THE DEVELOPMENT OF *LIT-PAR-LIT* GNEISS AT THE BICROFT URANIUM MINE, ONTARIO

A. M. EVANS

Department of Geology, Leicester University, England

ABSTRACT

Lit-par-lit gneiss is a common wall-rock of the uraniferous pegmatitic dykes at the Bicroft Mine and the neighbouring Croft Property. It is developed mainly from pelitic gneiss, but also from amphibolite. The transformation of pelitic gneiss into *lit-par-lit* gneiss has been studied in detail. The pelitic gneiss contains sillimanite, garnet, biotite, cordierite and quartz as its principal minerals. It shows evidence of considerable shearing during and after the crystallization of the garnet. The *lit-par-lit* gneiss consists of alternating layers of granitic and pelitic composition. The pelitic portion is devoid of quartz and much richer in biotite. Corundum, some pseudomorphous after sillimanite, is now present. Petrographic and chemical investigations suggest that the granitic material was not injected along the foliation planes of the pelitic gneiss but has been formed by metamorphic differentiation during a period of feldspathization resulting from the accession of alkalis and some calcium. It seems probable that the differentiation was initiated by shearing.

INTRODUCTION

This paper discusses the nature and origin of *lit-par-lit* gneiss at the Bicroft Mine, Ontario. Bicroft Uranium Mines, Limited, originally the two separate undertakings of Centre Lake Uranium Mines, Limited and Croft Uranium Mines, Limited, and now Macassa Gold Mines, Limited, Bicroft Division, holds a number of claims in the north-east of Cardiff Township, Haliburton County, Ontario. The mine location is shown in Fig. 1.

The uranium deposits occur in a swarm of uraniferous pegmatitic dykes which are emplaced in Grenville-type metasediments. The dominant metasediments are amphibolite and quartz-oligoclase-biotite-gneiss. Bands of pelitic gneiss occur throughout the mine area. The main ore bodies in the pegmatitic dykes are associated with these bands, but not wholly confined to them. The dykes form irregular bodies of granite- and syenite-pegmatite, the former being the dominant rock-type. Paragneisses in contact with the pegmatites are usually altered to *lit-par-lit* gneisses. Amphibolite and, in particular, pelitic gneiss are the rocks most commonly altered to *lit-par-lit* gneiss. For this reason and because most of the orebodies occur in the pelitic bands, the alteration of this rock to *lit-par-lit* gneiss has been studied by the writer in some detail.

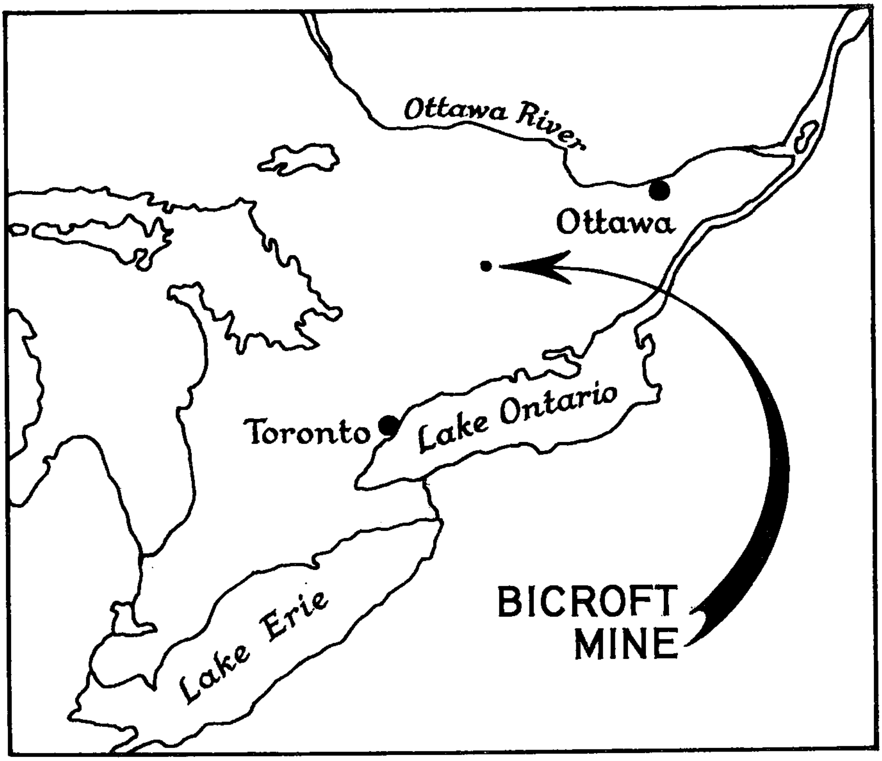

FIG. 1. Location of the Bicroft Mine, Ontario.

