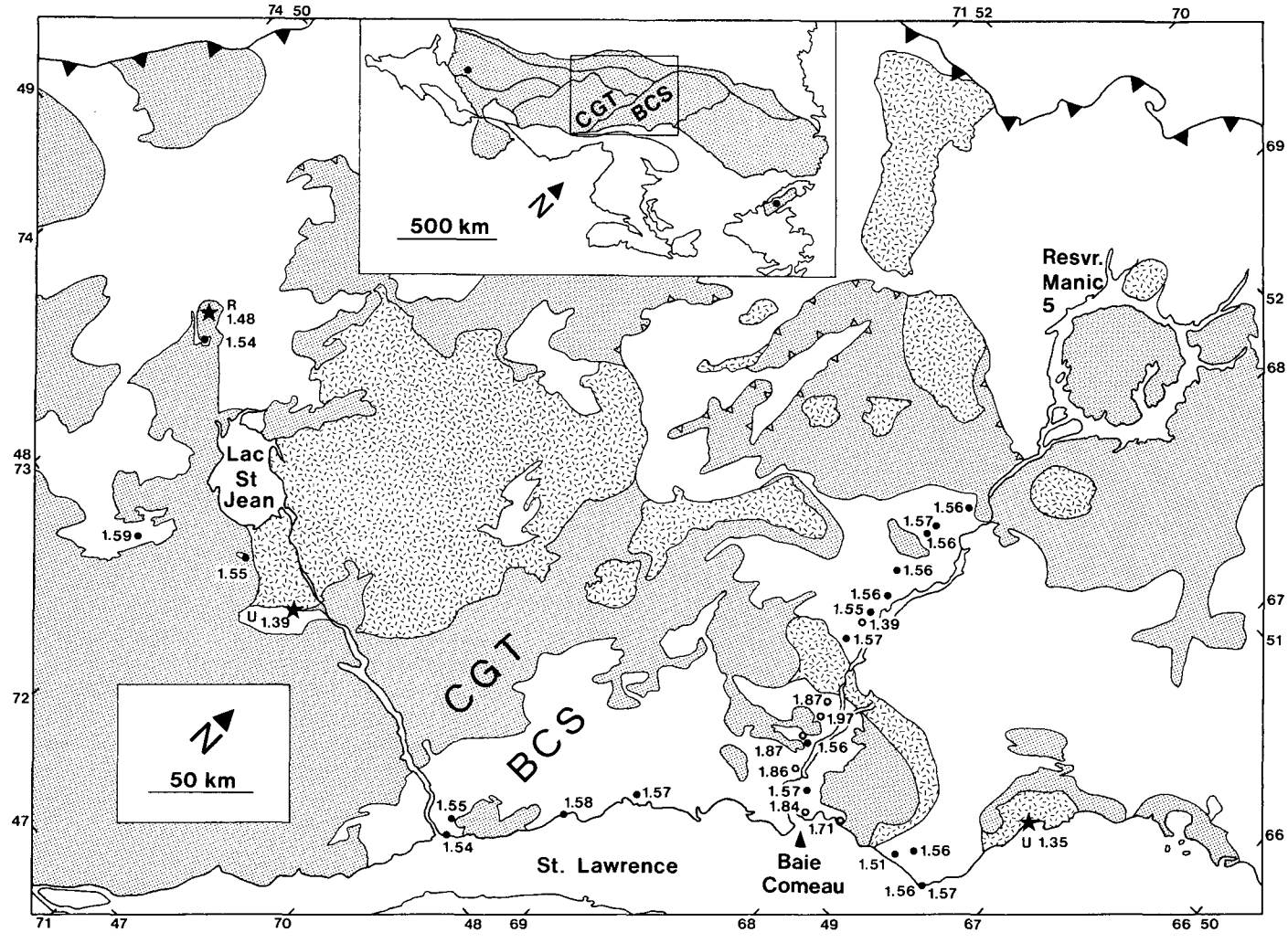

Figure 1. Map of central part of Grenville province showing T_{DM} model ages (Ga). Open symbols represent points omitted from isochron in Figure 2. Unpatterned = gray gneisses; stipple = anorthosite; dot pattern = all other units. Stars indicate units dated by Rb/Sr (R) and U/Pb (U). Lines with solid teeth indicate Grenville Front; lines with open teeth indicate "Allochthon Boundary Front" (Rivers et al., 1989). CGT = Central Granulite terrane; BCS = Baie Comeau segment. Inset shows location of study area in