The Canadian Mineralogist
Vol. 31, pp. 849-859 (1993)

GEOLOGY AND GEOPHYSICS OF THE "TYPE" ANORTHOSITE, CHÂTEAU-RICHER, QUEBEC*

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Abstract

Anorthosite was named in 1862 by T. Sterry Hunt following his detailed study at Château-Richer. Thus, in a broad sense, the anorthosite there merits recognition as a sort of type locality of this distinctive plutonic rock. The anorthosite at Château-Richer constitutes an oval body 125 km^2 in area, located 30 km NE of Québec City. It is composed nearly wholly of andesine antiperthite, with accessory pyroxene, biotite, ilmenite, and apatite. The Château-Richer anorthosite is more alkali-rich than average massif anorthosite or the classical Marcy type. Its composition closely resembles that of the nearby St-Urbain anorthosite. Foliation dips outward at the edges of the body, and is concordant with foliation and layering in enclosing high-grade country rocks. Toward the center of the body, foliation is horizontal or dips only gently. At first glance, the anorthosite seems to constitute a dome; however, the structural asymmetry of the body, the irregular distribution of rock types around its periphery, and the prevailing shallow plunge of lineations suggest that the Château-Richer anorthosite makes up a relatively thin sheet now exposed in a doubly plunging antiform. According to gravity and magnetic models, the body is a sheet no more than 2 km thick, and somewhat thinner at its center than near its edges. The absence of associated mafic or ultramafic rocks is in keeping with the view that the Château-Richer anorthosite has been uprooted from its source, possibly a layered mafic intrusion, to be emplaced tectonically at its present setting.

Keywords: anorthosite, chemical data, mineralogy, geophysical models, Château-Richer, Grenville Province, Québec.

Sommaire

C'est en 1862 que T. Sterry Hunt, suite à son étude détaillée à Château-Richer, a nommé de ce nom l'anorthosite. Ainsi, au moins au sens large, l'anorthosite de ce site mérite d'être reconnue comme la localité type de ces roches plutoniques singulières. L'anorthosite de Château-Richer forme un massif oval d'une superficie de 125 km^2, affleurant à 30 km au nord-est de la ville de Québec. Cette anorthosite est presqu'entièrement composée d'andésine antiperthitique avec, comme accessoires, pyroxène, biotite, ilménite, et apatite. Cet exemple se distingue de l'anorthosite commune de type massif, ou celle du Mont Marcy, par sa teneur plus élevée en alcalins. Sa composition chimique s'apparente à celle de l'anorthosite de St-Urbain, située à proximité. La foliation développée dans sa bordure est à pendage abrupt, incliné vers l'extérieur et concordant avec la foliation et le litage des roches encaissantes, métamorphisées à un faciès élevé. Vers l'intérieur, la foliation devient plus légèrement inclinée, et localement elle est horizontale. Un coup d'oeil à la carte géologique pourrait conduire à l'interprétation que l'anorthosite forme un dôme. Toutefois, le manque de symétrie, tant structural que lithologique, des roches encaissantes, et l'omniprésence d'une linéation à faible plongée, mènent à la conclusion que l'anorthosite de Château-Richer a la forme d'une lentille au sein d'un antiforme à double plongée. Les modèles gravimétriques et magnétiques corroborent cette interprétation. Ils indiquent que l'épaisseur de la lentille ne dépasse pas 2 km, étant légèrement plus mince au centre que sur les flancs. L'absence de faciès mafiques et ultramafiques liés à l'anorthosite suggère que l'anorthosite a été délaminée de sa source (possiblement une intrusion mafique stratiforme) et a été mise en place tectoniquement.

Mots-clés: anorthosite, données chimiques, minéralogie, modèles géophysiques, Château-Richer, Province du Grenville, Québec.

* Geological Survey of Canada contribution number 37392.

Historical Perspective

The Château-Richer anorthosite, located on the outskirts of Québec City, was the first individual rock body in the "Primary" (what today is known as the Grenville Province) to have been studied by the fledgling Geological Survey of Canada soon after its founding in 1842. Early work by Logan and his associates had already touched on anorthosite in the Morin massif and at Baie St-Paul. These rocks were poorly understood and considered to be a syenite facies of the "Metamorphic Group" (Osborne 1956). More detailed work on the anorthosite at Château-Richer was subsequently supervised by T. Sterry Hunt, chemist and mineralogist with the Survey from 1846 to 1872. He published the results of his largely chemical study in a remarkably modern and precise report (Hunt 1855), which also constituted an important contribution to the interpretation of the plagioclase solid-solution series, then still only poorly understood. Since Hunt went on some seven years later to define and to name the rock type (IUGS 1989), it seems that the Château-Richer, in spite of its small size and limited exposure, merits recognition as a sort of type locality of anorthosite.

Through the years, the Château-Richer anorthosite has been depicted on various geological maps (Sabourin 1973, Laurin & Sharma 1975, Rondot 1979). Nonetheless, excluding two studies of kaolinite saprolite (Cimon 1969, Dejou *et al.* 1982), to my knowledge the anorthosite itself has remained unstudied in the 140-odd years that have intervened since T. Sterry Hunt's original investigation.

The present report is, in a sense, an update of Hunt's work and seems particularly appropriate at this 150th anniversary of the Geological Survey of Canada. It summarizes the geology and geophysical expression of the Château-Richer anorthosite and its immediate host-rocks. The geological history and possible origin of the anorthosite will be discussed. This work is an offshoot of a topical study of the Grenville in the vicinity of Québec City, in progress by the author.

General Geology

The Château-Richer anorthosite makes up a single oval body 125 km^2 in area, situated some 30 km northeast of Québec City (Fig. 1). The anorthosite lies just north of the edge of the Shield, between the Rivière Montmorency on the west, and Mont Ste-Anne on the east. The settlement of St-Achillé-de-Montmorency is located near the center of the body.