PREVIOUS WORK

Bateman (1955) described briefly the uranium-bearing pegmatites of the Bancroft area. He wrote that they are unlike ordinary granite-pegmatites in that they lack graphic fabrics or large segregations of quartz and feldspar. The Bicroft deposits he considered to be "a late magmatic or deuteric stage in the evolution of the pegmatites". Satterly & Hewitt (1955), Satterly (1956) and Hewitt (1957) described the Bicroft Mine and Croft Property in detail. They favoured an intrusive (presumably magmatic) origin for the igneous-looking gneisses and the pegmatites of the area, though portions of the Bicroft dykes are said to be, "in part of replacement origin". They considered that the *lit-par-lit* gneisses at the Bicroft Mine were the result of *lit-par-lit* injection of pegmatitic magma into the paragneisses.

Kelly (1956, 1958) summarized the chief features of the pegmatites and concluded that metasomatic replacement played a large part in their formation. Robinson (1958) favoured an ultimate magmatic origin for the Bicroft-type pegmatites, but stated "the granite, pegmatitic and metasomatic deposits are largely characterised by field evidence pointing to dominance of replacement processes with fracture filling playing a minor role". In 1960 he reiterated this view and supported it with geochemical studies. Evans (1962) concluded that the pegmatites of the Bicroft Mine and the Croft Property were entirely of metasomatic origin and had replaced pre-existing metasediments, *lit-par-lit* gneiss and igneous-looking gneisses of metasomatic origin.

Pelitic Gneiss

Since we are here concerned with the formation of *lit-par-lit* gneiss from pelitic gneiss, the latter gneiss will be described first. This gneiss being the only rock-type in the area with abundant garnet is easily recognized even on the weathered outcrop surface. Polished surfaces of drill cores from this rock have a streaky appearance which is at once seen to be due to the aggregation of biotite into thin, discontinuous

FIG. 2. Sillimanite-garnet-biotite-gneiss, outcrop, Croft Property. Dark porphyroblasts of garnet; white streaks of sillimanite and larger, white areas of quartz and cordierite. (Photograph by Dr. D. F. Hewitt).

TABLE 1. ANALYSES OF PELITIC AND *LIT-PAR-LIT* GNEISSES FROM THE BICROFT MINE AND THE CROFT PROPERTY

	1	2	3	4	5	6	7	8	9
				Chemical Analyses					
SiO_2	57.44	59.33	61.26	62.55	60.23		60.66	78.23	67.83
Al_2O_3	19.50	21.30	15.70	17.60	18.09		17.50	11.60	15.55
Fe_2O_3	1.13	0.44	0.92	0.57	0.91		1.12		0.57
FeO	9.20	13.04	6.51	3.80	6.44		7.06	0.06	4.63
MgO	2.65	1.62	3.85	0.99	1.44		1.26	0.07	1.36
CaO	0.56	tr	1.33	1.67	1.30		tr	0.44	0.50
Na_2O	0.40	0.96	4.26	5.27	3.45		5.81	2.66	1.53
K_2O	3.84	2.40	4.35	5.78	6.90		4.24	6.18	5.01
H_2O^+	3.18	0.60	0.69	0.13	0.14		0.32	0.02	0.24
H_2O^-	0.47	0.06	0.11	0.32	0.19		0.15		1.60
TiO_2	1.16	1.04	0.86	0.67	0.66		0.94		0.58
MnO	0.12	0.15	0.13	0.06	0.10		0.08		0.06
	100.51	100.94	99.87	99.41	99.85		99.14	99.26	99.46
				Modes					
Biotite	24.6	17.2	36.0	24.8	32.5	26.9	21.2	0.6	
Cordierite	12.2	3.2	tr						
Garnet	16.5	16.3					0.6		
Sillimanite	11.2	19.1	1.7				4.0		
Corundum			0.6		0.4	5.8			
Quartz	27.8	30.7	14.0	5.7	28.0	18.5	23.6	39.7	
Microcline	2.8	2.1	2.8	12.7	13.9	16.8	10.8	36.0	
Plagioclase	0.8	7.8	40.4	54.4	22.8	30.8	33.6	22.5	
Graphite	2.0	1.2				0.1		0.2	
Iron ore	0.6	0.5	0.9	0.2	0.1	tr	0.3		
Pyrrhotite						0.7		0.9	
Sphene	0.3	0.2					0.1		
Sericite and chlorite	0.6	1.5	0.2	1.7	0.3	0.7	0.5	0.2	
Apatite	0.2		tr	0.3	0.1				
Zircon	tr	tr	0.1	0.1	0.2	tr	0.1	tr	
Tourmaline	0.4	tr	2.2	0.1	1.7		0.2		
Carbonate			1.1		tr			tr	