province as a whole, along with location of 1.55 Ga dates on rocks in eastern and western parts of province. Map area extends from long 66° to 74°W and from lat 47° to 52°N.

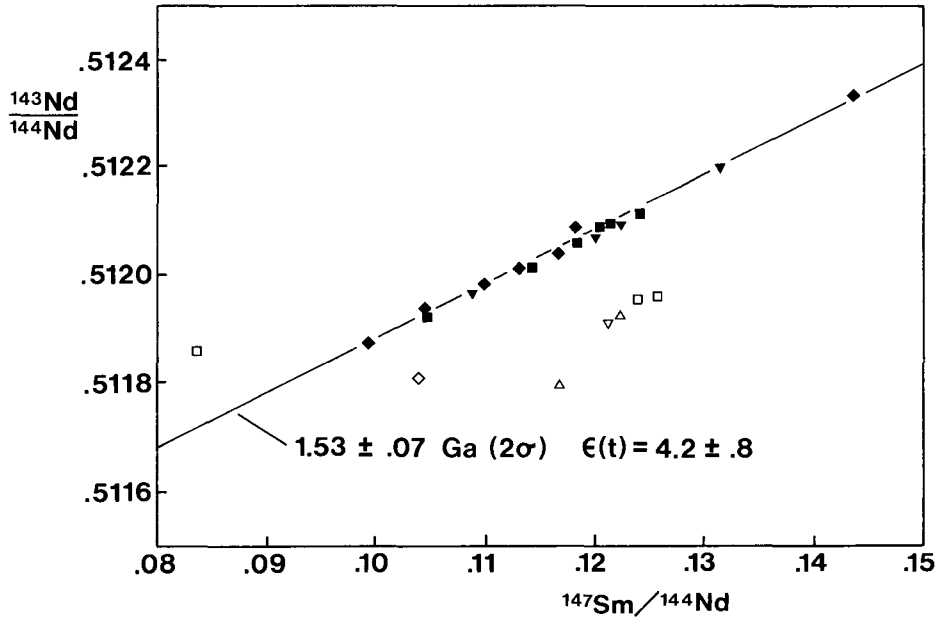

Figure 2. Sm/Nd isochron diagram for whole-rock samples of gray gneiss from central Grenville province. Open symbols were omitted from regression. Diamonds = tonalitic gneisses; squares = granodioritic gneisses; point-down triangles = adamellitic gneisses; point-up triangles = granitic gneisses; based on petrological grid in Figure 3.

