Geological Survey of Canada

CURRENT RESEARCH
2003-C12

Tracking the Wakeham Group volcanic rocks and associated copper-iron oxide hydrothermal activity from La Romaine eastward, eastern Grenville Province, Quebec

Louise Corriveau, Anne-Laure Bonnet, Otto van Breemen, and Pierre Pilote

2003

CURRENT RESEARCH

Natural Resources Canada
Ressources naturelles Canada

Canada

ISSN 1701-4387
Catalogue No. M44-2003/C12E-IN
ISBN 0-662-33534-1

A copy of this publication is also available for reference by depository libraries across Canada through access to the Depository Services Program's website at http://dsp-psd.pwgsc.gc.ca

A free digital download of this publication is available from the Geological Survey of Canada Bookstore web site:

http://gsc.nrcan.gc.ca/bookstore/

Click on Free Download.

Authors' addresses

***L. Corriveau** (lcorrive@nrcan.gc.ca)*
***A-L. Bonnet** (abonnet@nrcan.gc.ca)*
INRS-Eau, Terre et Environnement
P.O. Box 7500
Sainte-Foy, Quebec G1V 4V7

***O. van Breemen** (ovanbree@nrcan.gc.ca)*
Geological Survey of Canada
Continental Geoscience Division
601 Booth Street
Ottawa, Ontario K1A 0E8

***P. Pilote** (pierre.pilote@mrn.gouv.qc.ca)*
Ministère des Ressources naturelles du Québec
Complexe FTQ
545, boulevard Crémazie Est
bureau 1110
Montréal, Quebec H2M 2V1

Publication approved by GSC Quebec

Tracking the Wakeham Group volcanic rocks and associated copper-iron oxide hydrothermal activity from La Romaine eastward, eastern Grenville Province, Quebec[1]

Louise Corriveau, Anne-Laure Bonnet, Otto van Breemen,
and Pierre Pilote

Corriveau, L., Bonnet, A-L., van Breemen, O., and Pilote, P., 2003: Tracking the Wakeham Group volcanic rocks and associated copper-iron oxide hydrothermal activity from La Romaine eastward, eastern Grenville Province, Quebec; Geological Survey of Canada, Current Research 2003-C12, 11 p.

Abstract: The last field season of the Targeted Geoscience Initiative Eastern Grenville Transect in Quebec unveiled a < 10 km wide by 50 km long southeastern extension of the Wakeham Group, host to an extensive cupriferous hydrothermal system. The supracrustal rocks consist of granulite-facies metasandstone, 1.5 Ga lapillistone, amphibolite, marble, and calc-silicate rock enclosed within a metamorphosed, 1.5 Ga Pinwarian subvolcanic batholith. High-grade metamorphism in this belt would traditionally be seen as an impediment to mineral exploration. However, we have recognized and traced an extensive zone of aluminous gneiss that records strong hydrothermal leaching of metavolcanic units. Amphibolite occuring structurally above and likely serving as a caprock contains garnetite, diopsidite, and hornblendite and provides an effective guide to the site of fluid discharge and mineralization. A number of showings were discovered; their systematic occurrence, in a structural and stratigraphic sense, suggests that, although this supracrustal belt is of modest size, it should be explored.

Résumé : Dans le cadre de la dernière saison de travaux sur le terrain du projet de l'Initiative géoscientifique ciblée portant sur le transect du Grenville oriental au Québec, on a mis à jour un prolongement du Groupe de Wakeham vers le sud-est, sous la forme d'une bande large de moins de 10 km et longue de 50 km, dans lequel peuvent être reconnues les traces d'un système hydrothermal d'envergure à minéralisation cuprifère. Cette ceinture de roches supracrustales est enclavée dans un batholite subvolcanique métamorphisé de 1,5 Ga, lié à l'orogenèse pinwarienne. Elle renferme du grès, du lapillistone de 1,5 Ga, de l'amphibolite, du marbre et de la roche calco-silicatée métamorphisés au faciès des granulites. Selon des points de vue traditionnels, le métamorphisme de haut grade constituerait un obstacle à l'exploration minière de cette ceinture. Toutefois, nous avons pu identifier et délimiter une zone étendue de gneiss alumineux qui enregistre un lessivage hydrothermal important au sein de roches volcaniques. L'unité d'amphibolite, située structuralement au-dessus, a vraisemblablement servi de scellant et renferme de la grenatite, de la diopsidite et de l'hornblendite, des indicateurs de sites d'émission de fluides hydrothermaux et de minéralisation. Quelques indices minéralisés ont été identifiés et leur présence systématique, d'un point de vue structural/stratigraphique, suggère que cette ceinture de roches supracrustales, bien que de dimension modeste, devrait être explorée.

[1] Contribution to the Targeted Geoscience Initiative (TGI) 2000–2003.

INTRODUCTION

The discovery of a world-class zinc deposit in Grenvillian marble in the Adirondack Lowlands at the turn of the twentieth century has for decades oriented mineral exploration in the Grenville Province toward SEDEX-type environments (e.g. Sangster et al., 1992). In contrast, frontier high-grade metamorphic gneiss terranes have been considered intractable and sterile, and left largely unmapped. This paradigm is being challenged following recent discoveries in these terranes of copper-iron oxide hydrothermal systems and subeconomic deposits (Gower et al., 1995; Corriveau et al., 1996; McLelland et al., 2002; Clark, in press). The multipartnered Targeted Geoscience Initiative 'Eastern Grenville Transect' capitalizes on these findings to provide new models and guides that will stimulate and improve effectiveness in targeting mineral exploration in the gneiss terrane between the Wakeham Group of eastern Quebec and the volcano-plutonic, 1.55 to 1.4 Ga Pinware terrane of Labrador (Fig. 1a; Gower et al., 2001; Gobeil et al., in press).

The mostly arenaceous Mesoproterozoic Wakeham Group extends southeasterly from its main body as three supracrustal belts among granitic gneiss complexes (Fig. 1; Ministère des Ressources naturelles, 2001; Gobeil et al., in press). Supracrustal rocks also occur within adjacent terranes (*see* Claveau, 1950; Bassaget, 1970; Bourne et al., 1978) and may represent tectonically isolated fragments of an initially regionally continuous supracrustal cover sequence. Recent geological compilations suggest that the 'Wakeham Group' extends as far east as the La Romaine domain, which is considered to be mostly of supracrustal origin and hosts meta-arkose units distinct from the Wakeham Group (Fig. 1a; Ministère des Ressources naturelles, 2001). In order to assess the geological context of these rocks, boat-supported mapping was conducted in 2000 on Musquaro and d'Auteuil lakes (NTS 12 K/6, 10, 11, 14) and in 2001 along the coast of the Gulf of St. Lawrence from Kegashka to Wolf Bay and on Lake Washicoutai (NTS 12 K/1, 2, 3, 7). The detailed geology of these area was reported in Corriveau and Bonnet (2001) and Corriveau et al. (2002).