The anorthosite has no particular topographic expression of its own. The northern two thirds are in mountainous country, with many summits in excess of 700 meters and local relief commonly as great as 300 meters. The southern third, on the other hand, occurs in mostly low (average elevation, 250 meters) and swampy terrain, with less than 50 meters of local relief. Outcrops of the anorthosite tend to be small, but they are widely distributed. They are absent only in the drift-choked valleys on the northern part of the body.

Where fresh, the anorthosite is light grey to pale yellowish tan, in places flecked with pink to mauve spots 1 to 5 mm across. Weathered rock possesses a white chalky crust a few millimeters thick. Although uniform modally, the texture of the anorthosite is remarkably varied, depending at least in part upon its state of deformation. It ranges from massive, extremely coarse-grained plagioclase cumulate (two areas of this rock are demarcated on the geological map, Fig. 1), to aphanitic ultramylonite. Most of the anorthosite is variably ground down and recrystallized, weakly gneissic, medium-grained allotriomorphic inequigranular rock, with bent and broken porphyroclasts of plagioclase 1 to 5 cm across that constitute from a trace to 25% modally. Many outcrops present a vaguely layered appearance, with individual seams, ranging from a few centimeters to a meter in thickness, distinguished by grain size or subtle differences in modal composition. Although the layering may in part have been caused by differential strain during deformation of the anorthosite, some of it seems inherited from primary igneous layering.

Dykes from one to 15 cm thick, composed of pink granitic pegmatite, occur sporadically in the anorthosite. In many places, these dykes have been intensely deformed and are now mere films of dark flinty crush-rock or sheets of pink flaser gneiss enclosed in more weakly deformed anorthosite.

Petrography and Chemistry

The Château-Richer is an andesine anorthosite. It is composed of more than 97% andesine antiperthite (the average color index of the anorthosite, based on the estimated modes of 44 samples, is only 2.9), with small amounts of clinopyroxene, orthopyroxene, biotite, ilmenite, and apatite.

Plagioclase is well-twinned, unzoned antiperthitic andesine (average: An_{40}, with a range only from An_{38} to An_{42} based on 75 samples, determined in oils by dispersion). Relatively larger grains (porphyroclasts) commonly are bent and twisted. These are in turn surrounded by fine-grained granoblastic shells in a modified mortar texture. In a few samples, plagioclase has been wholly recrystallized and annealed to form a nonstrained equigranular medium-grained granoblastic mosaic. Microscopic blebs of exsolved brick-red potassic feldspar constitute from less than one to 12% of the antiperthitic plagioclase. It is this brightly colored phase that commonly renders the porphyroclasts greyish pink to mauve (typically 5RP 4/2) and gives a spotted appearance to many outcrops, a feature noted a century ago by Low (1892).

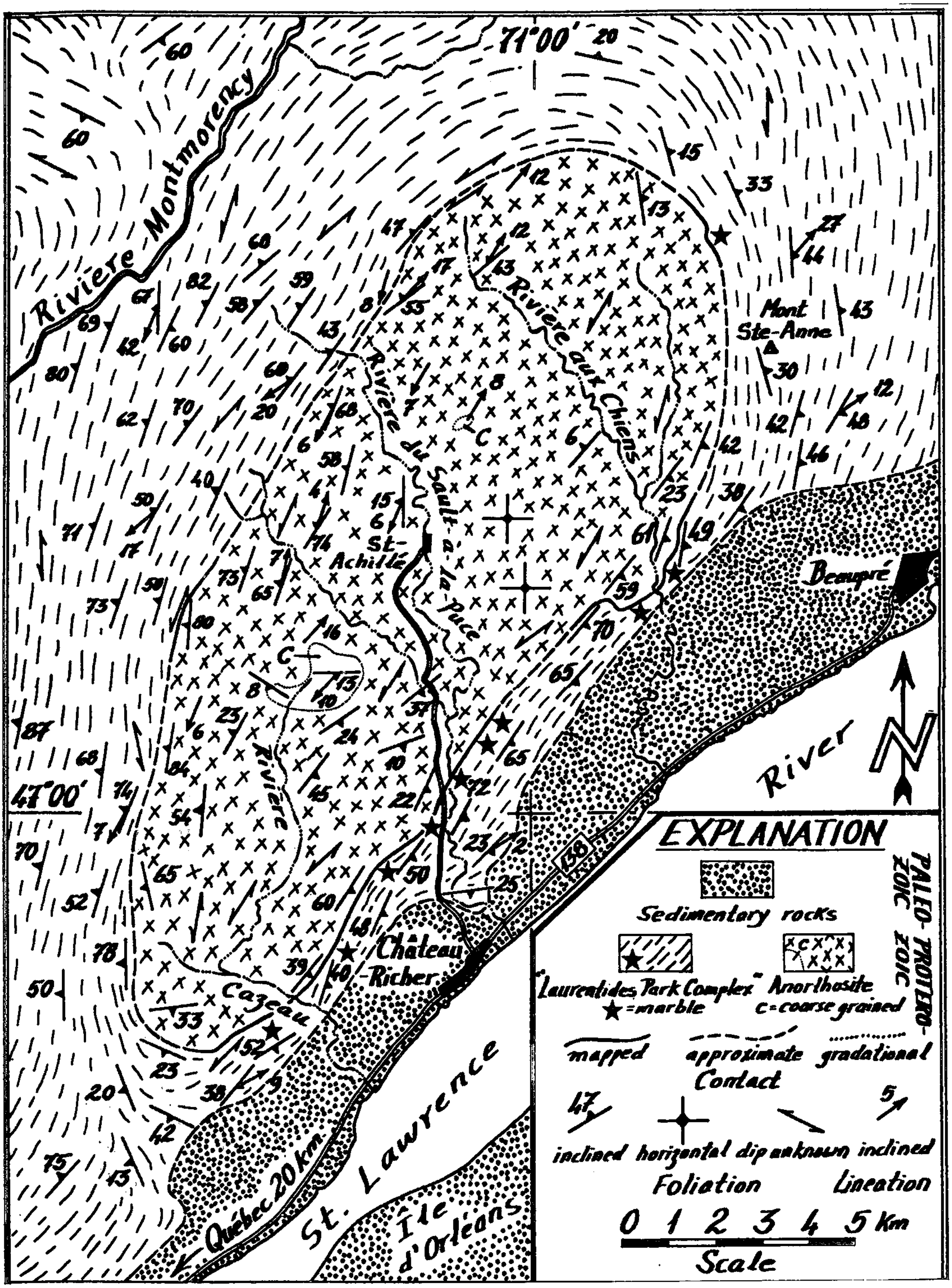

FIG. 1. Geological map of the Château-Richer anorthosite.