Footnotes on facing page.

layers parallel to the foliation; these form swirls around the garnet porphyroblasts and stand out against the white background of the quartz, feldspar and cordierite. The bands of pelitic gneiss have been strongly sheared and many garnets have been drawn out into ovoid shapes. Such penetrative movements would undoubtedly facilitate metasomatism and various metamorphic reactions. A slightly to fairly pronounced mineral banding was seen in a few sections of the rock. It is due to the development of layers rich in quartz and feldspar contrasting with mafic layers.

Modal analyses of two pelitic gneisses are given in Table 1. The most abundant minerals are quartz and biotite. The flakes of biotite range up to 2.5 mm long but most are 0.25–1 mm in length. When the rock shows some mineral banding the biotites in the quartz-feldspar-rich layers are much smaller than the biotites in the ordinary rock. Garnet usually forms 15–20 per cent of the rock. The refractive indices of garnets from the two analysed specimens were found to be 1.791 and 1.794. As these rocks contain only traces of manganese, these indices are sufficient to give a close approximation to the composition. According to the tables of Sriramadas (1957) this is about $almandine_{68}$ $pyrope_{32}$. Sillimanite is well developed in the pelitic gneisses. Its crystals range from fibrolite mats to euhedral prisms 2–3 mm long. Most of the sillimanite occurs as interwoven masses of acicular crystals which have grown in biotite.

The metamorphism which affected these rocks was of regional type. The absence of muscovite in the pelitic gneisses and the reaction of biotite→sillimanite, together with the appearance of clinopyroxene in the associated amphibolites, indicate that the PT conditions were those of the upper part of the amphibolite facies or sillimanite-almandine subfacies of Francis (1956). The presence of microcline, the absence of hypersthene and rutile and the ubiquity of sphene in the pelitic and associated gneisses, indicate that granulite facies conditions were not reached. This conclusion is supported by the garnet compositions which, plotted on Miyashiro's (1953) diagram, fall just on the lower grade side of the granulite/amphibolite facies boundary line.

Location of specimens:
1. Sillimanite-garnet-biotite-gneiss from the centre of the main pelitic band in the main crosscut, Adit Level, Bicroft Mine.
2. Sillimanite-garnet-biotite-gneiss. Drill core sample from the main pelitic band at the Croft Property.
3. *Lit-par-lit* gneiss, hanging wall, No. 1 Dyke, Adit Level, Bicroft Mine.
4. *Lit-par-lit* gneiss, enclave in No. 3 Dyke, just north-east of stn. 318 Adit Level, Bicroft Mine.
5. *Lit-par-lit* gneiss, 39 inches north of stn. 317, Adit Level, Bicroft Mine.
6. *Lit-par-lit* gneiss, 14863 crosscut, Adit Level, Bicroft Mine.
7. *Lit-par-lit* gneiss, K stripping, J Zone, Croft Property.
8. Granite layer from *lit-par-lit* gneiss, specimen 3 above.
9. Average of analyses 1 and 8.

Chemical analyses by J. G. MacDonald, S. E. Brett and A. M. Evans.

Lit-Par-Lit Gneiss

Occurrence

The usual development of the *lit-par-lit* gneiss is as sheaths of variable thickness—a few inches to 20 feet being the common limits—around the dyke rocks. Typical occurrences of *lit-par-lit* gneiss in the Bicroft Mine are illustrated in Figs. 3 and 4.