We report herein additional observations on the geology of the Musquaro–La Romaine area acquired in summer 2002 (Fig. 1b, c, d, e). We also trace the extension of the Wakeham Group from its main body to a series of thin belts traceable as far east as Wolf Bay (Fig. 1d). The objectives of the fieldwork were 1) to gain additional tectono-stratigraphic insight on the volcanic and sedimentary packages recognized in previous years; 2) to establish their lateral distribution within the limits of the transect; and 3) to better assess the nature and distribution of the hydrothermal units they host. Géologie-Québec and the GSC pooled their respective expertise on metallogeny and recognition of metamorphosed hydrothermal systems to study some key areas in greater detail. Field observations led to a better definition of the geological context and metallogenic potential of the Wakeham Group extension and demonstrate that it hosts a significant hydrothermal system with specific targets for mineral exploration.

MUSQUARO AREA

The recognition of felsic metavolcanic rocks associated with meta-arenite typical of the Wakeham Group in the Musquaro Lake–La Romaine region greatly expanded the known field distribution of this sedimentary basin and provided a first opportunity to establish the precise depositional age of the Wakeham supracrustal succession (Corriveau and Bonnet, 2001; Corriveau et al., 2002). The units at Musquaro Lake appear to be continuous with the main body of the Wakeham Group (Ministère des Ressources naturelles, 2001). However, as no volcanic rocks are interbeded with the sedimentary rocks at Musquaro Lake, one key element remained missing for constraining the age of sedimentation by dating the volcanic rock package, i.e. the nature of the contact between the subvertical arenaceous and pyroclastic units (Fig. 1b). A recently discovered key exposure in which basal polygenic lapillistone is in direct contact with sedimentary rocks shows that no structural break occurs between these two packages. This outcrop is particularly significant as it features well preserved primary pyroclastic flow textures both parallel and perpendicular to pumice elongation (Fig. 2a, b), indicating that deformation is locally weak despite amphibolite-facies metamorphism (*see* Bonnet and Corriveau, 2003). Primary textures in underlying sedimentary rocks indicate that the volcanic rocks were deposited on the sediments. A grey polygenic lapillistone, identical to and in structural continuity with the one exposed at the contact, and an undeformed feldspar porphyry intrusive into the pyroclastic unit yielded ages of 1511 ± 13 Ma and 1493 ± 10 Ma respectively; a lapillistone on an island south of the contact yielded an age of 1506 ± 11 Ma (O. van Breemen and L. Corriveau, unpub. U-Pb SHRIMP data, 2002). These ages provide lower age limits for sedimentation. The upper age limit is given by detrital zircon ages of ca. 1.52 Ga from a subarkose north of the contact (O. van Breemen and L. Corriveau, unpub. U-Pb SHRIMP data, 2002). Consequently, sedimentation is constrained in the 1.54 to 1.50 Ga interval (taking into account age uncertainties). This age bracket is consistent with and further constrains the age interval obtained from Wakeham Group metasedimentary rocks and adjacent granitoid units (Wodicka et al., in press).

The arenite unit is interbedded with nodular muscovite- and fibrolite-bearing gneiss, minor marble, and finely layered garnetiferous hornblendite, garnetite, and magnetite-bearing coticule systematically enriched in manganese (Fig. 2c; Corriveau and Bonnet, 2001). Barium-rich coticule with yellowish to dark pink garnet and garnet amphibolite associated with finely laminated tuffaceous beds (Fig. 1b, 2d) are exposed as in situ rafts within granitic gneiss dated at 1.5 Ga (van Breemen and Corriveau, 2001). Such a lithological package is interpreted as typical of regionally metamorphosed exhalite, and its common association with massive-sulphide deposits makes its recognition a key element in the search for concealed mineral deposits in this high-grade metamorphic terrane (e.g. Spry et al., 2000).