TABLE 1. RESULTS OF ELECTRON-MICROPROBE ANALYSES OF PYROXENES FROM THE CHÂTEAU-RICHER ANORTHOSITE

	Clinopyroxene						Orthopyroxene						
	TFQ-1002		TFQ-1064		TFQ-1069		TFQ-813B		TFQ-1069		TFQ-810		
SiO_2 wt.%	52.01		52.09		51.27		54.78		51.89		52.76		(52.46-53.03)*
TiO_2	0.20		0.23		0.14		0.04		0.04		0.10		(0.07-0.12)
Al_2O_3	2.24		2.74		2.00		1.17		1.32		2.86		(2.55-3.18)
FeO_t	8.67		7.93		10.15		19.95		25.40		19.12		(19.04-19.22)
MnO	0.22		0.30		0.25		0.45		0.66		0.34		(0.33-0.35)
MgO	13.15		13.51		12.84		24.49		20.01		24.87		(24.65-25.05)
CaO	22.60		22.82		22.33		0.49		0.52		0.36		(0.30-0.46)
Na_2O	0.58		0.52		0.51		0.04		0.08		n.a.		
K_2O	n.a.		0.00		0.00		0.00		0.00		n.a.		
Sum	99.67		100.14		99.49		101.41		99.92		100.41		
	Numbers of ions on the basis of 6 (O)												
Si	1.95		1.94		1.94		1.98		1.97		1.92		
Ti	0.01	2.00	0.01	2.00	0.00	2.00	0.00	2.00	0.00	2.00	0.00	2.00	
Al^{iv}	0.04		0.05		0.06		0.02		0.03		0.08		
Al^{vi}	0.06		0.07		0.03		0.03		0.03		0.04		
Fe_t	0.27		0.25		0.32		0.60		0.80		0.58		
Mn	0.01	2.02	0.01	2.03	0.01	2.03	0.01	1.98	0.02	2.01	0.01	1.99	
Mg	0.73		0.75		0.72		1.32		1.13		1.35		
Ca	0.91		0.91		0.91		0.02		0.02		0.01		
Na	0.04		0.04		0.04		0.00		0.01		-		
X_{Mg}	0.72		0.74		0.69		0.68		0.58		0.70		

Note: X_{Mg} = Mg/(Fe_t+Mn+Mg). *Range of six analyses.
Sample sites: TFQ-1002, hillside outcrop, 7.0 km N12°E of the church at St-Achillé-de-Montmorency; TFQ-1064, outcrop on nose (elev. 600 m) of ridge, 1.7 km N79°E of the church at St-Achillé-de-Montmorency; TFQ-1069, hillside outcrop, 3.9 km N39°W of the church at St-Achillé-de-Montmorency; TFQ-813B, Rivière du Sault-à-la-Puce, under the high-tension lines, 2.5 km south-southeast of St-Achillé-de-Montmorency; TFQ-810 (megacryst), outcrop under the high-tension lines, 2.0 km southwest of Rivière des Sept-Crans.

TABLE 2. RESULTS OF ELECTRON MICROPROBE ANALYSES OF BIOTITE, ILMENITE AND AMPHIBOLE FROM THE CHÂTEAU-RICHER ANORTHOSITE

	Biotite		Ilmenite		Amphibole
	TFQ-813B	TFQ-1064	TFQ-813B	TFQ-1069	TFQ-1064
SiO_2 wt.%	38.73	38.76	n.a.	n.a.	44.19
TiO_2	4.71	4.65	43.94	44.90	1.81
Al_2O_3	14.14	14.18	n.a.	n.a.	11.84
FeO_t	11.01	13.51	51.01	48.08	13.15
MnO	0.05	0.11	0.26	0.58	0.16
MgO	16.98	14.87	1.14	0.97	12.38
CaO	n.a.	n.a.	n.a.	n.a.	12.05
Na_2O	0.04	0.05	n.a.	n.a.	1.15
K_2O	9.89	9.78	n.a.	n.a.	2.16
Sum	95.55	95.91	96.35	94.53	98.89
	Number of ions on the basis of 22 (O)		6 (O)		23 (O)
Si	5.66	5.71	-	-	6.47
Ti	0.52	0.51	1.79	1.85	0.20
Al	2.44	2.46	-	-	2.04
Fe_t	1.35	1.66	-	-	1.61
Fe^{2+}	-	-	1.89	1.96	-
Fe^{3+}	-	-	0.42	0.24	-
Mn	0.01	0.01	0.01	0.03	0.02
Mg	3.70	3.20	0.09	0.08	2.70
Ca	-	-	-	-	1.89
Na	0.01	0.01	-	-	0.33
K	1.85	1.84	-	-	0.40
X_{Mg}	0.73	0.66	-	-	0.62

Note: X_{Mg} = Mg/(Fe_t+Mn+Mg); Fe^{2+} and Fe^{3+} calculated stoichiometrically.
Sample sites: TFQ-813B, Rivière du Sault-à-la-Puce, under the high-tension lines, 2.5 km south-southeast of St-Achillé-de-Montmorency; TFQ-1064, outcrop on nose (elev. 600 m) of ridge, 1.7 km N79°E of the church at St-Achillé-de-Montmorency; TFQ-1069, hillside outcrop, 3.9 km N39°W of the church at St-Achillé-de-Montmorency.