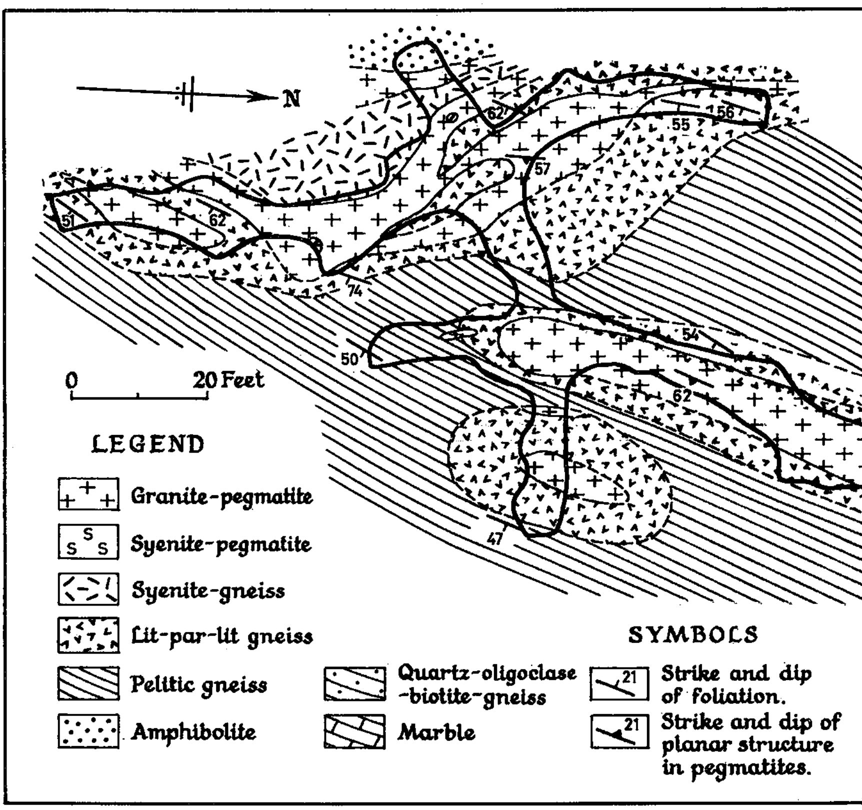

Fig. 3. Map of part of the Adit Level, Bicroft Mine showing typical occurrences of *lit-par-lit* gneiss.

Petrography

The rock consists of altering dark- and light-coloured layers usually between a few millimetres and one centimetre thick. The rock is illustrated in Figs. 5 and 6. The light layers are granitic. The dark layers are rich in biotite and comprise about half the rock. Modal analyses of *lit-par-lit* gneiss are given in Table 1.