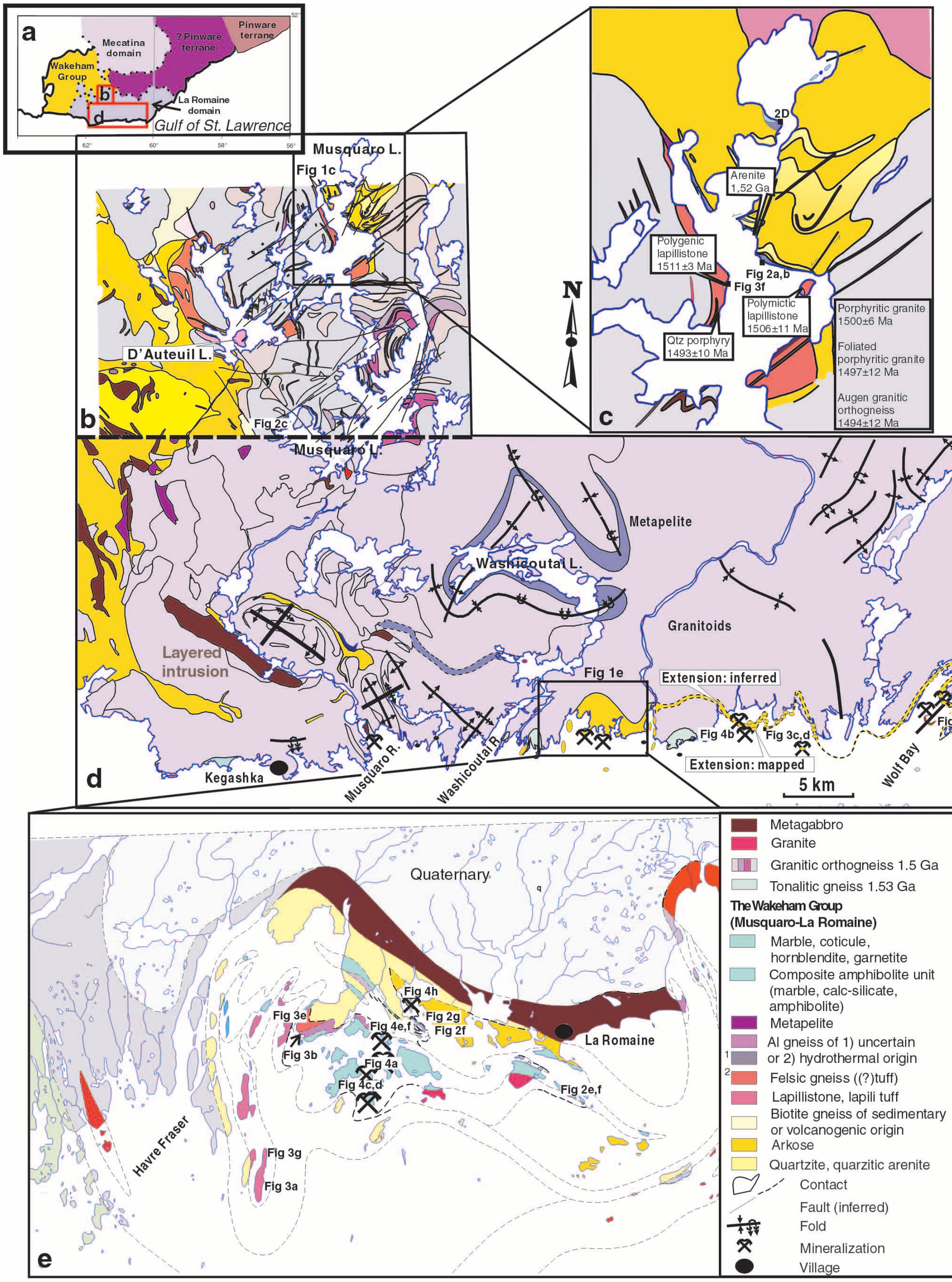

Figure 1. ***a)*** *Location of transects with respect to major lithotectonic divisions of the eastern Grenville Province* (modified from *Gower et al., 2001, and Ministère des Ressources naturelles, 2001). The western margin proposed for the La Romaine domain varies according to authors.* ***b)*** *Simplified map of the Musquaro Lake area.* ***c)*** *Detail of the metasedimentary and metavolcanic package at Musquaro Lake with unpublished U-Pb zircon SHRIMP ages obtained by O. van Breemen and L. Corriveau (2002) for dated granitoid rocks, arenite, and lapillistone.* ***d)*** *Geology of the La Romaine–Wolf Bay area showing the presumed extension of the Wakeham Group and its mineral showings.* ***e)*** *Detail of map sheet 12 K/2 centred on La Romaine, lower North Shore, Quebec.*

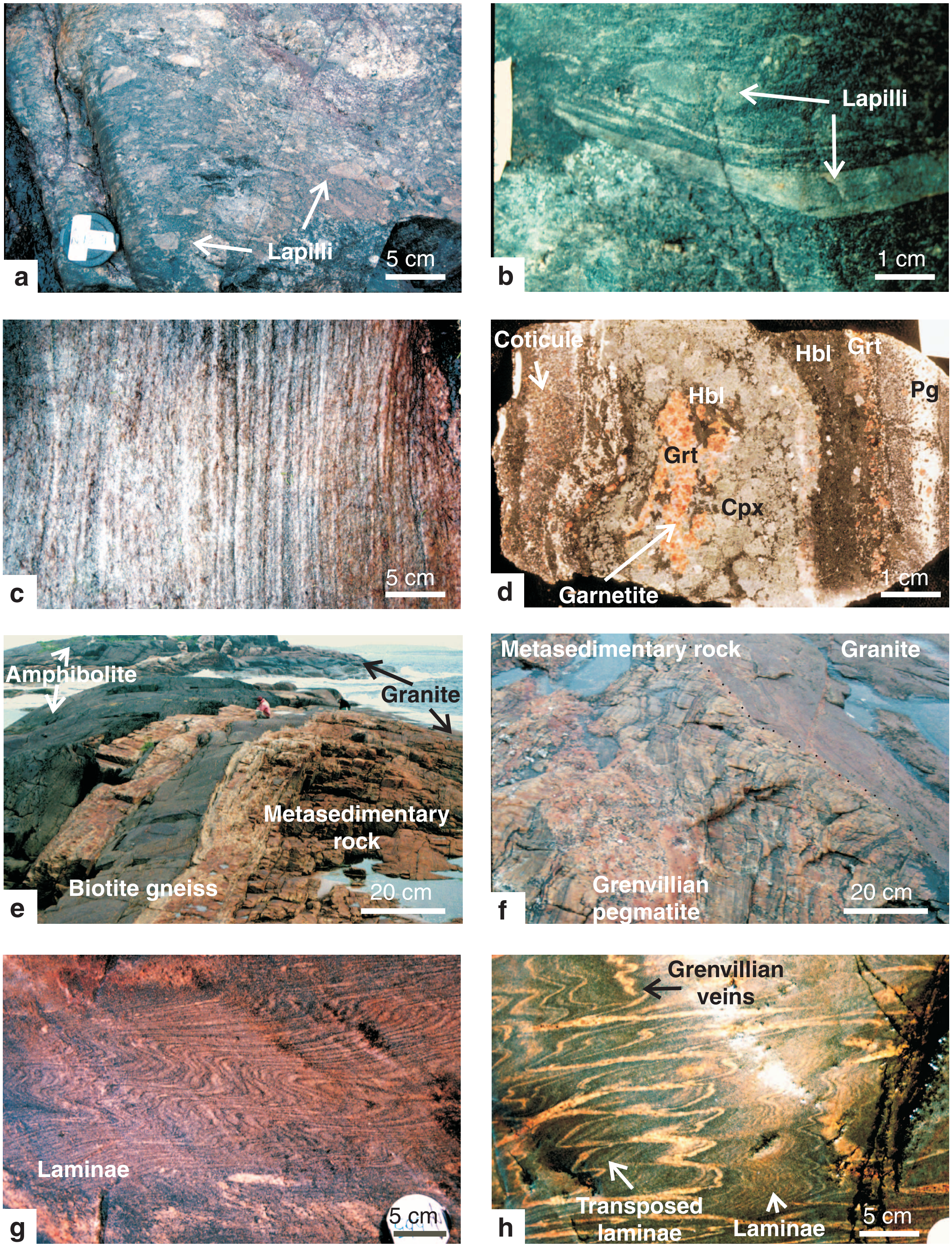

Figure 2. *Pyroclastic rocks at Musquaro Lake and metasedimentary rocks at La Romaine (location in UTM co-ordinates, zone 20, NAD 83)*. ***a)*** *Felsic lapillistone texture perpendicular to pumice elongation (635022mE 5618678mN);* ***b)*** *pumice flow structure parallel to pumice elongation (635022mE 5618678mN);* ***c)*** *finely laminated tuffaceous bed (625845mE 5596277mN);* ***d)*** *finely layered garnetiferous diopsidite, hornblendite, and coticule (634386mE 5624676mN) (Cpx, clinopyroxene; Grt, garnet; Hbl, hornblende; Pl, plagioclase);* ***e)*** *metasedimentary rocks in contact with the composite amphibolite unit (666153mE 5564019mN);* ***f)*** *close-up of* ***(e)*** *showing a late-stage granite crosscutting metasedimentary rocks (666153mE 5564019mN);* ***g)*** *laminated meta-arenite layer (663563mE 5565533mN);* ***h)*** *meta-arenite unit with transposed layers (663084mE 5565684mN).*

LA ROMAINE AREA

Regional geology

Mapping in summer 2001 of coastal exposures in the Kegashka–La Romaine region revealed that large tracts of layered granitic gneiss previously interpreted as meta-arkose consist of metre- to decametre-wide granitic dykes with internal magmatic layering within streaky to augen granitic orthogneiss (*see* Corriveau et al., 2002, Fig. 4). Thus, the La Romaine domain is plutonic rather than metasedimentary (cf. Fig. 1a vs. d *in* Corriveau et al., 2002). In addition, the discovery of a layered mafic intrusion and its potential extension for up to 20 km, opened the area to exploration for magmatic nickel-copper sulphides and PGE. Following publication of our reports, part of the area was staked, leading to the discovery of a PGE showing. Recently acquired geochronological data indicate that the layered intrusion is Grenvillian (1.07 Ga) and intrusive within Pinwarian (1.5 Ga) granitic gneiss (O. van Breemen and L. Corriveau, unpub. SHRIMP zircon ages, 2002).