TABLE 3. CHEMICAL COMPOSITION OF THE CHÂTEAU-RICHER ANORTHOSITE AND THE COMPOSITION OF AVERAGE MASSIF ANORTHOSITE

	I	II	III	IV	IX	1	TFQ-804	TFQ-939	TFQ-999	TFQ-1050	2
SiO_2 wt.%	59.55	59.85	59.80	58.50	57.20	57.30	57.2	57.6	56.7	57.0	54.54
TiO_2	n.a.	n.a.	n.a.	n.a.	n.a.	0.80	0.45	0.34	0.39	0.59	0.52
Al_2O_3	25.62	25.55	25.39	25.80	26.40	25.00	24.7	25.4	25.8	24.8	25.72
Fe_2O_3	0.75	0.65	0.60	1.00	0.40	1.10	0.50	0.27	0.35	0.59	0.83
FeO	n.a.	n.a.	n.a.	n.a.	n.a.	0.00	0.45	0.33	0.39	0.46	1.46
MnO	n.a.	n.a.	n.a.	n.a.	n.a.	tr.	tr.	tr.	0.01	0.01	0.02
MgO	tr.	0.11	0.11	0.20	n.a.	tr.	0.31	0.28	0.23	0.22	0.83
CaO	7.73	6.94	7.78	8.06	8.34	7.40	7.55	7.95	8.37	7.30	9.62
Na_2O	5.09	5.09	5.14	5.45	5.83	6.10	5.83	5.68	5.60	6.04	4.66
K_2O	0.96	0.96	1.00	1.16	0.84	1.22	1.22	1.05	0.92	1.20	1.06
P_2O_5	n.a.	n.a.	n.a.	n.a.	n.a.	0.05	0.10	0.07	0.08	0.08	0.11
L.O.I.	0.45	0.30	0.00	0.40	0.65	0.64	0.46	0.44	0.40	0.52	0.63
Sum	100.15	99.45	99.82	100.57	99.66	99.61	98.8	99.4	99.2	98.8	100.00

Samples I to IX from Hunt (1855); 1, from Dejou *et al.* (1982); TFQ-804 to TFQ-1050, this study (analyses performed at Centre de Recherches minérales, ministère de l'Énergie et des Ressources du Québec); 2, average massif anorthosite based on 9 analyses (Nockolds 1954).
Sample sites: I to IX, locations unknown; 1, abandoned kaolin mine, Château-Richer; TFQ-804, hillside outcrop, 5.2 km N81°W of the church at Château-Richer; TFQ-939, Rivière aux Chiens, 0.5 km downstream from Rivière des Sept-Crans; TFQ-999, hilltop outcrop (elev. 720 m), 7.5 km N14°E of the church at St-Achillé-de-Montmorency; TFQ-1050, hillside outcrop, 1.2 km N25°W of the church at St-Achillé-de-Montmorency.

Pyroxenes make up small, colorless anhedral to subhedral grains, most of which are altered. The clinopyroxene is augitic (average: $Wo_{48}En_{38}Fs_{14}$; Table 1), whereas the orthopyroxene is Al-poor enstatite (average: En_{63}; Table 1). In rare outcrops, orthopyroxene occurs as kinked, bronze-colored, silky-lustered megacrysts. One such megacryst, 10 × 6 × 3 cm, was collected for study. Based on the analysis of six fragments taken from various parts of the megacryst, it is evident that this orthopyroxene is homogeneous and marginally more aluminous and magnesian than the prevailing small grains in the anorthosite's matrix (Table 1). The composition of the megacryst matches that of orthopyroxene megacrysts from the St-Urbain anorthosite, situated 70 km to the northeast (Dymek & Gromet 1984).

Other minerals in the anorthosite include nearly ubiquitous laths of primary magnesian biotite (Table 2), and nonmagnetic ilmenite. Analyses of the ilmenite (Table 2) show a deficiency of TiO_2 relative to ideal ilmenite due to pervasive microscopic lamellae of hematite. The totals are low because all iron was calculated as Fe^{2+}. A few samples contain subhedra of olive-green amphibole (ferroan pargasitic hornblende, Table 2), as well as scattered anhedra of apatite and quartz.

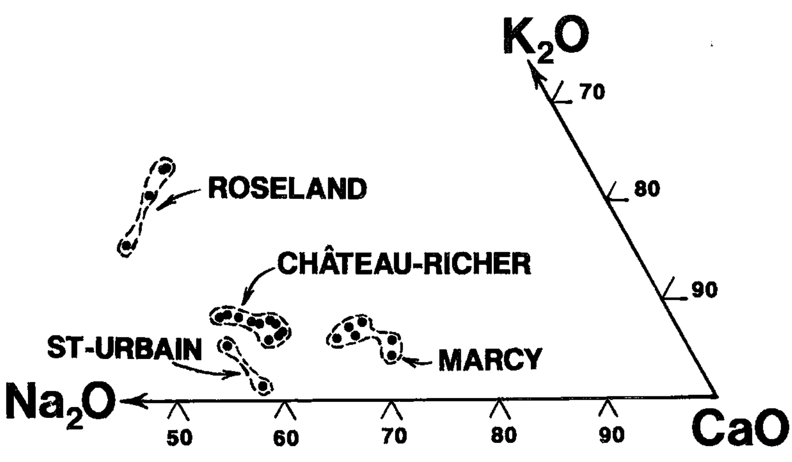

FIG. 2. Part of the K_2O–Na_2O–CaO triangle (weight percent) showing the distribution of selected anorthosites. Sources: Roseland, Herz & Force (1987), Château-Richer, Hunt (1855), Dejou *et al.* (1982), and the present report; St-Urbain, Mawdsley (1927); Marcy, Buddington (1939). Average massif anorthosite (Nockolds 1954) falls in the Marcy field.

The Château-Richer anorthosite is relatively alkali-rich (Table 3); it is close to but slightly more potassic than the St-Urbain anorthosite (Fig. 2). It falls between the unusual alkali-rich anorthosite at Roseland, Virginia, and the classical Marcy type from the Adirondack Mountains. Average massif anorthosite (Table 3) resides in the Marcy field. In passing, it is instructive to note the excellent correspondence between the results of Hunt's analyses, carried out nearly a century and a half ago, and those made in modern laboratories (Table 3).