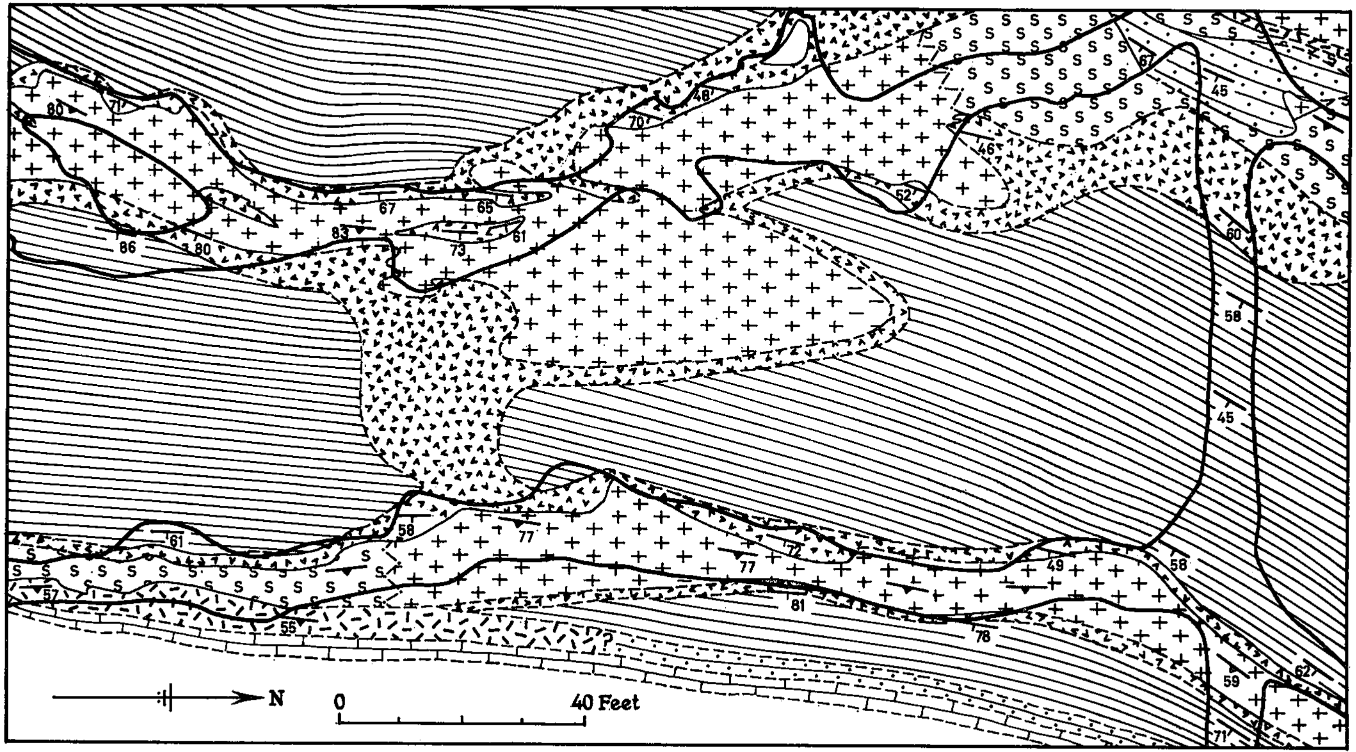

FIG. 4. Map of part of the 1st Level, Bicroft Mine showing typical occurrences of *lit-par-lit* gneiss and the associated syenitic and granitic, pegmatitic dykes. For the legend and symbols employed see Fig. 3. (Location of drill holes omitted).

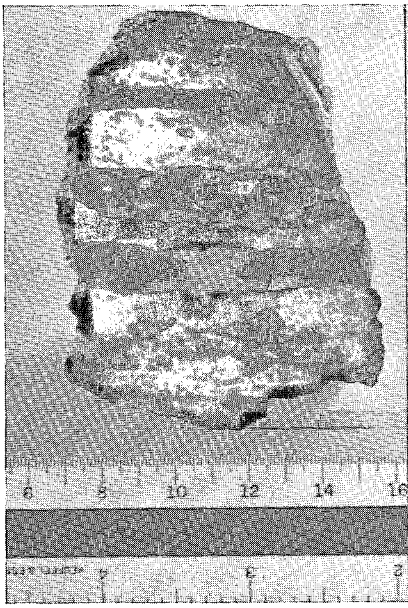

FIG. 5. *Lit-par-lit* gneiss from the Adit Level, Bicroft Mine. Lower scale is in inches.

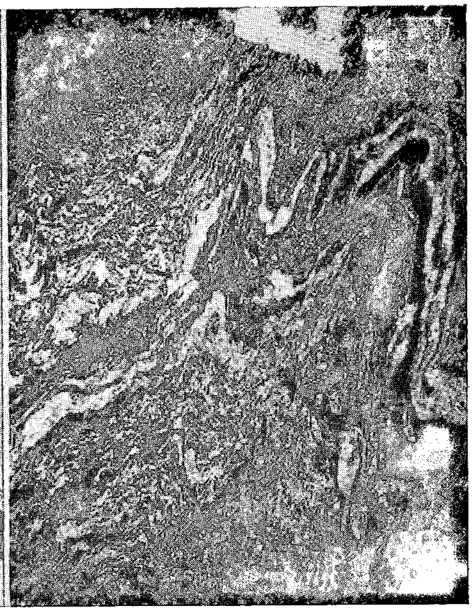

FIG. 6. Folded *lit-par-lit* gneiss, Adit, Croft Property.

Since the dykes cut across the metasediments, the zones of *lit-par-lit* gneiss are discordant and therefore it is possible to follow pelitic gneiss along the foliation and observe the progressive changes as this gneiss passes into *lit-par-lit* gneiss. The first changes are the appearance of small lenses of granite and an increase in biotite in the darker intervening rock, which still carries garnet and sillimanite. Traced towards the dyke contact, the various layers become more distinct and their contacts sharpen —Fig. 5. The dark layers become still richer, and the light layers poorer in biotite. The garnet and some of the sillimanite disappear from the dark layers, the place of the latter being taken by corundum. The last two minerals have been found in the same thin section but an example showing the actual mineral change has not been found. Pseudomorphs of corundum after sillimanite are, however, quite common—Fig. 7. The corundum is restricted to the dark layers. In these the principal minerals are biotite and plagioclase; microline and quartz are absent. The granitic bands are usually very rich in quartz which tends to form elongate patches in the centres of these layers. The patchy extinction, partial breakdown into smaller grains and fracturing indicate the effects of cataclasis. Plagioclase is the dominant feldspar.