Bourne et al. (1978) reported the occurrence of a quartzite-rich package at La Romaine. Our field re-evaluation indicates that the sequence includes a distinctive unit of metavolcanic rocks structurally located between metasedimentary rocks and amphibolite. In addition, the amphibolite unit comprises screens of calc-silicate rock and quartzite (Fig. 2e, f). This supracrustal belt is hosted by and locally intercalated with granitic gneiss and intruded by late-stage foliated granitic stock, sills, and dykes (Fig. 2f, g, h), one of which has yielded a 1.02 Ga Grenvillian age (van Breemen and L. Corriveau, unpub. U-Pb SHRIMP zircon data, 2002). A mafic dyke swarm is exposed as elongate boudins within the granitic gneiss; apophyses are rare but do occur locally.

The supracrustal package is composed of the following, from structural base to top: 1) a complexly folded grey gneiss unit of uncertain origin traceable for tens of kilometres that locally contains well laminated to massive meta-arenite (Fig. 2g, h); 2) a discontinuous lapillistone unit in contact with a variety of felsic gneiss bodies characterized locally by the presence of sillimanite-muscovite nodules (Fig. 3a to e; cf. Fig. 3f showing a similar set of veins at Musquaro Lake), white siliceous gneiss (Fig. 3g), and nodular to disseminated sulphides (Fig. 3h); 3) a sillimanite-garnet-cordierite-bearing aluminous gneiss, locally with relict lapilli (Fig. 3b); 4) a discontinuous unit of finely layered marble and calc-silicate rocks; and 5) a composite amphibolite unit 0.5 to 2 km thick locally associated with quartzite or calc-silicate rocks. This amphibolite unit is locally laden with large grey to white pegmatite dykes, which contrast with the pervasive pink Grenvillian pegmatite and related granitic dykes (Fig. 4a). Disseminated magnetite and/or hematite is pervasive in the pink felsic gneiss and in amphibolite, in the latter locally reaching concentrations up to 20% in centimetre-thick, foliation-parallel, discontinuous layers or lenses. This supracrustal rock package has been traced discontinuously for over 50 km, from Havre Fraser to Wolf Bay, as a tightly to openly folded, up to 10 km thick belt within granitic gneiss. Its lithological assemblage shows marked similarities with the Musquaro Lake 1.5 Ga supracrustal units, host to hydrothermally altered and meta-exhalite-like rocks (Corriveau and Bonnet, 2001).

Metasedimentary units

Gneiss bodies of presumed sedimentary origin are common within the grey gneiss unit (Fig. 2g) and are best exposed in a bay 2 km west of La Romaine and at Wolf Bay. They include a unit of granoblastic, fine-grained, grey quartzofeldspathic gneiss locally exhibiting continuous, millimetre- to centimetre-thick layering expressed as variations in modal biotite. These rocks are invariably invaded by granitic veins that are tightly folded and transposed along the axial plane of the folds (Fig. 2h). They share many hallmarks of the Wakeham Group meta-arenite. In addition, marble and calc-silicate rocks occur locally as thin irregular layers within the amphibolite unit and as a discrete unit within the sedimentary succession. In the latter, the marble is granoblastic, fine to medium grained, layered, and consists mostly of calcite, diopside, and phlogopite. The calc-silicate rocks are granoblastic, fine to medium grained, with a nematoblastic texture. They contain calcite±diopside±epidote±feldspar±hornblende± phlogopite±quartz and scapolite in varied proportions as well as disseminated sulphides.

Volcanic units

The volcanic package comprises grey lapillistone intercalated with grey and pink quartzofeldspathic gneiss of uncertain origin; the grey gneiss resembles the grey tuff intercalated with volcanic rocks at d'Auteuil Lake, whereas the pink gneiss resembles nodular gneiss intercalated with lapillistone at Musquaro Lake.

Lapillistone contains abundant, centimetre- to decametre-long, buff-weathering, elongate, subrounded lapilli among which are interspersed centimetre-long angular to rounded lapilli. The lapilli have a high aspect ratio (1 cm wide, 2 cm to 2 dm long) and are mostly quartzofeldspathic, leucocratic, very fine grained, and homogeneous. Biotite (approximately 1%) prevails as the mafic accessory mineral. A few lapilli display quartz-feldspar mosaic texture, which may point to a vesicular protolith. Some contain a small percentage of fine-grained biotite, and some are mafic. The lapillistone bears marked similarities with that at Musquaro Lake, but textures are not as well preserved because of granulite-facies metamorphism (Corriveau et al., 2002). Farther east, an outcrop of felsic gneiss has textures akin to those expected for strongly deformed and recrystallized lapillistone (cf. Fig. 3b and c vs. a). The gneiss comprises distinct blocks, some rounded and felsic (Fig. 3d) and others angular and more mafic. It is interpreted to have a pyroclastic origin.

The pink nodular gneiss in contact with the lapillistone unit at Havre Fraser is composed of a series of zoned veins with muscovite-fibrolite aluminous cores and quartz-feldspar rims that are strongly boudinaged and folded (Bonnet and Corriveau, 2003). Crosscutting relationships among veins