Country Rocks

Metamorphic rocks that surround the Château-Richer anorthosite range from upper amphibolite to granulite grade. These rocks, members of the poorly defined "Laurentides Park Complex", are chiefly fine- to medium-grained layered charnockites and granitic gneisses. Other and less abundant rock-types include alaskite, pyroxene amphibolite, marble, and black skarn-like pyroxenite. The pyroxenite is particularly interesting, and the question arises if it might not have developed in response to metasomatism by the adjacent anorthosite. This seems unlikely, because in spite of its dark color, the clinopyroxene that makes up these rocks, as determined by electron microprobe, is highly magnesian (X_{Mg} 0.84) and little resembles the more Fe-rich pyroxenes typical of skarns. The pyroxenite formed by the recrystallization of impure dolomitic marble during the regional Grenvillian metamorphism, and is unrelated to the anorthosite. The so-called classical associates of anorthosite, namely gabbro, ferrodiorite, and mangerite, are absent at Château-Richer.

The exposed edge of the Shield lies only a kilometer or two southeast of the anorthosite (Fig. 1). Along this edge, the metamorphic rocks are overlain unconformably by the Trenton Limestone (commonly with a basal glauconitic sandstone) of Middle Ordovician age (Riva 1972).

Structural Geology

At least a feeble foliation can be recognized in most of the anorthosite. The pattern of this foliation is orderly. Toward the periphery of the body, the foliation dips outward; over large areas of the interior of the body, it is horizontal or nearly so (Fig. 1). Foliation in the anorthosite at its contacts is concordant with foliation and layering in the adjacent country-rocks. No dyke or sill of anorthosite has been found in the surrounding country-rocks, and no inclusion of country-rock has been recognized in the anorthosite.

The intensity of deformation is unrelated to proximity to the contacts of the body. For example, although the anorthosite has been reduced to ultramylonite at the contact with country-rocks in the Rivière du Sault-à-la-Puce, coarse-grained, nearly massive anorthosite is found at the contact in the Rivière Cazeau only 5 km to the southwest, and around much of the northern edge of the body. Also, the degree of deformation of anorthosite and adjacent country-rocks is not everywhere related. Relatively unstrained anorthosite may be in contact with intensely strained gneiss, for example, whereas elsewhere mylonitic anorthosite may abut relatively massive country-rock.

Foliation and layering in the country-rocks commonly are prominent. In places, two foliations can be distinguished: a weak early foliation is overprinted by a pervasive and strong younger foliation, the one depicted on the geological map (Fig. 1). The regional strike of the foliation is north to northeast, except where it is deflected at the northern and southern ends of the anorthosite. In the south, foliation has been transposed by regional deformation to a northeasterly strike, parallel to the edge of the Shield. This deformation has been attributed to late Proterozoic right-lateral wrench faulting (Lachapelle 1992). Lineations defined by mineral streaming are locally well developed. They are everywhere horizontal or plunge only gently.

Owing to the pattern of outcrops on the geological map (Fig. 1), the Château-Richer anorthosite might give the impression that it constitutes a dome that pushed aside the country-rocks during emplacement. Three observations cast doubt upon this view. The first is the structural asymmetry of the anorthosite itself. Dips along its western edge are steep, ranging to vertical, whereas those along the east are more gentle, commonly less than 45°. The second observation is the lithological asymmetry of the country-rocks around the anorthosite. As an illustration, the distinctive marble and associated black skarn-like pyroxenite that follow the eastern contact of the anorthosite are absent on the west, as noted by Hunt (1855). Finally, the pervasive gentle plunge of mineral lineations is inconsistent with a vertical rise of the anorthosite and its envelope of country-rocks.

A preferred interpretation, and one in keeping with field observations, is that the anorthosite constitutes a relatively thin sheet in the core of a doubly plunging antiformal fold. A test of this interpretation using geophysical techniques is presented below.

Gravity Anomalies

Prior to the onset of the present study, gravity observations on the Shield within a radius of 5 km of the Château-Richer anorthosite were limited to a single station (Fig. 3). To fill this void, more than 100 new gravity stations were established in the area with a Worden gravity meter (W–807) in 1989 and 1991. Station elevations were read from 1:20,000-scale topographic maps published by the Service de la cartographie (ministère de l'Énergie et des Ressources du

