Aluminous nodules in the central Grenville Province: the missing andalusite?

Jean-Emmanuel Martelat* (Université de Montréal)
Département de Géologie, C.P. 6128, Succursale Centre Ville, Montréal, Québec, H3C 3J7,
martelaj@magellan.umontreal.ca

Jacques Martignole (Université de Montréal)

The genesis of aluminous nodules (knots, faserkiesel) is a matter of controversy since 1930 [see Losert 1968; Kerrick 1990 and references therein]. Hypotheses on the origin of aluminous nodules include metasomatism, porphyroblastic growth, pseudomorphic replacement, and pebbles. The aim of the present contribution is to present new occurences of aluminous-rich nodules from the Grenville Province with emphasis on the origin of sillimanite.

In western Québec, north of the Morin Terrane in the Mont-Laurier and the Reservoir Taureau Terranes, **Figure 1**, aluminous nodules occur in mappable units of paragneisses, and quartzites [Hébert et Nantel 1999]. These units of Mesoproterozoic age are metamorphosed in the amphibolite facies but show no trace of migmatization. They are deformed by east-west trending isoclinal folds. Maximum percentage of sillimanite (concentrated in nodules) reaches 27% of the rock.

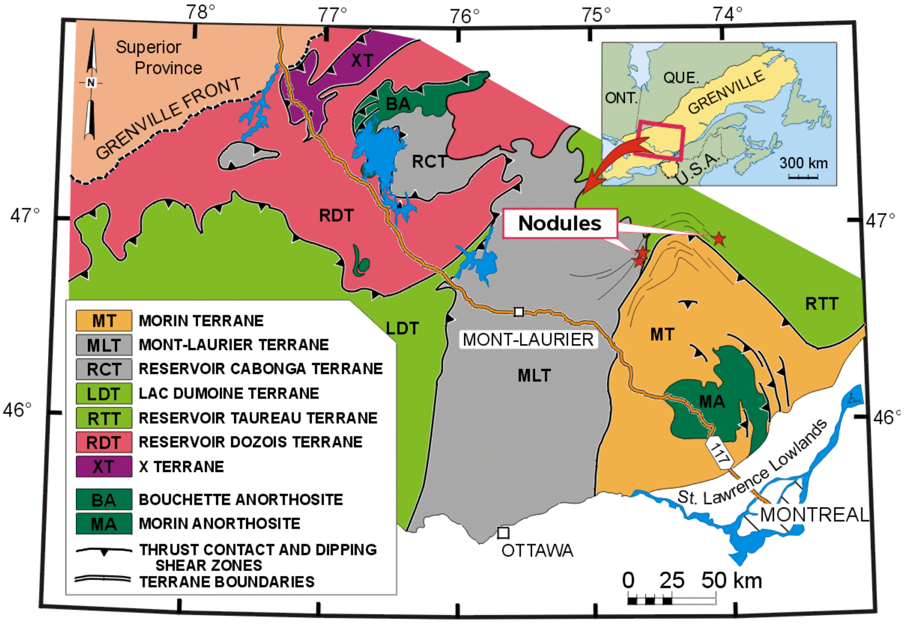

Figure 1: Localisation of outcrops of aluminous nodules in their geological context.

The nodules are macroscopically homogeneous. They are light-grey and tend to resist weathering. **Figure 2** shows their typical shape and size nodules. Up to 30% of some outcrops are occupied by closely packed nodules occasionally tiled but unconnected. The nodules are elliptical, 2 mm to 8 cm in length (averaging about 8 mm) in the XZ section of the finite strain ellipsoid, and 2 mm to 6 cm in length (averaging about 6 mm) in the YZ section. The long axes of the nodules are parallel to a north-south mineral lineation. Whatever their original shape, the final shape is always elliptical and probably results from strain. Shape analysis of samples done on both XZ and YZ planes shows that nodules behave as rigid bodies and that the matrix accomodated most of the strain. **Figure 3** shows that shape fabrics of the nodules fall in the flattening field.