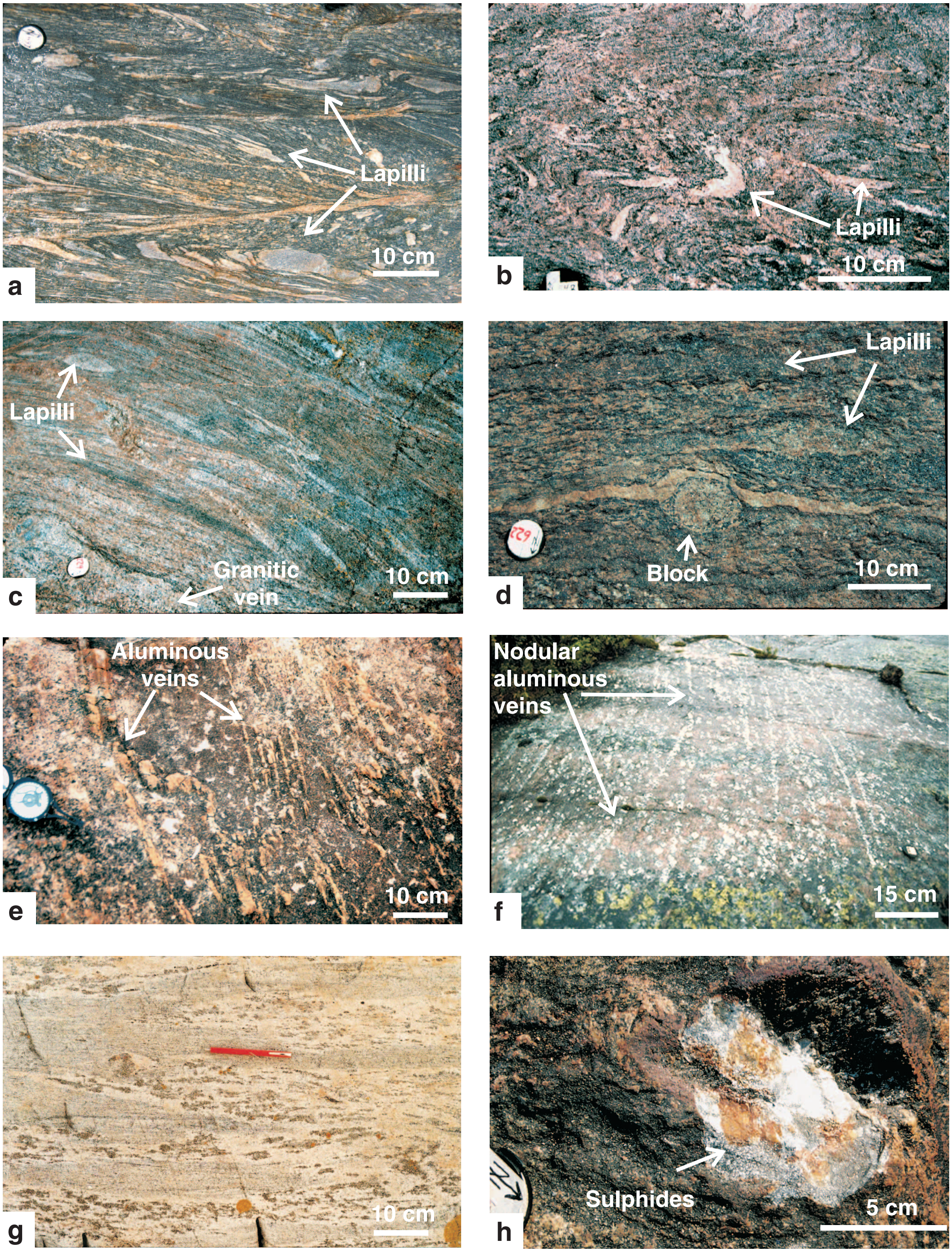

Figure 3. *Lapillistone, hydrothermally altered felsic gneiss, and mineralization.* ***a)*** *Folded and sheared lapillistone (Havre Fraser; 660414mE 5562232mN)****; b)*** *hydrothermally altered lapillistone (Havre Fraser; 661143mE 5565115mN);* ***c)*** *deformed lapillistone (La Romaine E; 680631mE 5566181mN);* ***d)*** *subcircular block in lapillistone (La Romaine E; 680631mE 5566181mN);* ***e)*** *aluminous veins in pink nodular gneiss (Havre Fraser; 661079mE 5565335mN);* ***f)*** *train of nodules with aluminous cores and quartz-feldspar borders (W Musquaro; 632579mE 5617377mN);* ***g)*** *silicification of lapillistone in (a) (Havre Fraser; 660507mE 5563033mN);* ***h)*** *sulphide nodules in quartzofeldspathic gneiss (La Romaine E; 701697mE 5568718mN).*

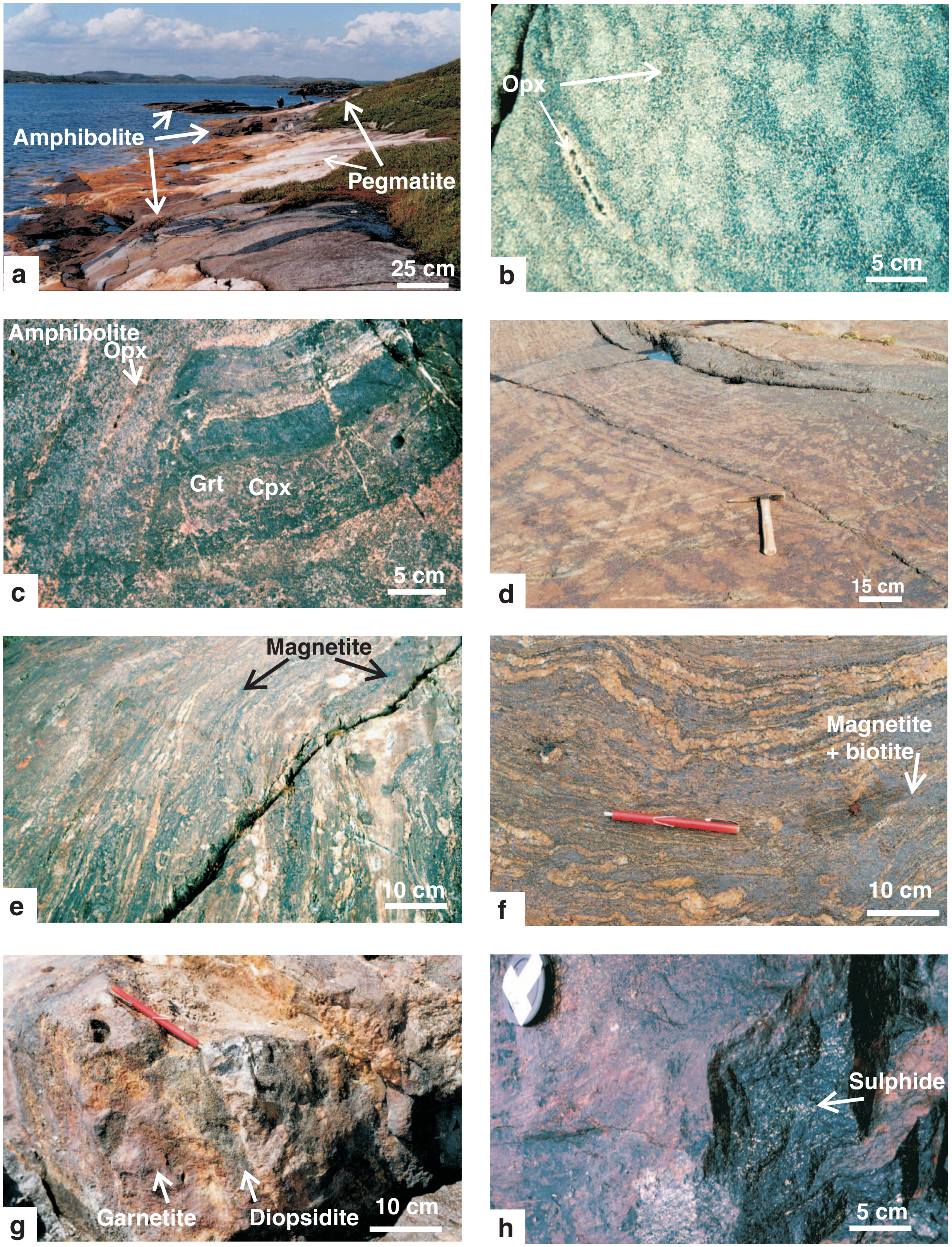

Figure 4. *Composite amphibolite unit at La Romaine.* ***a)*** *Amphibolite intruded by garnet-muscovite pegmatite (662403mE 5564323mN);* ***b)*** *spotted texture of an amphibolite with orthopyroxene (Opx)-bearing vein (678847mE 5566708mN);* ***c)*** *enclave of garnet (Grt)- and clinopyroxene (Cpx)-bearing mafic layered gneiss in amphibolite (662659mE 5564574mN);* ***d)*** *breccia texture (662630mE 5564663mN);* ***e)*** *biotite-magnetite-laminated gneiss interpreted as a banded iron-formation (662670mE 5565091mN);* ***f)*** *close-up of (e);* ***g)*** *garnetite, diopsidite, and iron-sulphide mineralization (662429mE 5564402mN);* ***h)*** *disseminated sulphides in amphibolite 663084mE 5565684mN).*