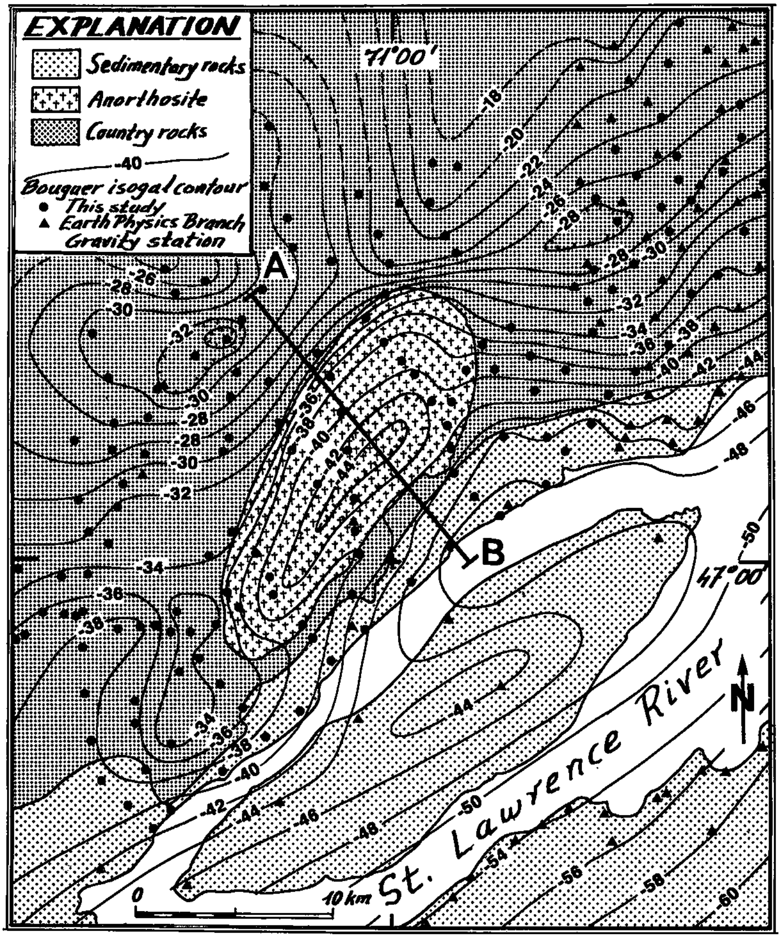

FIG. 3. Simple Bouguer gravity anomaly map of the Château-Richer anorthosite and surrounding country. A–B is the line of the profile in Fig. 5.

Québec), corroborated by aneroid barometry. Simple Bouguer anomalies were calculated on a personal computer, using the GRAVSYS programme developed at the Geophysical Data Centre, Geological Survey of Canada. Combined errors caused by nonlinear instrumental drift, inaccurate elevations, and topographic effects probably nowhere exceed 2 mGal. The resulting map (Fig. 3) was hand-contoured.

The Bouguer gravity field is uneven over the Shield (the northwestern two thirds of the map, Fig. 3), again a reflection of the varied character of its constituent rock-types. Among the several gravity highs and lows, an 8-mGal residual low follows closely the outline of the Château-Richer anorthosite. The anomaly is asymmetrical, being steep toward the northwest but only ill-defined toward the southeast, where it faces the regional negative anomalies associated with the Appalachian orogen across the St. Lawrence River.

MAGNETIC ANOMALIES

On the total-field aeromagnetic map (Fig. 4), the Château-Richer anorthosite coincides with a prominent, steep-sided, and rather flat negative anomaly that is, on average, more than 1000 nT below the field over the surrounding Shield. The anomaly is substantiated by magnetic susceptibilities measured on cores taken from selected hand-specimens of anorthosite and country rocks. The susceptibility of the anorthosite is, on average, fully two orders of magnitude less than that of the country rocks (Table 4). The imposing relief of the magnetic field beyond the confines of the anorthosite is a measure of the varied character of the country rocks and perhaps, to a lesser extent, the rugged topography (particularly north and west of the anorthosite), which made it impossible to fly the magnetometer at constant elevation above ground

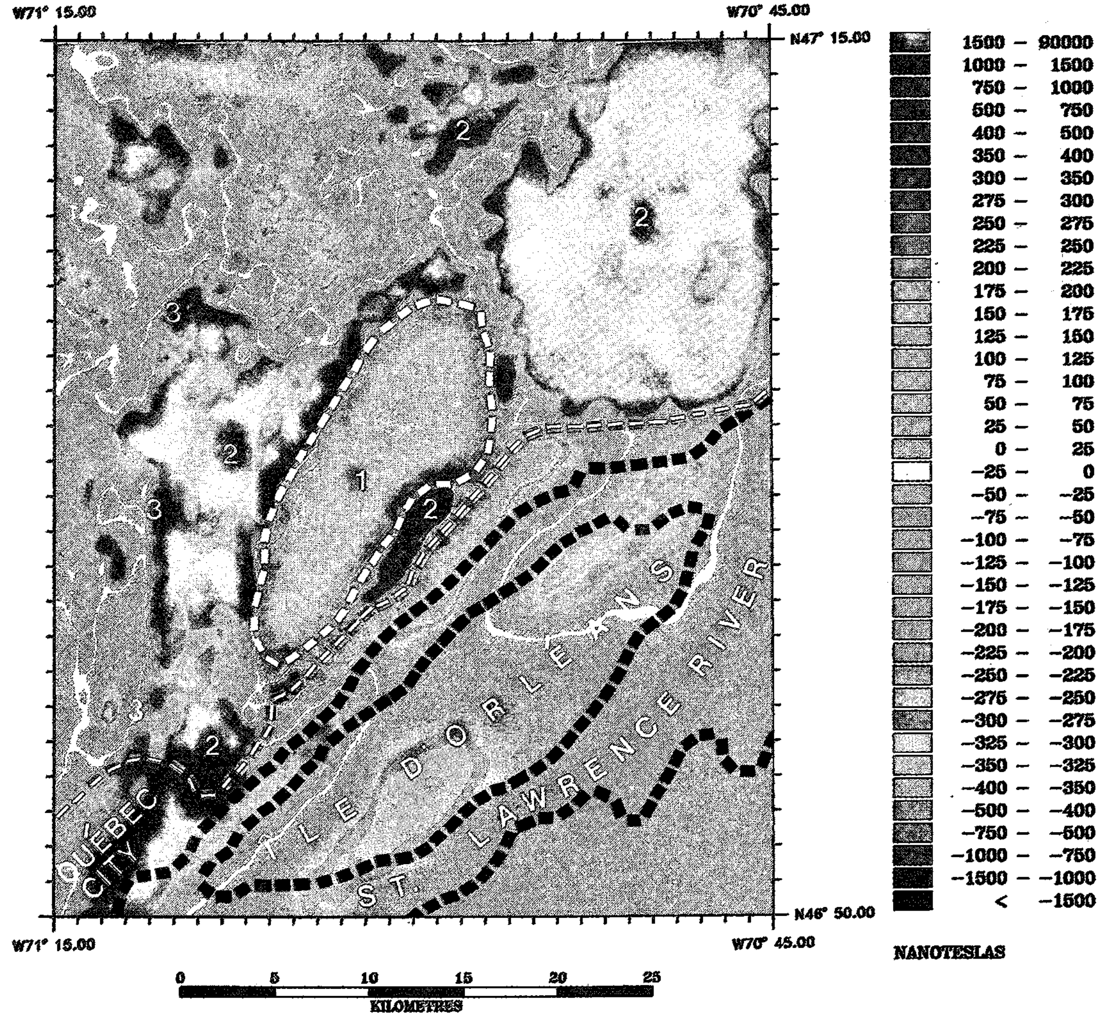

FIG. 4. Total-intensity aeromagnetic anomaly map of the Château-Richer anorthosite and surrounding country. Conventions: 1. Negative anomaly on the anorthosite; 2. Positive anomalies on rocks of the Laurentides Park complex; 3. The eastern contact of a north-striking granite batholith. Lines: white dashed, outline of the Château-Richer anorthosite; white and orange dashed, edge of the Shield; black dashed, shoreline of the St. Lawrence River.