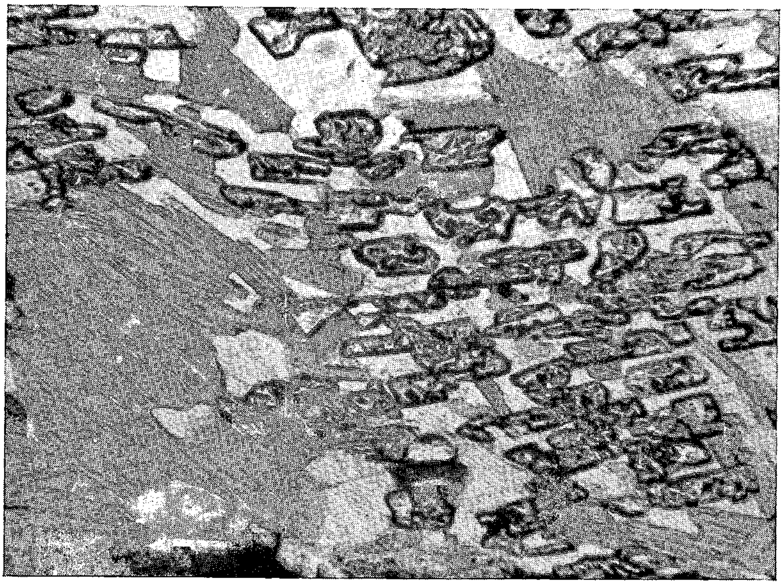

FIG. 7. Pseudomorphs of corundum after sillimanite. *Lit-par-lit* gneiss, Adit Level, Bicroft Mine.

Genesis

Lit-par-lit gneisses from the Grenville subprovince were described by Osborne (1936) from Shawinigan Falls, Quebec. Osborne considered them to be the result of injection of granite along the foliation planes of pelitic gneiss. The *lit-par-lit* gneisses at the Bicroft Mine were considered by Satterly & Hewitt (1955) and Hewitt (1957) to be the result of *lit-par-lit* injection of pegmatite into the paragneisses. These workers have followed the majority in preferring the hypothesis of injection origin put forward by Michel-Lévy (1887). But, as is pointed out by Read (1948) in his summary of the theories of origin of *lit-par-lit* gneiss, many geologists, starting with Greenly (1903), have preferred an origin by solid diffusion. Like Greenly, Fenner (1914) and Barrell (1921) pointed attention (to quote Read) "to the undisturbed and unsupported nature of exceedingly thin septa in *lit-par-lit* complexes and . . . favoured a gradual transfusion rather than the violent intrusion usually pictured". Perrin & Roubault (1937, 1939) considered *lit-par-lit* structure to be the result of solid diffusion and that this structure (again from Read) "is only a forerunner of granitization and not an end-product of solidification —it is a metamorphic process".

Some Scottish *lit-par-lit* gneisses described by Read (1931) were developed from pelitic and semi-pelitic gneisses. In discussing their origin, Read compared analyses of the altered and unaltered gneisses and called attention to the constancy of silica and alumina and the increase in soda during the alteration process. Read concluded that oligoclasic solutions had been fixed by the pelitic gneisses during their transformation.

Reynolds (1946) plotted analyses of pelitic gneiss and permeation gneiss from Read (1931) on a von Wolff diagram and demonstrated that the development of the permeation gneiss from the pelitic gneiss was accomplished by a process of feldspathization and desilicification, as distinct from one of granitization. Reynolds' plots are reproduced in Fig. 8.