suggest that the first generation of veins has a paragenesis of quartz+feldspar+muscovite+fibrolite+magnetite whereas a second generation contains hematite instead of magnetite (Fig. 3e). Similar veins were recognized within felsic gneiss and associated lapillistone in the Musquaro area. There, felsic gneiss commonly contains subhexagonal to ovoid muscovite-sillimanite-plagioclase-quartz nodules apparently randomly distributed within the unit, or occurring as systematic trains of nodules locally linked by fine veins or as series of nodes defining 3 to 10 cm wide veins with irregular contacts (Fig. 3f). These types of nodules have been described in the Bathurst mining camp and in association with Kiruna-type copper-iron oxide deposits. They are interpreted to be the product of strong hydrothermal leaching by an acidic fluid (e.g. Lentz and Goodfellow, 1993; McLennan et al., 2002). A distinct zone of striped, fine-grained, quartz-feldspar siliceous gneiss marks the upper contact of the lapillistone unit at Havre Fraser and is interpreted to be a zone of intense silicification (Fig. 3g). Mineralization is locally associated with felsic gneiss in the vicinity of the composite amphibolite unit at Wolf Bay (Fig. 3h).

Aluminous gneiss

In addition to the aluminous veins described above, the area includes a series of aluminous gneiss units closely associated with the volcanic rocks or with discrete marble and calc-silicate units. This lithofacies consists of medium-grained biotite-garnet, biotite-garnet-sillimanite, garnet-sillimanite, and biotite-garnet-sillimanite-cordierite gneiss with a granolepidoblastic texture. In most cases, sillimanite and fibrolite form lenticular clusters and garnet occurs as coarse-grained porphyroblasts (3–7 mm). Magnetite is common and cordierite is found preferentially in leucosomes, in contact with biotite and garnet (Bonnet and Corriveau, 2003). With these characteristics, the aluminous gneiss would normally be regarded as a metapelite (i.e. sedimentary origin). The maximum-phase AFM assemblage recorded by biotite-garnet-cordierite granitic leucosomes and their amoeboid to stromatitic shape is compatible with in situ anatexis without significant melt remobilization (*see* Bonnet and Corriveau, 2003). The gneiss is therefore not a restite. Biotite-poor white garnet-sillimanite gneiss and garnetite occur on an island south of La Romaine. The modal proportion of sillimanite reaches 20 to 40% and records an excess of aluminium with respect to normal sedimentary protoliths (e.g. Gromet et al., 1984). At one locality, lapilli are preserved (Fig. 3b) and indicate a volcanic protolith. Thus, the aluminous composition must result from strong hydrothermal leaching prior to metamorphism. With such an obvious hydrothermal origin for at least one regionally extensive unit, the presence of true metapelite within the entire sequence becomes questionable and must be assessed with caution.

THE COMPOSITE AMPHIBOLITE UNIT AND ITS MINERALIZATION

The main characteristics of the composite amphibolite unit are strikingly persistent from La Romaine to Wolf Bay. The unit comprises layers of medium-grained, migmatized amphibolite, either homogeneous, spotted, or with laminated textures (Fig. 4b). The layers are all concordant with the regional structural grain. Leucosomes are orthopyroxene-bearing, amoeboid, or stromatitic (Bonnet and Corriveau, 2003) and can be associated with a hornblende-rich melanosome, reflecting an in situ origin. Most amphibolite layers have a granoblastic polygonal texture with faint foliation defined by hornblende or biotite. Spotted amphibolite consists of large, ovoid, poikiloblastic orthopyroxene grains disseminated within a hornblende-plagioclase matrix with a granoblastic polygonal texture. The ovoids are discrete or faint, round to highly flattened, and could have started as oikocrysts. Their presence may be construed as evidence for a gabbroic protolith. Conversely, well preserved blasto-ophitic textures are rare. Mineral paragenesis consists of hornblende-orthopyroxene-plagioclase with accessory biotite and magnetite; the colour index is about 40. These layers are presumed to have had a basaltic protolith and are unlikely to be derived from a coarse-grained differentiated gabbro. This is in marked contrast with a package of coarse-grained amphibolite with leucocratic and anorthositic layers that is exposed throughout the village of La Romaine. Enclaves of layered amphibolite and garnetite are abundant within one amphibolite layer (Fig. 4c), but are rare elsewhere. Hornblendite zones are common and occur as thin, discrete veins, irregular schlieren, or anastomosing diffuse patterns. No textural relicts of pillow lava have been recognized, although in one outcrop the patterns defined by the hornblendite may resemble breccia texture at the top of a flow unit (Fig. 4d). In most cases, the hornblendite veins could be interpreted in terms of irregular alteration or veining in an igneous body.

Much of the amphibolite contains between 1 and 5% magnetite, with a few local concentrations up to 20%. Such high magnetite content cannot result solely from metamorphic reactions. The presence of magnetite-rich laminated mafic gneiss parallel to the regional foliation may indicate the presence of banded iron-formation (Fig. 4e, f). Moreover, the amphibolite unit is commonly associated with aluminous gneiss and hosts irregular coarse-grained garnetite interfingered with hornblendite, diopsidite, and talc zones (Fig. 4g). Adjacent amphibolite comprises bluish amphibole and unusually abundant biotite or garnet and accessory zircon or monazite in thin section. Collectively, these rocks register a departure from a normal basaltic-gabbroic protolith and could be indicative of hydrothermal activity. Detailed mapping has unveiled a number of potential showings, one with up to 1.1 weight per cent Cu (Fig. 1d, e, 4g, h). Sulphides (pyrite, pyrrhotite, chalcopyrite) are either disseminated or

Table 1. Location of mineralization in the Wakeham Group extension at La Romaine.