TABLE 1. Sm/Nd DATA FOR GRAY GNEISSES FROM THE CENTRAL GRENVILLE PROVINCE

Sample number	Grid reference	Rock type	Normative cor.	Normative qz.	Nd (ppm)	Sm (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	T_{DM} (Ga)
Lac St. Jean									
LSJ1	XK 585118	TN	3.2	24.8	34.16	8.128	0.1438	0.512335	1.54
LSJ2	YJ 055320	AD	1.3	27.0	53.47	10.84	0.1226	0.512093	1.59
LSJ4	CD 022593	TN	0.2	24.2	23.38	4.247	0.1099	0.511985	1.55
St. Lawrence River (north shore)									
NS9	DD 456393	TN	2.0	24.1	nd	nd	0.0993	0.511875	1.55
NS11	DD 498324	TN	2.1	30.4	nd	nd	0.1044	0.511939	1.54
NS18a	DD 814761	AD	3.3	19.2	34.45	6.853	0.1202	0.512072	1.58
NS20	DD 984062	GD	2.2	28.0	12.28	2.311	0.1143	0.512014	1.57
MB1	EE 589512	GD	2.1	33.1	6.70	1.375	0.1240	0.511957	1.84
NS27	EE 718592	TN	2.5	29.3	14.12	2.442	0.1045	0.511808	1.71
NS29	EE 996666	TN	1.5	18.4	13.43	2.604	0.1171	0.512081	1.51
NS29	repeat dissolution				nd	nd	0.1192	0.512102	1.51
NS31	FE 054734	GD	3.9	16.9	nd	nd	0.1208	0.512091	1.56
NS32a	FE 178638	GD	4.2	33.2	42.79	7.778	0.1099	0.511981	1.56
NS32b	FE 178638	GR	3.2	33.1	32.07	6.287	0.1186	0.512059	1.57
Manicouagan River									
MA12.5	EE 523607	TN	1.8	30.7	4.38	0.845	0.1167	0.512045	1.57
MA25.8	EE 431643	AD	3.0	25.0	26.90	5.402	0.1212	0.511911	1.86
MA40	EE 383743	GD	1.9	16.5	27.18	5.460	0.1214	0.512097	1.56
MA42.7	EE 363753	GD	1.6	31.9	14.94	3.108	0.1257	0.511960	1.87
MA58.1	EE 326867	GR	0.5	27.7	49.16	9.499	0.1168	0.511791	1.97
MA67	EE 297937	GR	0.2	27.9	42.21	8.556	0.1226	0.511925	1.87
MA103	EF 179205	GD	0.5	25.6	45.43	9.319	0.1241	0.512116	1.57
MA114.3	EF 183304	GD	1.5	26.5	20.36	2.784	0.0826	0.511850	1.39
MA114.3	repeat dissolution				20.32	2.832	0.0844	0.511860	1.39
MA121	EF 177364	TN	2.0	26.3	16.07	3.008	0.1131	0.512016	1.55
MA132.5	EF 180464	AD	1.4	30.9	39.52	8.599	0.1315	0.512197	1.56
MA153.2	EF 132573	GD	2.5	33.8	4.12	0.713	0.1048	0.511930	1.56
MA178.4	EF 122812	GD	1.0	28.2	28.62	5.204	0.1100	0.511981	1.56
MA182.3	EF 131859	AD	3.1	32.0	41.32	7.447	0.1089	0.511964	1.57
MA199.8	EG 173022	TN	1.8	24.9	16.94	3.412	0.1217	0.512097	1.56

Note: nd = not determined.
Gneissic type: TN = tonalite; GD = granodiorite; AD = adamellite; GR = granite.
Normative mineralogy: cor = corundum; qz = quartz.
Reproducability of $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ is estimated as 0.2% and 0.004% (2σ).
Average within-run precision on Nd isotope ratios is 0.000012 (2σ).

points are clearly distinct from the isochron and correspond (with one exception) to depleted-mantle model ages of 1.71 to 1.97 Ga. In other words, the isochron is very solidly based and not easily susceptible to bias by subjective rejection of data points. The initial ratio of 0.51087 ±0.00005 (2σ) corresponds to an epsilon value of +4.2 ±0.8, which is within error of the value of the depleted-mantle model of DePaolo (1981) at 1.53 Ga (ϵ = +4.6).

Most of the samples that yield Early Proterozoic model ages come from just northwest of Baie Comeau. They might represent a separate, earlier crust-forming event; alternatively, they might be a supracrustal sequence with a lithology resembling arc-derived sediments. This question is discussed below.