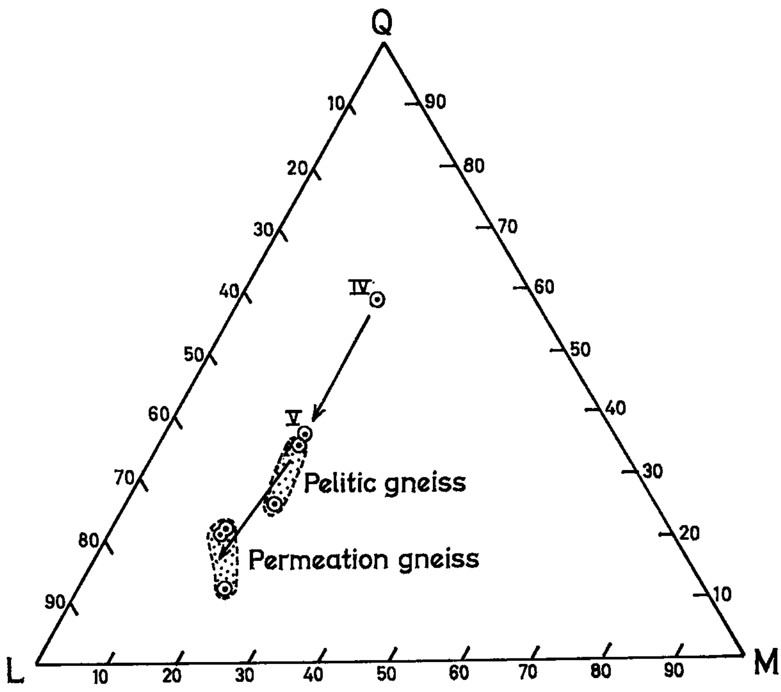

FIG. 8. Von Wolff diagram showing changes involved in transformation of Sutherland pelitic gneiss into permeation gneiss (dotted areas) after Reynolds (1946) and plots of analyses IV and V (pelitic and *lit-par-lit* gneiss respectively) from Osborne (1936).

Harry (1954) described another Scottish occurrence of *lit-par-lit* gneisses, this time from Ardgour. Harry was concerned with the origin of the oligoclase-biotite-quartz-gneisses of the area and put forward chemical and field evidence which, he concluded, demonstrates their formation from pelitic gneiss by desilification and basification. This led him on to deduce that the quartz-oligoclase folia in the *lit-par-lit* gneisses were not magmatic injections but the result of metamorphic differentiation. He ends his discussion by pointing out that the word injection should be dropped from the description of these rocks as *lit-par-lit* injection gneisses.

The comparison of modal analyses of *lit-par-lit* gneiss from the Bicroft Mine with those of the pelitic gneiss (Table 1), shows a surprising correspondence in the amounts of certain minerals in both rocks; the only constant major difference between the two is the strong development of feldspar in the *lit-par-lit* gneiss and the disappearance of cordierite and garnet. It seems that the origin of the gneiss was not by injection layer by layer of granitic magma, a theory of origin which here too is open to all the objections of Greenly, Fenner and Barrell, but by metamorphic differentiation. Indeed, as the beginnings of a metamorphic differentiation of mineral phases in the sillimanite-garnet-biotite-gneiss of the Bicroft Mine can be seen in many places, it appears that this is the most probable origin of these banded gneisses. The most significant chemical change suggested by a comparison of the modes is an increase in alkalis. In other words much of the material for the granitic layers must be regarded as having been derived from the pelitic gneiss. The subtraction of silica from the dark layers led to the complete disappearance of quartz and is presumably responsible for the partial replacement of sillimanite by corundum. It is most unlikely that the latter mineral would have been formed by the layer by layer intrusion of a silica-rich magma! The above hypothesis may be tested and confirmed by a consideration of the chemistry of these rocks.

Chemical analyses of *lit-par-lit* and pelitic gneisses are given in Table 1. A comparison of these analyses confirms the conclusions drawn from the modal analyses. Silica is not significantly higher in the *lit-par-lit* gneisses. Iron and aluminum are a little lower. The feldspar-forming oxides, potash, soda and lime show an increase, especially the potash. Had the gneiss been formed by injection of the material of the granite layers into pelitic gneiss then the resultant rock should have a composition intermediate between that of the pelitic gneiss and the granite layers. To demonstrate that this is not the case, an analysis of some granitic layers (No. 8 in Table 1) was combined with an analysis (1) of pelitic gneiss. The resultant analysis (9) represents the hypothetical *lit-par-lit* gneiss which would be formed by the injection of the granitic material of the actual *lit-par-lit* gneiss into pelitic gneiss in a one-to-one proportion. It is clear from Table 1 that this hypothetical rock has considerably more silica than the *lit-par-lit* gneiss. This comparison of the silica percentages argues against the injection hypothesis. Such an hypothesis also yields rather low alumina, iron oxide, lime and soda contents. The point