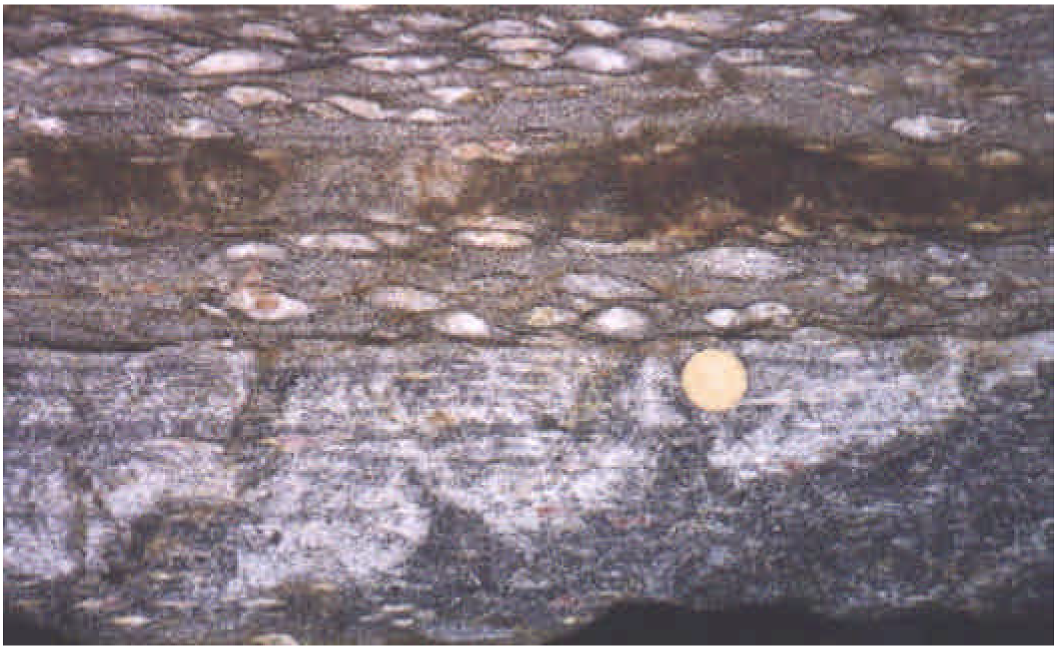

Figure 2: Top of the picture: nodules in a paragneiss (garnets in red are localized in the center of the nodules). Bottom: nodules in quartzite.

Thin section study shows the **matrix** of the rocks to vary widely in the proportion of phases. Main components are quartz, biotite and K-feldspar as illustrated in **Table 1**. White mica (almost pure muscovite) is usually present. Garnet occurs in some of the samples. Mutual contact exist between muscovite/quartz, garnet/plagioclase and garnet/biotite. Other minerals include, ubiquitous tourmaline, graphite (both around 3% according to modal analyses) and sodic plagioclase. The low content of Ca is a common caracteristic of nodular rocks [Elliott and Morton 1965; Breaks and Shaw 1973; Bernier 1993]. Accessory minerals are apatite, zirconoid and rare opaques. Grain size of different phases is around 300 to 800 µm (**Figure 4**). No alumino-sillicate is found in the matrix.

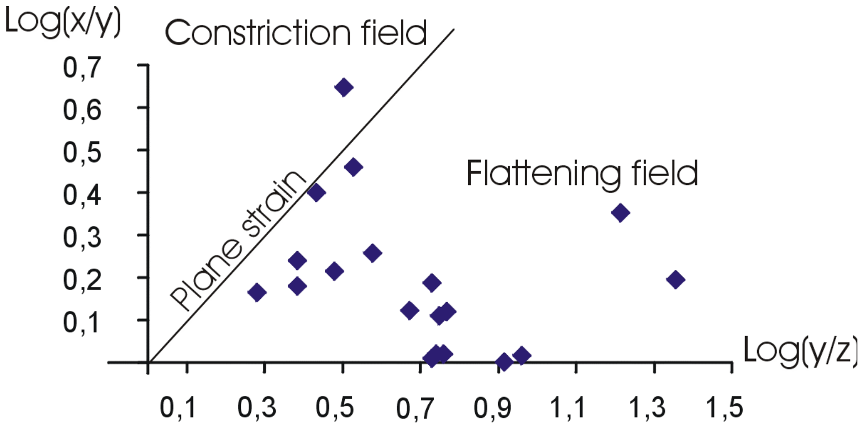

Figure 3: Flinn diagram of nodules shape analysis.

The **nodules** are of variable mineralogical composition even at thin section scale. They do not show the biotite or opaque rim described by several authors in similar rocks [Touret et Macaudière 1969; Kerrick 1990]. They may be classified in two groups: i) biotite bearing nodules (Type 1); ii) biotite-free nodules

(Type 2). Type 1 nodules are essentially made of, by decreasing aboundance, quartz, biotite and sillimanite as fibrolite mats or prismatic grains. Small grains of K-feldspar and muscovite also occur in some of Type 1 nodules, as well as traces of tourmaline and graphite. Type 2 nodules mainly consist of pluri-millimetric muscovite, which often encloses sillimanite needles. Partial to complete disappearance of muscovite lead to fibrolite aggregates with prismatic sillimanite. Other phases which are in Type 2 nodules are quartz, K-feldspar and plagioclase. Type 2 nodules show garnet growing in the center of the nodule at the expense of sillimanite. Wherever garnet crystals are present in the nodules they are also present in the matrix. The Al_2SiO_5 precursor of sillimanite, if it was present, has not yet been identified.