Location NAD83 UTM zone 20	Type of sulphides	%	Distribution	Host rock: composite amphibolite unit
662426mN	Py	2	Disseminated	Amphibolite
5564402mE	Po	3–5	Disseminated	Calc-silicate rock, garnetite
	Sulphides	2	Disseminated	Magnetite-rich amphibolite
	Ccp, Py	2	Diss.+vein 2mm	Siliceous gneiss
663084mN 5565684mE	Py or Ccp	5	Disseminated	Magnetite-rich gneiss
662659mN	Py, Ccp	5, <1	Disseminated	Calc-silicate rock
5564574mE	Py, Ccp	3, 3	Disseminated	Quartz vein in amphibolite
	Po	3	Disseminated	Magnetite-rich gneiss
662469mN 5563943mE	sulphides	2	Disseminated or nodular	Amphibolite
666252mN	Ccp, Po	1, 1	Disseminated	Amphibolite lens
5564020mE	sulphide	2	Disseminated	Aluminous gneiss
679330mN 5566483mE	Po	2–4	Disseminated	Calc-silicate amphibolite + stockwerk, over 4 m by 60 m
679206mN 5566246mE	sulphides	3	Disseminated	Magnetite-rich gneiss
701697mN 5568718mE	Po, Ccp	3, <1	Disseminated	Calc-silicate rock
700167mN	sulphides	2	Disseminated	Calc-silicate rock
5569771mE		2–5	Massive nodules	Quartzofeldspathic unit
662711mN 5564905mE	Py, Ccp	2, 5	Veins	Calc-silicate rock, garnetite

Po-pyrrhotite; Py-Pyrite; Ccp-chalcopyrite

nodular and reach concentrations of 5%, although a centimetre-wide vein of massive sulphide also occurs (Table 1). Anastomosing veins of fluorite-bearing calc-silicate rock occur within the main amphibolite and calc-silicate–marble units. Mineralization and host units are metamorphosed to granulite facies.

DISCUSSION

The meta-arenite unit observed at La Romaine and eastward has field textures (e.g. fine lamination and possibly crossbedding) and a rock association similar to that of the typical Wakeham Group arenite unit in the Musquaro Lake area. Moreover, a grey lapillistone from La Romaine is dated at 1.5 Ga (van Breemen and Corriveau, prelim. unpub. SHRIMP ages, 2002). From the aforementioned field observations and this U-Pb age, the slivers of metasedimentary and metavolcanic rock in the La Romaine area are interpreted to be an extension of the Wakeham Group. Their granulite-facies metamorphic grade is in marked contrast with the prevailing medium-grade metamorphism in the main body of the Wakeham Group. On the basis of 1) the porphyritic to augen textures of the granitic gneiss, their systematic exposures, and the enclaves of metasedimentary rocks they contain, 2) the reassessment of the previously reported arkosic units as granitic dykes, 3) the preliminary U-Pb ages and geochemical interpretation that point toward a coeval volcanic and plutonic event, and 4) the age constraints on sedimentation, we postulate that the granitic gneiss domain that extends from the Wakeham Group eastward to the La Romaine area represents part of a Pinwarian batholith that penetrated, disrupted, and enclaved large tracts and screens of the Wakeham Group supracrustal sequence during the last stages of its deposition. Hence, what was previously regarded as a first-order lithotectonic domain of the Grenville Province (e.g. Gower et al., 2001) is now interpreted to be part of the 1.5 Ga plutonic domain mapped to the west and north (e.g. Complexe de Boulain, Complexe de Buit; Verpaelst et al., 1999; Gobeil et al., in press).

In the village of La Romaine, a layered metagabbro with meta-anorthositic and metaleucogabbroic layers is clearly plutonic. However, in the main composite amphibolite unit, most amphibolite layers have basaltic or gabbroic compositions and may be metamorphosed, fine- to medium-grained sill injections or basaltic flows. If the first alternative is correct, the unit could belong to the Robe Noire mafic suite. However, the presence of interspersed marble, calc-silicate rock, and finely laminated amphibolite layers, the textural variations among layers, the lack of convincing blasto-ophitic textures, and the presence of lapillistone in the vicinity of this composite unit are all features that militate against a straightforward correlation with the Robe Noire mafic suite. That the mafic package may include lava flows, sills, tuff, and/or volcaniclastic material cannot be ruled out, despite the absence of conclusive volcanic features.

Hydrothermal alteration leads to extreme rock compositions that, once metamorphosed, give rise to distinct mineral assemblages and modal proportions. Such alteration zones have been described in detail near metamorphosed ore deposits (e.g. Hodges and Manojlovic, 1993; Lentz and Goodfellow, 1993; Spry et al., 2000). However, in unmapped high-grade metamorphic terrane, such alteration zones may not be recognized during regional mapping; aluminous, hydrothermally altered rocks may look like metapelite or migmatitic restite, carbonate alteration zones may resemble marble and calc-silicate rock, and silicified rocks may look like quartzite. Meta-exhalite units including coticule, tourmalinite, and banded iron-formation are diagnostic and serve as an ore exploration guide (Spry et al., 2000). However, their extent may be limited and they may therefore be difficult to find. In contrast, hydrothermal alteration zones and iron-oxide precipitation can cover a wider area and their recognition is potentially valuable in the search for concealed mineralization (e.g. Lentz and Goodfellow, 1993; Large et al., 2001). During our survey, because grain size had been enhanced by high-grade metamorphism, we consistently appraised atypical mineral parageneses, modes, and colours, and used these macroscopic features to identify potential hydrothermally altered rocks. This approach led to the recognition of zones with aluminous veins grading into sillimanite- biotite-garnet gneiss. During mapping, we compared the nature of the leucosomes with that of the host and described the shape of the leucosomes in order to check whether unusual sillimanite or garnet content could simply be due to anatectic segregation having escaped the system, leaving a restitic residue. Only in the Washicoutai Lake area could such an interpretation apply as the rocks there are definitively metatexitic (i.e. laden with leucosomes). In all other outcrops, however, we found that leucosome AFM paragenesis was consistent with that of the host in terms of potential leucosome-forming reactions, and that the shape and amount of leucosomes were compatible with in situ melting with little transport (i.e. decimetre-scale extent and parallel to gneissosity). Hence, we deduce that in general in the La Romaine area, no compelling evidence exists for garnetite or garnet- or sillimanite-rich units to be restite. In contrast, the presence of lapilli in one garnet-cordierite-sillimanite unit is conclusive evidence of premetamorphic hydrothermal leaching of a volcanic protolith.

Targeted staking at Musquaro and d'Auteuil lakes took place in early spring 2002 following the publication of our preliminary results (Corriveau and Bonnet, 2001). In that area, the association of felsic pyroclastic rocks with feldspar porphyry above a metasedimentary substrate hosting exhalite-like units that were deposited coevally with extensive granitic magmatism is compatible with a paleotectonic setting in which volcanic and subvolcanic intrusions could sustain hydrothermal cells and mineral (e.g. Cu, Pb, Zn, Au) precipitation, a geological context favorable for SEDEX, VMS, or copper-iron oxide deposits (Corriveau and Bonnet, 2001). With the discovery of a potential cap rock, i.e. the composite amphibolite unit with locally intensely leached volcanic substrate, the La Romaine area is now shown to potentially host base- and precious-metal deposits. Mineralization zones with disseminated or nodular copper-iron sulphides occur throughout the belt and are spatially associated with garnetite and calc-silicate zones in the amphibolite unit. In addition, in the eastern part of the area, anomalous metal concentrations are hosted in a quartzofeldspathic gneiss in contact with the amphibolite unit.

