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# THE CLOTTY GRANITE AT PERRAULT FALLS, ONTARIO, CANADA*

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## Abstract

A granite at Perrault Falls, Ontario, is characterized by disseminated dark clots, 1 to 10 cm across. The major clot minerals are green biotite, quartz, sillimanite, and cordierite. The amount of clots is variable from 0 to 10%. They are mostly irregular in shape and disseminated without alignment, but rarely they may be foliated both by alignment of disc shapes and by arrangement in rows. The groundmass granite has a eutectic composition of microcline, albite and quartz, with accessory brown biotite and sillimanite.

The clotty granite was sampled at 14 scattered outcrops in two areas, each about 1 × 1 km, separated by about 2 km. Although obscured by glacial drift, the granite does have intrusive contact relationships into the surrounding biotite-cordierite gneiss.

The clots may be refractory relics of an original biotite-cordierite-sillimanite gneiss that was partially melted, with relict layers of refractory Mg-Fe-Al minerals being broken up into clots. Such an origin, by anatexis in the upper crust, is appropriate for the position of this rock in a terrain of high-grade metamorphism, the English River Gneissic Belt.

## Résumé

Un granit de Perrault Falls en Ontario, est caractérisé par des flocons fonçés éparpillés de un à 10 cm d'un côté à l'autre. Les principaux minéraux à flocon sont la biotite verte, le quartz, la sillimanite et la cordiérite. La quantité de flocons varie de 0 à 10%. Ils sont, pour la plupart, de forme irrégulière et éparpillés sans alignement, mais ce n'est que rarement qu'ils peuvent être lamellaires et par un alignement de formes de disques et par un arrangement en rangées. Le granit matrice possède une composition eutectique de microcline, d'albite et de quartz, avec les minéraux secondaires de biotite brune et de sillimanite.

Le granit en flocons a été échantillonné de quatorze affleurements dispersés dans deux régions, chacune d'une grandeur de 1 × 1 km et séparées par environ 2 km. Le granit malgré qu'il est obscurci par un dépôt glaciaire, possède quand même des relations de contact intrusif sur le gneiss de biotite-cordiérite environnant.

Les flocons peuvent être des reliefs réfractaires provenant d'un gneiss original de biotite-cordiérite-sillimanite qui aurait partiellement fondu, avec des couches résiduelles de minéraux réfractaires Mg-Fe-Al ayant été cassées en flocons. Une telle origine, par anatexie dans la croûte supérieure, est appropriée à la position de cette roche dans un terrain de métamorphisme de haute-qualité, celui de la ceinture gneissique de la rivière English.

(Traduit par le journal)

## Introduction

A peculiar clotty granite crops out at Perrault Falls, which is on the Red Lake Road (Ontario Highway #105) in northwestern Ontario, 34 miles (55 km) north of Vermilion Bay. This locality is close to the center of a belt of high-grade metamorphic and migmatitic rocks, in the Superior (Archean) Province of the Precambrian Shield of Canada, and the petrography of the clotty granite is interpreted with regard to a *P-T* grid of high-grade metamorphism.

## Regional Geology

The Archean rocks of northwestern Ontario and Manitoba have, as a regional structure, a belted or striped pattern, trending east-west, made up of alternate belts of low-grade and high-grade metamorphic terrains. This structure was defined by Wilson & Brisbin (1963), and more detail is given by Wilson (1971). The English River Gneissic Belt is one of these high-grade belts. It is made up of paragneisses, migmatites, granitic intrusive rocks and gneisses. These rocks form large domes and basins and irregular-shaped intrusions. Some petrography of these rocks has been done by Dwibedi (1966) and Jones (1972). Geological mapping by Breaks *et al.* (1974) supplements a compilation map by Davies *et al.* (1970), which was based on available reports and air photos. The English River Gneissic Belt is about 60 miles wide north of Vermilion Bay, and Perrault Falls is in the middle of the Belt.

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## Petrology at Perrault Falls

At Perrault Falls there are three major rock types, viz: clotty granite, paragneiss, and massive granite. The locations of outcrops and sample numbers are shown in Figure 1. The area is 90% covered by glacial drift, so the shape and continuity of the clotty granite cannot be followed. Two areas of clotty granite are shown in Figure 1, one at Perrault Falls, the other on Wabaskang Lake; both are about one mile across.