Table 1: Mineral composition of the matrix and the nodules. Mineral symbols after Kretz [1983].

Matrix								Nodules								
Bt	Ms	Qtz	Kfs	Pl	Grt	Tur	Gr	Bt	Ms	Sil	Qtz	Kfs	Pl	Grt	Tur	Gr

There is no ghost internal fabric that would attest for a development of the nodules by replacement. However there is no deflection of external foliation away or towards the nodules which implies a constant volume transformation. As monomineralic muscovite porphyroblasts may act as precusors of aluminous nodules there is a need for double diffusion, Al^{3+} towards the nodules and K^+ away from the nodule. Consequentely metasomatism is probably the dominant mechanism which occurs in constant volume framework.

Temperature estimated using garnet-biotite thermometer (unzoned garnet: Xalm 0.8, Xprp 0.1, Xgrs 0.5 and biotite : Xann 0.47, Xphl 0.29 with 3.5 %wt of TiO_2) indicate low grade conditions (500-520 °C). Mineral textures show that the rocks did not reach the second sillimanite isograd. Given the above temperatures and with stable sillimanite, pressure is bracketed between 3 and 4.5 kbar. Flat grossular profile in garnet indicate that the rocks are not retrogressed from higher pressure. Moreover as there is no evidence for the growth of sillimanite after kyanite, the above data are compatible with a LP-HT prograde evolution of mid-amphibolite grade metamorphism. In this case, however, the absence of andalusite as a Al_2SiO_5 precursor remains problematic. A one-stage metamorphic evolution resulting either from regional extension and crustal thinning or emplacement of the nearby Lanthier leucogranite [Hébert et Nantel 1999] may be responsible for the above high geothermal gradient. The question arises as to relationship of sillimanite nodules and high geothermal gradients. The metamoprhic regime pertainning to the growth of sillimanite nodules is rarely supported by quantitative PT esimates but similar conclusions have been presented elsewhere [e.g. Dallwig *et al.* 1986].

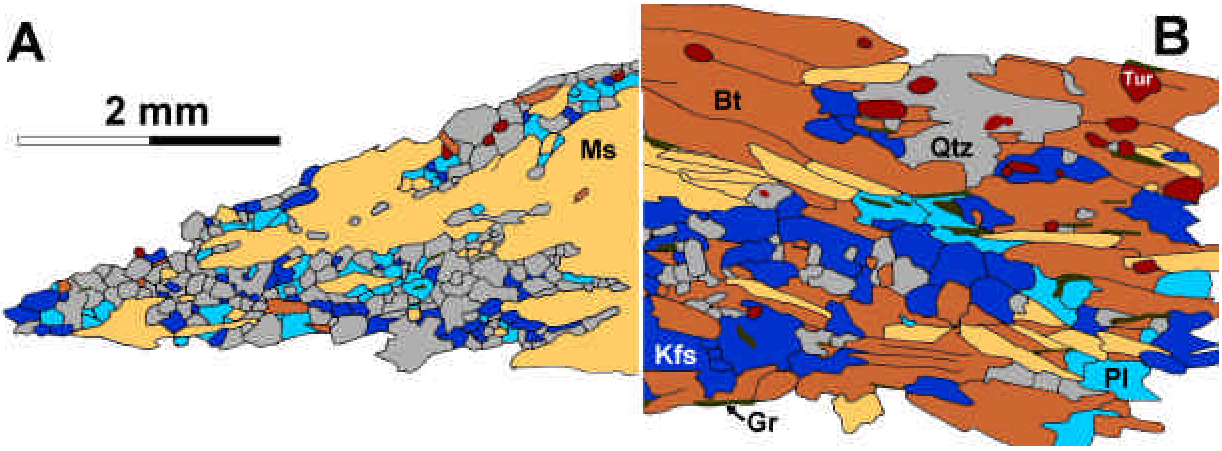

Figure 4: Sketch showing the texture of half a Type 2 nodule **(A)** and a part of the matrix **(B)**. Scale bar valid for A and B. Different colors correspond to different phases: yellow: Ms, orange: Bt, light blue: Pl, heavy blue: Kfs, grey: Qtz, brown: Tur, black: Gr. The half nodule **(A)** shows poikilitic muscovite. In this nodule, modal analyses are 52% Ms, 31% Qtz, 8% Pl, 7% Kfs, 1% Bt, <1% Tur, <1% Gr; in the matrix modal analyses are 50% Bt, 18% Kfs, 15% Ms, 9% Qtz, 3% Pl, 2% Tur, 2% Gr.

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