Major and trace element data are presented on three discriminant diagrams in Figure 3, and as normative corundum and quartz contents in Table 1, in order to characterize the petrology and chemistry of the dated gneisses. As a further basis for tectonomagmatic comparison, Figure 3 shows the field of plutonic orthogneisses from the Ontario Grenville province (Dickin et al., 1990). These gneisses were identified as having an anorogenic chemical signature by Dickin and McNutt (1990).

Figure 3a shows the chemical-mineralogical grid of Debon and Lefort (1983); the gray gneisses form a well-defined trend from tonalite, through granodiorite and adamellite, to granite. This is the typical rock association of arc terranes, and it contrasts sharply with the trend of plutonic orthogneisses from Ontario. On the AFM diagram (Fig. 3b), most of the gray gneisses fall below the discriminant line of Irvine and Baragar (1971), placing them within the calc-alkalic field. Again, they are largely distinct from the field of plutonic orthogneisses from Ontario.

Immobile trace elements are also used to test the tectonomagmatic affinity of the gray gneisses on the discriminant diagram of Pearce et al. (1984). The data confirm the orogenic affinity of their protoliths; they fall mostly in the field of volcanic arc and syncollisional granites (Fig. 3c). Orthogneisses from Ontario are again quite distinct in composition.

Finally, the corundum levels of 0%–2% and

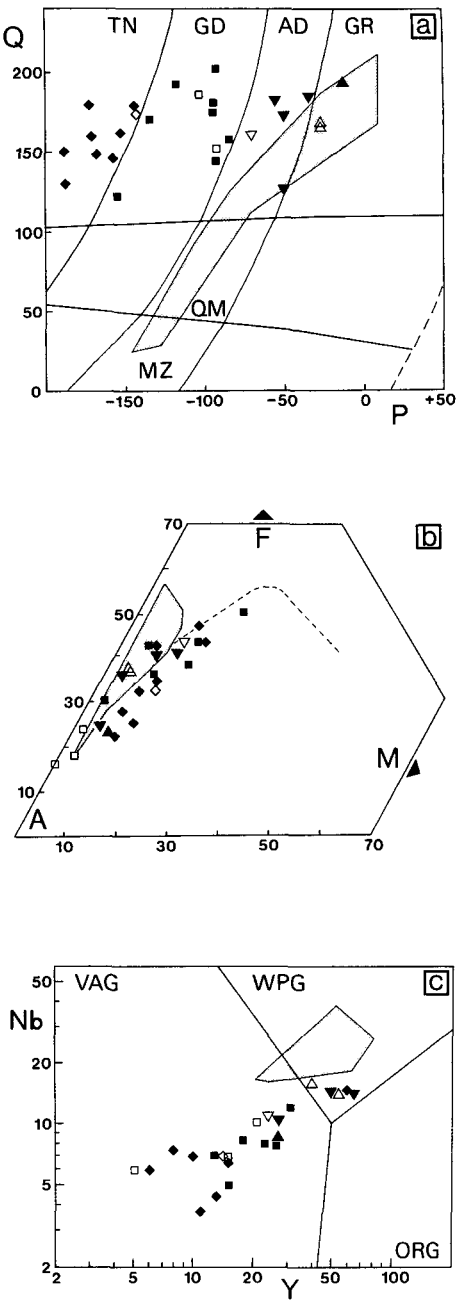

Figure 3. Geochemical discriminant diagrams to characterize petrology and tectonic affinity of protoliths of analyzed gray gneisses (symbols as in Figure 2). Shaded field, for comparison, comprises plutonic orthogneisses from Ontario (Dickin et al., 1990; Dickin and McNutt, 1990). a: Chemical-mineralogical grid of Debon and LeFort (1983) for granitoid classification. Q = 1/3 Si – (K + Na + 2/3Ca); P = K – (Na + Ca). TN = tonalite; GD = granodiorite; AD = adamellite; GR = granite; MZ = monzonite; QM = quartz monzonite. b: AFM diagram (based on weight percent $Na_2O + K_2O$, FeO + Fe_2O_3, and MgO) showing calc-alkalic/tholeiitic discriminant line (dashed) of Irvine and Baragar (1971). c: Plot of Nb vs. Y concentration in parts per million, showing tectonomagmatic grid of Pearce et al. (1984). VAG = volcanic arc granitoids and syncollisional granitoids; WPG = within-plate granitoids; ORG = ocean-ridge granitoids.