The clotty granite occurs both as intrusions of undefined shape (Fig. 1) and as small dykes. It is intrusive into paragneiss, as indicated by observation of: (1) cross-cutting and crumpling of gneissic layering at contacts; (2) inclusions of paragneiss in clotty granite; (3) dykes and lenses of clotty granite in paragneiss.

Paragneiss is heterogeneous, with various layers of biotite gneiss, granitic gneiss, amphibolite and biotite schist. Widespread occurrence of cordierite and sillimanite in the biotite gneisses indicates that they are the product of regional metamorphism, upper-amphibolite facies, low-pressure (Abukuma) facies series. The presence of layers and small dykes of granite suggests that the temperature of partial melting had been reached. The mineral mode of a biotite schist is given in Table 1, and chemical analyses of four samples, given in Morin (1970), show the diversity of composition.

A massive leucogranite, medium grained, was found around the central part of Perrault Lake. Chemical analyses of four samples (Morin 1970) indicate that they have significantly higher $K_2O/Na_2O$ than the clotty granite.

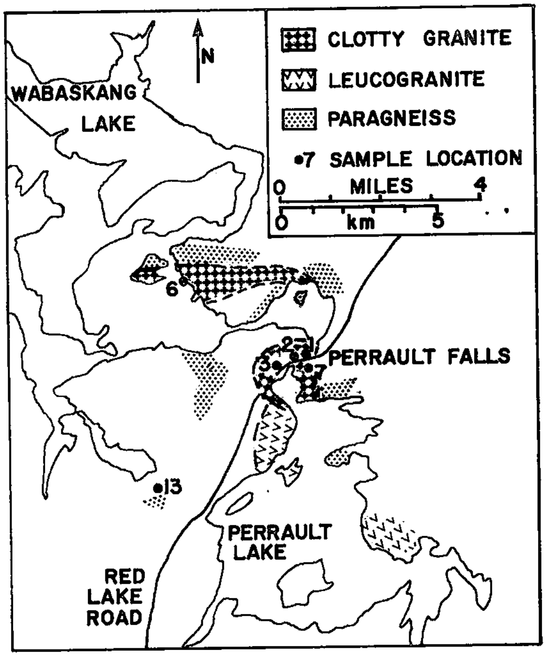


Fig. 1. Map of the area around Perrault Falls, Ontario, showing major rock types and selected sample locations.

## Petrography of the Clotty Granite

The clotty granite is characterized by dark clots, which are obviously concentrations of biotite, disseminated in a groundmass of medium-grained granite. The amount of clots is variable from 0 to 10%. At station 1 (Fig. 1) they are estimated to make up 5% of the rock, as shown in Figure 2, with a very even distribution. The size of the clots is variable from 1 to 6 cm across. The shape is commonly irregular, uncommonly they are disc-shaped. As shown in Figure 2b, elongate disc-shaped clots may be aligned and the resultant foliation may be folded. The boundaries of the clots are not sharp, but are irregular and interlocking on a 3 mm scale with the groundmass.

Small, rare, irregular veins of pegmatite (2-50 cm wide, 1-10 metres long) cut the granite groundmass (Fig. 2a). They have the appearance of late igneous segregation pegmatites. They rarely contain clots, which were in place in the regular array of clots in the groundmass.

Table 1 presents the mineral modes of the clots and the granite groundmass. The typical assemblage of the clots is biotite-quartz-albite-sillimanite-cordierite (muscovite is present, but apparently retrograde; microcline is absent). The typical assemblage of the groundmass is microcline-quartz-albite-biotite (muscovite is a rare accessory, apparently retrograde). Garnet is a rare accessory mineral in both clots and groundmass. Other very rare accessories are zircon and green spinel in the groundmass and magnetite in the clots.