level. The relatively featureless magnetic field in the southeastern part of the map (Fig. 4) reflects the thick cover of Paleozoic sedimentary rocks of the Appalachian orogen.

GEOPHYSICAL MODELS

Computer-generated gravity and magnetic models of the Château-Richer anorthosite were constructed

TABLE 4. MAGNETIC SUSCEPTIBILITIES OF ROCKS AT CHÂTEAU-RICHER

Unit	N_{cores}	$N_{samples}$	Magnetic susceptibilities (emu·cm^{-3})		
			$\bar{x}$	Max.	Min.
Château-Richer anorthosite	10	34	5.41×10^{-4}	38.4×10^{-4}	0.29×10^{-4}
Country-rocks	8	28	4.38×10^{-3}	12.5×10^{-3}	0.10×10^{-3}

TABLE 5. DENSITIES OF ROCKS AT CHÂTEAU-RICHER

	N	g·cm^{-3}			
		$\bar{\rho}$	S.D.	Max.	Min.
Château-Richer anorthosite	126	2.689	0.019	2.77	2.65
Country-rocks	178	2.849	0.193	3.34	2.58

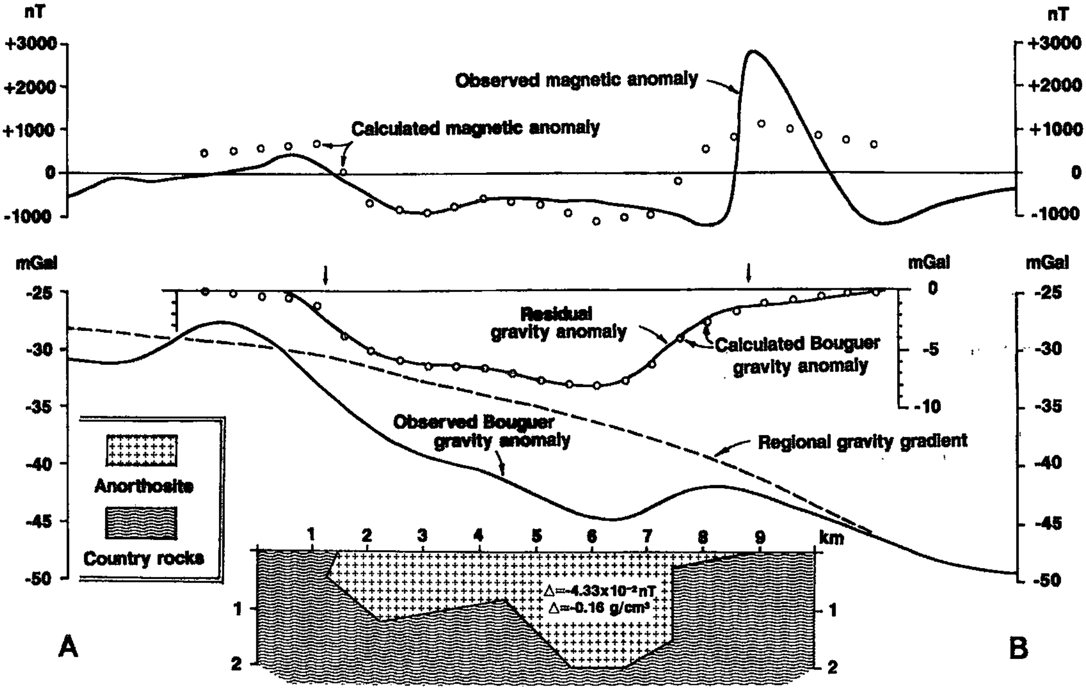

FIG. 5. Geophysical model of the Château-Richer anorthosite.

using the MAGRAV 2.5-D programme (Broome 1988). The models are based on a variety of data: geological mapping and gravity observations are the field components, whereas rock densities and magnetic susceptibilities were measured in the laboratory.

Gravity model

A gravity model (Fig. 5) was constructed for the Château-Richer anorthosite along a profile (A–B, Fig. 3) that crosses the anorthosite near its center and is oriented more or less at right angles both to the long axis of the body and to the general trend of the regional gravity field. The precision of this model is hampered by two elements: (1) the substantial variability in density of the country rocks (Table 5, Fig. 6), and (2) the erratic nature of the Bouguer gravity field over the Shield beyond the anorthosite (Fig. 3). To deal with these obstacles, simple averages were used for densities of the country rocks and anorthosite (Table 5); the anorthosite thus comes out to have a density contrast of –0.16 g·cm^{-3}. To define the regional gradient in gravity along the profile, a smoothed curve (dashed on Fig. 5) was drawn through the regional gravity field along the profile, beginning and ending beyond the limits A and B, and ignoring the anomaly over the anorthosite. The arithmetic difference between this curve and observed gravity over