ACKNOWLEDGMENTS

The authors would like to thank Alphée Lalo, Jérémie Lehmann, and Philippe Normandeau for their significant contribution to field work; Léopold Nadeau for very constructive review and discussions; mining company geologists for helpful discussions in the field; and the communities of La Romaine and Unamen Shipu for becoming significant partners in this project, in particular the Collard and Guillemette families, A. Jenniss, M.-A. Bellefleur, and A. Stubbert. This study was financed by the TGI 00019 project and a Ministère des Ressources naturelles project and is a contribution to the DIVEX network research on metamorphosed hydrothermal alteration.

REFERENCES

Bassaget, J.P.
1970: Géologie de la région de Kégashka, comté de Duplessis; ministère de l'Énergie et des Ressources, Québec, RP 597, 19 p. (1 carte, échelle 1/63 360).

Bonnet, A-L. and Corriveau, L.
2003: Caractérisation structurale et métamorphique de la marge sud-est du Groupe de Wakeham, régions du lac Musquaro et de La Romaine, Province de Grenville, Québec; Commission géologique du Canada, Recherches en cours 2003-C17.

Bourne, J.H., Ashton, K., Goulet, N., Helmstead, H., Lalonde, A., and Newman, P.
1978: Portions of the Natashquan, Musquaro and Harrington Harbour map-sheets, Eastern Grenville Province, Quebec — a preliminary report; Geological Survey of Canada, Paper 78-1A, p. 413–418.

Clark, T.
in press: Métallogénie des métaux usuels, précieux et énergétiques, et des éléments des terres rares, région de Manitou-Wakeham, Moyenne-Côte-Nord; *in* Synthèse géologique et métallogénique de la partie est de la Province de Grenville, (ed.) D. Brisebois et T. Clark; ministère des Ressources naturelles, Québec, DV 2002-03.

Claveau, J.
1950: La Côte-nord du Saint-Laurent, d'Aguanish à la baie Washicoutai, comté de Saguenay; ministère de l'Énergie et des Ressources, Québec, RG 043, 74 p. (1 carte, échelle 1/63 360).

Corriveau, L. and Bonnet, A-L.
2001: Volcanisme pyroclastique protérozoïque dans le Groupe de Wakeham, région des lacs Musquaro et d'Auteuil, Province de Grenville, Québec; Commission géologique du Canada, Recherches en cours 2001-D18, 11 p.

Corriveau, L., Brouillette, P., Scherrer, G., and Bonnet, A.L.
2002: Extension orientale des roches volcaniques du Groupe de Wakeham et intrusion litée troctolitique de Musquaro, Province de Grenville, Basse-Côte-Nord, Québec; Commission géologique du Canada, Recherches en cours 2002-C29, 11 p.

Corriveau L., Tellier M.L., and Morin, D.
1996: Le dyke de minette de Rivard et le complexe gneissique cuprifère de Bondy; implications tectoniques et métallogéniques pour la région de Mont-Laurier, Québec; Commission géologique du Canada, Dossier public 3078, 70 p.

Gobeil, A., Brisebois, D., Clark, T., Verpaelst, P., Madore, L., Wodicka, N., andChevé, S.
in press: Synthèse géologique de la région de Manitou-Wakeham (Moyenne-Côte-Nord); *in* Synthèse géologique et métallogénique de la partie est de la Province de Grenville, (ed.) D. Brisebois et T. Clark; ministère des Ressources naturelles, Québec, DV 2002-03.

Gower, C.F., McConnell, J.W., and van Nostrand, T.
1995: New mineral-exploration targets in the Pinware Terrane, Grenville Province, southwest Labrador; Newfoundland and Labrador Geological Survey, Report no. 95-1, p. 15–24.

Gower, C.F., Perreault, S., Heaman, L.M., and Knight, I.
2001: The Grenville Province in southeasternmost Labrador and adjacent Quebec; Geological Association of Canada–Mineralogical Association of Canada, Fieldtrip Guidebook A7, 72 p.

Gromet, P.L., Dymek, R.F., Haskin, L.A., and Korotev, R.L.
1984: The "North American shale composite": its compilation, major and trace element characteristics; Geochimica et Cosmochimica Acta, v. 48, p. 2469–2482.

Hodges, D.J. and Manojlovic, P.M.
1993: Applications of lithogeochemistry to exploration for deep VMS deposits in high-grade metamorphic rocks, Snow Lake, Manitoba; Journal of Geochemical Exploration, v. 48, p. 201–224.

Large, R.R., McPhie, J., Gemmel, J.B., Herrmann, W., and Davidson, J.
2001: The spectrum of ore deposit types, volcanic environments, alteration halos, and related exploration vectors in submarine volcanic successions: some examples from Australia; Economic Geology, v. 96, p. 913–938.

Lenz, D.R. and Goodfellow, W.D.
1993: Petrology and mass-balance constraints on the origin of quartz-augen schist associated with the Brunswick massive sulfide deposits, Bathurst, New Brunswick; The Canadian Mineralogist, v. 31, p. 877–903.

McLelland, J., Morrison, J., Selleck, B., Cunnigham, B., Olson, C., and Schmidt, K.
2002: Hydrothermal alteration of late- to post-tectonic Lyon Mountain granitic gneiss, Adirondack Mountains, New York: origin of quartz-sillimanite segregations, quartz-albite lithologies, and associated Kiruna-type low-Ti Fe-oxide deposits; Journal of Metamorphic Geology, v. 20, p. 175–190.

Ministère des Ressources naturelles
2001: Musquaro - 12K; Ministère des Ressources naturelles, Québec, carte SI-12K-C2G-01A.

Sangster, A., Gauthier, M., and Gower, C.F.
1992: Metallogeny of structural zones, Grenville Province, northeastern North America; Precambrian Research, v. 58, p. 410–426.

Spry, P.G., Peter, J.M., and Slack, J.F.
2000: Meta-exhalites as exploration guides to ore; *in* Metamorphic and Metamorphogenic Ore Deposits, (ed.) P.G. Spry, B. Marshall, and F.M. Vokes; Reviews in Economic Geology, v. 11, p. 163–201.

van Breemen, O. and Corriveau, L.
2001: 1.5 Ga pyroclastic volcanism in the Wakeham Group, eastern Grenville Province, Quebec; Geological Society of America, Abstracts with Programs, v. 33/6, p. A-89.

Verpaelst, P., Madore, L., Brisebois, D., Hocq, M., and Dion, D.J.
1999: Géologie de la région du lac Jérôme, du lac Sanson et de la petite rivière de l'Abbé-Huard (SNRC 12L/13, 12L/14, 12M/03); ministère des Ressources naturelles, Québec, RG 98-02, 38 p.

Wodicka, N., David, J., Parent, M., Gobeil, A., and Verpaelst, P.
in press: Géochronologie U-Pb et Pb-Pb de la région de Sept-Îles - Natashquan, Province de Grenville, Moyenne-Côte-Nord; *in* Synthèse géologique et métallogénique de la partie est de la Province de Grenville, (ed.) D. Brisebois et T. Clark; ministère des Ressources naturelles, Québec, DV 2002-03.

Geological Survey of Canada Project TGI-00019