The biotites in the clots are green to pale yellow-green, those in the groundmass are very

TABLE 1. MINERAL MODES (VOLUME %)

| | CGG 1-1a | CGG 1-1b | CGG 1-1c | CGG 1-3 | CGG 2-1d | CGG 1-1d | CLOT 6-1d | CLOT 7-1a | CLOT 7-1b | GNEISS 13-1 |
|---|---|---|---|---|---|---|---|---|---|---|
| QUARTZ | 24.0 | 23.8 | 26.5 | 23.1 | 32.4 | 23.8 | 50.9 | 45.7 | 48.5 | 29.1 |
| PLAG | 15.3 | 21.0 | 17.4 | 13.3 | 16.7 | 14.0 | 3.5 | 2.0 | 3.5 | 7.1 |
| P-K | 55.3 | 48.5 | 51.7 | 59.6 | 46.1 | 57.7 | 0.2 | 0.2 | 0.9 | 40.6 |
| BIOTITE | 4.1 | 4.4 | 2.6 | 3.7 | 4.0 | 3.3 | 27.5 | 25.9 | 16.2 | 21.8 |
| SILL | 0.6 | 2.0 | 1.0 | 0.1 | 0.2 | 1.0 | 7.4 | 15.0 | 10.8 | 0.2 |
| MUSC | 0.4 | 0.1 | 0.6 | 0.1 | 0.3 | 0.0 | 8.9 | 3.6 | 2.2 | 0.4 |
| CORD | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 5.7 | 16.8 | 0.0 |
| ZIRCON | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.5 | 0.3 | 0.5 | 0.2 |
| GARNET | 0.2 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 1.3 | 0.6 | 0.0 |
| SPINEL | 0.0 | tr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| MAGNETITE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.3 | 0.1 | 0.6 |

Counting was at points on a grid 0.2 x 0.4 mm. CGG = clotty granite groundmass. CLOT = clotty granite clot. P-K = perthitic-microcline. tr = < 0.1.

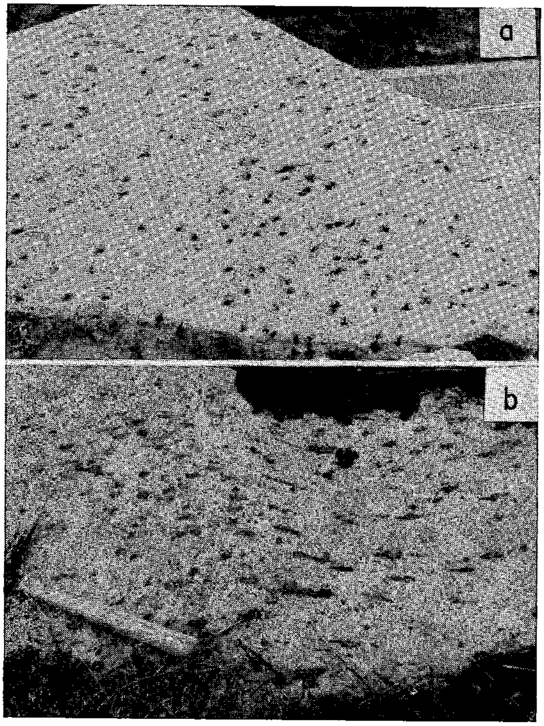

FIG. 2. Photographs of outcrops of the clotty granite. (a) Locality 1 on Figure 1 (Perrault Falls), road in background. Note pegmatite with included clots. (b) Locality 2 on Figure 1.

dark brown to pale yellowish-brown. Chemical analyses of mineral separates (see below) indicate that the clot biotites contain more Mg, Al, Si, $CO_2$, and less Ti, $Fe^{+3}$, $Fe^{+2}$, and Mn than groundmass biotites.

The microclines of the groundmass and of patches of pegmatite within it, are maximum microclines (15 determinations of triclinity $\Delta = 85$ to 94) with disseminated blebs (exsolution perthite).

The texture of the clots is medium-grained xenomorphic granular, with irregular interlocking grain boundaries. Biotites contain sillimanite inclusions in a core zone, surrounded by an intermediate zone free of inclusions, and an outer zone which fingers out in a poikiloblastic manner (Fig. 3) with angular inclusions of quartz, and these outer parts are intergrown with muscovite. These outer growths have no reaction relationship to any other mineral, and they are interpreted to be late- or post-magmatic. The cordierite is partly altered to pinite and sericite, but there is no relationship to the micas.