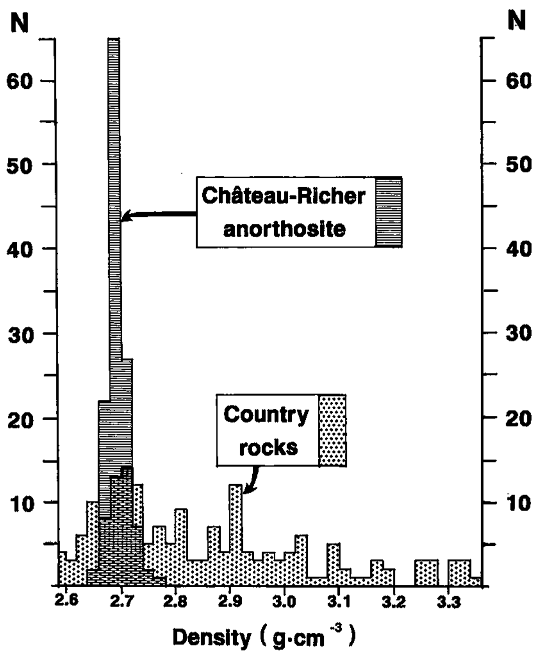

FIG. 6. Histogram of densities of rocks at Château-Richer.

the Château-Richer anorthosite (lowermost curve on Fig. 5) is the residual anomaly caused by the anorthosite alone. This anomaly is slightly wavy, and has a maximum amplitude of –8 mGal, located one km southeast of the center of the body.

The model that most closely fits the Château-Richer gravity anomaly is that of an uneven slab, no more than 2 km thick, and markedly thinner at its center than toward its extremities (Fig. 5). Clearly, this model depends heavily on the regional gravity gradient chosen. Nevertheless, the general view of the anorthosite as a relatively thin slab will not change. Several conclusions are pertinent: (1) The volume of the Château-Richer anorthosite is restricted; it cannot be a domelike mass that enlarges with depth. (2) The anorthosite is sheetlike, with a thickness that is only a fraction of its lateral extent. (3) The central thinning of the sheet is consonant with the interpretation based on field mapping, mentioned earlier, that the anorthosite is exposed in an antiformal fold. (4) Finally, no substantive bodies of dense mafic or ultramafic rocks hidden at depth are associated with the anorthosite.

Magnetic model

The averaged magnetic susceptibilities of the Château-Richer anorthosite and country rocks (Table 4) were applied to the corresponding bodies of the model constructed from the gravity anomalies (Fig. 5). The magnetic anomaly calculated from this configuration (small circles on the upper panel of Fig. 5) corresponds, in a general way, with the observed magnetic anomaly. The principal departure is the peaked positive anomaly observed over the narrow corridor of country rocks southeast of the anorthosite at the right-hand end of the profile. The great amplitude of this anomaly reflects the peculiar local concentration of accessory magnetite in feldspathic gneiss that, in some layers, exceeds 5% modally.

PETROGENESIS

The petrogenesis of the anorthosite at Château-Richer is of particular interest because of the historical significance of the body. T. Sterry Hunt, largely on the basis of work at Château-Richer, came to regard all anorthosite as a metasedimentary rock. Indeed, a sedimentary–metasomatic origin was revived briefly for the Adirondack anorthosites (Gresens 1978). However, the least-deformed anorthosite at Château-Richer, particularly the very coarse-grained rock (Fig. 1), preserves the irrefutable imprint of crystallization from magma and dispels any doubts about its primary igneous origin. This rock is a plagioclase cumulate composed of crowded euhedral plagioclase crystals with sparse intercumulus filling, chiefly of pyroxene and ilmenite. Also, the seeming preservation of some sort of igneous layering suggests that the anorthosite may once have been part of a layered intrusion, as is the case in many instances around the world. At Château-Richer, however, gravity anomalies (Fig. 3) show that the anorthosite, in its present setting, is isolated. If it was ever a member of a layered mafic intrusion, the Château-Richer anorthosite has been tectonically dismembered and transported far from any mafic roots. Thus the absence of apophyses of anorthosite in adjacent country-rocks, although it may have weighed heavily on Hunt's mind, is no argument against an igneous origin.

The anorthosite at Château-Richer displays an apparent disequilibrium of phases similar to that observed in the andesine anorthosite at St-Urbain by Dymek & Gromet (1984). Such apparent disequilibrium is reflected in the coexistence of magnesian pyroxenes (Table 1) with unexpectedly sodic plagioclase. The absence of reaction textures between these phases, which in thin section abut in sharp contact, suggests that this association is not due to disequilibrium. Perhaps unusually high magmatic temperatures, coupled with the limited compositional range of the anorthosite, promoted equilibrium. The strong development of antiperthitic textures in the plagioclase points just to such postulated former high temperatures (Kay 1977). On the other hand, the elevated oxygen fugacity of the magma, now reflected by the ubiquitous presence of hematite-bearing ilmenite, drastically buffered the X_{Mg} of the pyroxenes. If either of these mechanisms (or a combination of the two) was effective, the parent magma could have had a basaltic composition. The relatively aluminous and magnesian megacrysts of orthopyroxene may be xenocrysts, having crystallized elsewhere during an earlier stage of differentiation.

The only fine-grained rocks observed at the contact are occasional mylonitized anorthosites. No "chilled border" of parental rocks envelops the body. Also, the nearly anhydrous composition and intense regional metamorphism of the country rocks around the anorthosite preclude the recognition of a thermal aureole.

ACKNOWLEDGEMENTS

Many people helped substantially in this study, and they merit my most sincere thanks. Marco Quirion determined plagioclase compositions. Jean-Pierre Tremblay carried out the mineral analyses at the electron-microprobe laboratory, Université Laval. Summer students Hal Perry and Kamal El haji, as well as my daughter Ingrid, conducted parts of the gravity survey and helped to measure the densities of rock samples. Warner Miles prepared the color aeromagnetic map, and Peter McGrath executed the total-field magnetic profile across the anorthosite. Liza Tanczyk measured the magnetic susceptibilities. My colleagues Ron

Emslie, Ken McConnell, Philip Salib, and Léopold Nadeau offered constructive discussion. Prof. R.F. Dymek furnished an early review. Lise Michard provided the word processing. I am grateful to two reviewers, and to Robert Martin for his helpful editorial annotations.

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Received February 15, 1993, revised manuscript accepted April 15, 1993.