quartz levels of 20%–30% in the gray gneisses are typical of compositions attributed to a juvenile arc source by Dickin and McNutt (1989). Therefore, we conclude that the protolith of these gneisses represented either a magmatic arc or juvenile arc-derived sediments.

Comparison of data points with mid- and Early Proterozoic model ages shows some overlap between the two groups (Fig. 3), but the rocks with older model ages tend to be more evolved and have a weaker orogenic signature. This suggests that these gneisses may represent not an older arc fragment, but possibly a sedimentary sequence derived by erosion of Early Proterozoic granitoids within the foreland.

DISCUSSION

The tight clustering of most of the depleted-mantle model ages around 1.56 Ga (Table 1), suggests that this provides a fairly firm upper limit for the formation age of the crustal segment under investigation. In contrast, lower age limits for its metamorphic consolidation are provided by dates on crosscutting younger intrusions (Fig. 1). These include a 1.354 ±0.003 Ga U-Pb age for the Pentecote anorthosite (Machado and Martignole, 1988), a 1.39 ±0.02 Ga U-Pb age for a gabbroic intrusion southeast of the Lac St-Jean anorthosite complex (Hervet et al., 1990), and a 1.48 ±0.04 Ga Rb-Sr age for the Chamouchouane monzonitic complex northwest of Lac St-Jean (Frith and Doig, 1973; recalculated to the new Rb decay constant).

These data bracket the 1.53 Ga Sm/Nd isochron age, which probably represents the actual crustal formation age of a terrane that was extracted from the mantle and consolidated within a fairly short period of time. The remarkable geographical consistency of the Sm-Nd data, especially on the upper part of the Manicouagan River transect, coupled with the orogenic chemical signature of the rocks, points to an origin for this gneiss terrane as an island arc accreted to the Laurentian craton in the mid-Proterozoic.

This evidence for a mid-Proterozoic arc terrane in the central Grenville province provides a tectonic framework within which to interpret published data for the eastern and western parts of the province. For example, Owen and Erdmer (1990) cited U-Pb evidence of a 1.55 Ga crystallization age for the protolith of a high-grade gneiss terrane within the Long Range inlier of Newfoundland, and Dickin and McNutt (1990) measured Sm-Nd model ages around 1.55 Ga in the Muskoka domain of the Ontario Central Gneiss Belt. These results imply that fragments of mid-Proterozoic arc terrane were accreted to an Early Proterozoic margin along the whole length of the Grenville belt.

U-Pb ages of plutonic rocks can provide evidence for the timing of the accretionary process. In Ontario there was widespread granitoid plutonism between 1.46 and 1.40 Ga (Huntsville, Britt, McKellar, Cosby, and Muskoka plutons; van Breemen et al., 1986; Easton, 1986). However, these plutons display anorogenic chemical affinities that contrast sharply with the gray gneisses (Fig. 3). They probably represent post-collisional magmatism. Hence, we suggest that the proposed 1.53 Ga arc terranes were accreted to the older foreland about 100 m.y. after their formation.

Van Breemen and Davidson (1988) suggested that the 1.45 Ga plutonic event in Canada may correlate with igneous activity in the 1.5 to 1.3 Ga "Granite-Rhyolite province" of the central United States. Patchett and Ruiz (1989) attributed the widespread crustal melting that characterizes the Granite-Rhyolite province to the accretion of arc terranes. Our study anchors these proposals by demonstrating a large mid-Proterozoic arc terrane whose accretion, along with other arc fragments, probably triggered this activity.

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