The texture of the granite groundmass is also medium-grained xenomorphic granular, with interlocking and sutured grain boundaries, and there is an irregular development of mortar texture. The edges of quartz crystals are sutured (corroded?) against albite, microcline, and muscovite. In the outer parts of albite crystals, especially adjacent to microcline, myrmekite and drop-quartz are common. Sillimanite, in bundles of fibrous prisms, is preserved by inclusion, commonly in quarz, uncommonly in muscovite, and rarely in microcline. Garnet, which occurs disseminated in irregular-shaped crystals, may have beside it a crystal of brown or green biotite. The rare crystals of green spinel are euhedral, and they are surrounded by brown biotite and by muscovite.

The biotite of the groundmass is disseminated interstitially between quartz and feldspars, and is therefore interpreted to be late-magmatic.

Muscovite, a rare accessory in the groundmass, occurs in irregular form, mostly as overgrowths and intergrowths at the edges of biotite in interstitial position. Muscovite is therefore interpreted to be a post-magmatic (retrograde) alteration.

## Chemical Composition

Table 2 lists analyses of major elements of clotty-granite whole rock, separated fractions of clots and groundmass, and mineral separates of biotite. The clots were separated from the groundmass by hand-picking of fragments after rough-crushing to 1 to 10 mm pieces; by visual estimate the fractions used for analyses were 95% pure. Biotite was separated magnetically, and inclusions of sillimanite and muscovite are estimated at 2%. Chemical analyses were done at the University of Manitoba by K. Ramlal.

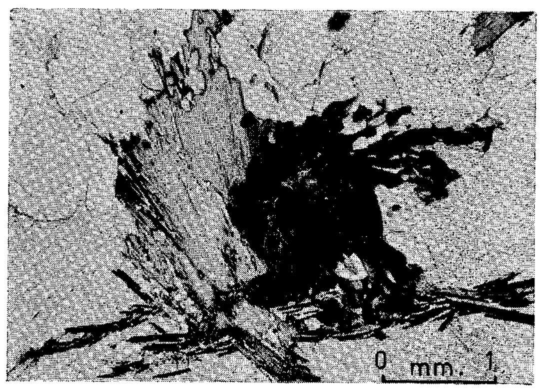


FIG. 3. Photomicrograph of large biotite crystals in a clot (sample 1). Note the poikiloblastic nature of the edges, with angular inclusions of quartz. The wispy inclusions in the center of the dark crystal of biotite are sillimanite.

TABLE 2. CHEMICAL ANALYSES OF CLOTTY GRANITE ROCKS, AND SEPARATE FRACTIONS.

| | 1-1W Whole | 1-1M Matrix | 2-1W Whole | 2-1M Matrix | 3-2W Whole | 3-2M Matrix | 1-1C Clot | 2-1C Clot | 3-2C Clot | 1-1C Biotite | 1-1M Biotite |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 74.60 | 74.15 | 72.70 | 74.70 | 74.35 | 75.40 | 73.15 | 69.65 | 60.85 | 38.80 | 35.10 |
| $Al_2O_3$ | 13.73 | 14.38 | 13.86 | 13.71 | 12.99 | 13.11 | 14.36 | 14.51 | 16.32 | 20.95 | 17.74 |
| $Fe_2O_3$ | 0.35 | 0.39 | 0.91 | 0.10 | 0.18 | 0.04 | 1.06 | 1.12 | 2.20 | 3.04 | 6.31 |
| FeO | 0.81 | 0.60 | 0.02 | 0.24 | 0.29 | 0.14 | 3.87 | 3.76 | 3.66 | 15.09 | 20.28 |
| MgO | 0.28 | 0.12 | 0.30 | 0.08 | 0.37 | 0.22 | 3.78 | 2.68 | 6.28 | 7.25 | 4.40 |
| CaO | 0.76 | 0.84 | 1.40 | 1.72 | 2.22 | 2.27 | 0.13 | 0.61 | 0.55 | 0.37 | 0.40 |
| $Na_2O$ | 3.90 | 4.35 | 4.13 | 4.02 | 4.41 | 4.05 | 0.30 | 0.55 | 0.55 | 0.26 | 0.17 |
| $K_2O$ | 4.88 | 4.92 | 5.57 | 4.84 | 4.28 | 4.17 | 0.88 | 2.56 | 5.98 | 8.80 | 9.10 |
| $H_2O$ | 0.37 | 0.23 | 0.44 | 0.12 | 0.30 | 0.03 | 2.05 | 3.88 | 3.14 | 4.05 | 3.55 |
| $CO_2$ | 0.01 | 0.00 | 0.01 | 0.03 | 0.03 | 0.03 | 0.07 | 0.03 | 0.03 | 0.40 | 0.28 |
| $TiO_2$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.19 | 0.17 | 2.41 |
| $P_2O_5$ | 0.24 | 0.22 | 0.20 | 0.20 | 0.17 | 0.18 | 0.12 | 0.12 | 0.12 | 0.21 | 0.28 |
| MnO | 0.01 | 0.02 | 0.04 | 0.00 | 0.01 | 0.01 | 0.21 | 0.05 | 0.15 | 0.15 | 0.29 |
| TOTAL | 99.94 | 100.22 | 99.68 | 99.76 | 99.60 | 99.65 | 99.48 | 99.52 | 100.32 | 99.54 | 100.31 |

The first number refers to the locality in Fig. 1. W = whole rock. M = matrix (granite groundmass) separated fraction. C = clot separated fraction.

The composition of the groundmass is approximately eutectic granite. The CIPW normative Ab:Or:Qz values of the three groundmass analyses of Table 2 plot close to the 2 to 4 kb position range of the eutectic (and corresponding minimum) melting (for $P_{total} = P_{H_2O}$) as determined experimentally by Tuttle & Bowen (1958).

In contrast with the groundmass, the clots are richer in Mg, Fe, Mn, $H_2O$, and poorer in Si, Na, Ca and P.

## INTERPRETATION

The clotty granite is interpreted as an igneous intrusion, on the basis of the intrusive nature of its edges against the country gneisses, and the granite-eutectic composition of its groundmass. The granite has an overprint of minor reaction textures and strain textures, that suggest that it was a syntectonic intrusion. The origin of the clots, however, it is not obvious, and various explanations of their origin must be considered.

The clots are too regular in size and distribution to be stoped inclusions of wall-rock (see Fig. 2).

The clots do not resemble any igneous phenocryst, or glomeroporphyritic clot. Phenocrysts of cordierite are known in granitic stocks (Taubeneck 1964), but they are single euhedral crystals, altered to muscovite and chlorite, dissimilar to these clots.

The clots may be refractory relics of anatexis. From experimental studies of the melting of metasedimentary rocks, it has been shown that: "only small amounts of biotite, cordierite and silliminite can be dissolved in the melt; together with surplus An-rich plagioclase and or some quartz they form the crystalline residue" (Winkler 1974, p. 273; see also p. 303). The mineral assemblage of the clots (Bio + Qtz + Cord + Plag + Sill), in a granite eutectic as they are, are analogous to the results of experimental partial melting. Furthermore, the clot mineral assemblage is common in migmatites and gneisses as the dark layers in with granitic leucosomes (Mehnhert 1968, 64-67). The compilation of petrographic data and theoretical phase analysis of Grant (1973) indicates that this assemblage is stable in the presence of a granitic liquid, and under the following conditions: $T$ = 650 to 700°C, $P_{H_2O}$ = 1 to 5 kb. The reaction curves for an applicable $P$-$T$ grid are shown in Figure 4. Curve 1, granite eutectic melting, gives minimum temperatures and pressures on the basis that the groundmass was molten. Curve 2, the muscovite-quartz stability, gives approximate maximum pressures, on the basis that muscovite is a post-magmatic growth. However, curve 2 is calibrated for $P_{total} = P_{H_2O}$, and it would be shifted to higher pressures if $P_{total} > P_{H_2O}$. The activity of water during magmatic crystallization of the clotty granite was great enough to stabilize the biotites (both green and brown), but there is no evidence that it was equal to $P_{total}$. Curve 3 in Figure 4 is a possible upper-temperature limit, because the mineral assemblage of the clots is the low-temperature assemblage of the reaction; cordierite is common in the clots but garnet is not (garnet is very rarely present in both groundmass and clots, and it may be a relic of an earlier stage of metamorphism). This reaction has not been calibrated experimentally but is in the petrogenetic grid of Grant (1973).

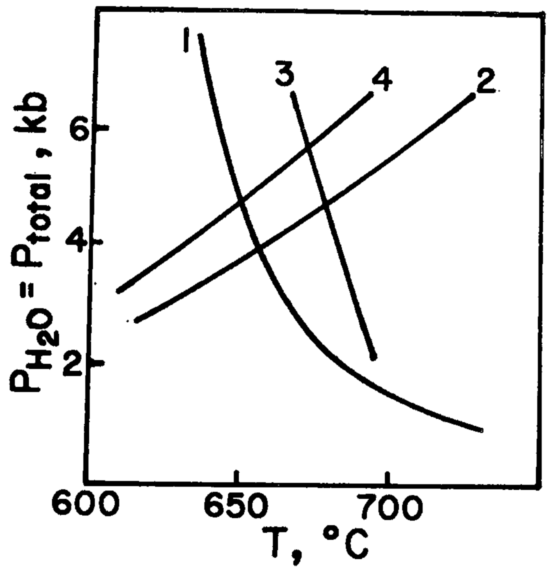


FIG. 4. *P-T* grid for the following reactions: 1. granite eutectic (and minimum) melting (Tuttle & Bowen 1958). 2. Musc + Qtz = Kspar + Sill + V (Evans 1965). 3. Plag + Sill + Bio + Qtz + V = Cord + Gar + L. 4. Calculated stability limit of the brown biotite of the groundmass.

These conditions of anatectic origin are further restricted to the range $P = 5$ to 6 kb, $T \approx 650°C$, by calculations based on the stability field of biotite (Wones & Eugster 1965; Wones 1972). The stability limit of the brown biotite of the groundmass (analysis 1-1M-Bio, Table 2) is calculated to be curve 4, in Figure 4, which intersects the granite solidus (curve 1 in Figure 4, Tuttle & Bowen 1958) at 4.7 kb, and this would be a minimum pressure for a magmatic formation of biotite. Also, as shown by Rutherford (1969), this pressure minimum should be increased to account for the effect of Na in biotite, to approximately 6 kb. The green biotite in the clots, being richer in Mg, would be stable to higher temperatures, and thereby fit into the refractory-relic hypothesis.

It is unreal that in Figure 4, curve 4 lies at a lower temperature than curve 2, because the texture of the rock indicates that biotite crystallized before muscovite. The position of the biotite curve is subject to errors in the chemical analyses and corrections for non-stoichiometry of many kinds not accounted for in the calculation, and therefore the position of the biotite curve may be too high. Also, there may be displacements of both curves if $P_{H_2O} < P_{total}$.

The refractory-relic hypothesis requires that the original rock was a gneiss or migmatite, with layers or lenses of the melasome that could be dispersed as disseminated clots when the granite groundmass became molten. The major-element chemical composition (Table 2) is suitable for an igneous granite, but the presence of sillimanite, not only concentrated in the clots but also disseminated in the groundmass, suggests that the parent rock was rich in alumina, perhaps an arkose with some clay content. Calculation of the discrimination function (DF3) of Shaw (1972) indicated an igneous parentage, but this function does not take into account the amount of alumina.

## Other Localities of Clotty Granite

A rock with some similarities, the "Flecky Gneiss" of Vastervik, Sweden, has been described by Loberg (1963). The dark flecks of the Vastervik rock do not contain cordierite, but contain andalusite and sillimanite (versus sillimanite only in the Perrault Falls clots), and green biotite lower in Ti and Fe than brown biotite from the groundmass (similar to Perrault Falls). However, Loberg finds that the flecks are chemically similar to the groundmass, except for K enrichment in the groundmass, and he finds evidence of a tectonite fabric in the groundmass. He interprets the origin to have been by differentiation during metamorphism.

Another clotty granite occurs 10 miles northwest of Shebandowan, Ontario, Canada, in the Quetico gneissic belt. Here a transition from gneiss to clotty granite can be seen in outcrop (Morin 1973).

## Acknowledgements

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This rock was discovered by H. D. B. Wilson, and W. C. Brisbin, and they contributed the original observations and ideas.

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