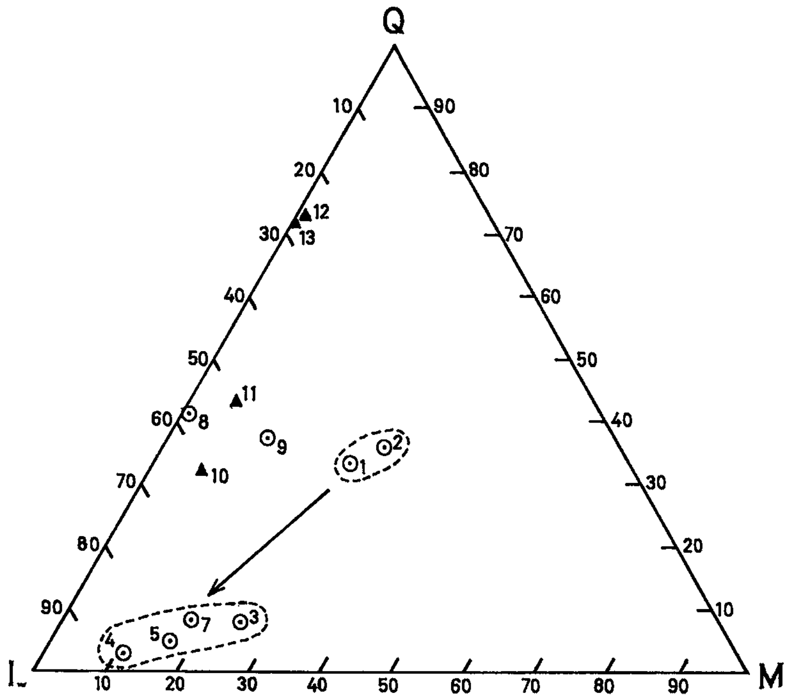

FIG. 9. Von Wolff diagram with plots of analyses 1–13 from tables 1 and 2 o this paper. The areas enclosed with pecked lines represent pelitic gneiss (1, 2) and *lit-par-lit* gneiss (3, 4, 5, 7) from the Bicroft Mine.

may be brought out in a pictorial manner by plotting the above analyses on a von Wolff diagram—Fig. 9. Analysis 9—the hypothetical rock which would be formed by the injection of magma 8 into rock 1 plots at 9 on the line jointing 8 and 1, and whatever the proportions of 8 and 1, the resultant would still fall on this line; but the actual *lit-par-lit* gneisses (3, 4, 5, 7) fall in a very different part of the diagram. This exercise indicates that the *lit-par-lit* gneiss cannot have been formed by injection of granitic magma of composition similar to that of analysis 8 along the foliation of the pelitic gneiss.

Before finally ruling out the injection hypothesis, we must consider the possibility that the granitic layers represent mobilized injected dyke rock. Chemical analyses of four specimens of dyke, collected from points in the dykes close to the analysed *lit-par-lit* gneisses, are given in Table 2. Two of these (12 and 13) represent very siliceous phases whose injection into the pelitic gneiss would have produced an injection gneiss with a much higher silica content than the actual specimens of this rock possess.

TABLE 2. ANALYSES OF DYKE ROCKS FROM THE BICROFT MINE AND CROFT PROPERTY

	10	11	12	13
SiO_2	70.10	74.75	86.78	85.30
Al_2O_3	14.20	12.80	5.50	7.70
Fe_2O_3	1.91	1.37	0.59	0.25
FeO	1.36	2.36	0.82	0.36
MgO	1.48	0.77	tr	tr
CaO	3.49	1.76	0.71	1.07
Na_2O	3.45	3.55	1.08	2.32
K_2O	1.59	2.06	2.54	2.50
H_2O^+	0.79	0.18	0.11	0.30
H_2O^-	0.77	0.48	0.88	0.10
TiO_2	0.31	0.18	tr	0.05
MnO	0.26	<0.03	<0.03	<0.03
	100.01	100.26	99.04	99.98

Location of specimens:
10. Pegmatitic pyroxene-granite from back, 80 inches north of stn. 317, Adit Level, Bicroft Mine.
11. Coarse-grained hornblende-biotite-granite from back, just north-east of stn. 318 Adit Level, Bicroft Mine.
12. Coarse-grained leucocratic granite (from back) 12 inches from specimen 11.
13. Granite-pegmatite, J. Stripping, J. Zone, Croft Property.
Analyses by J. G. MacDonald, S. E. Brett and A. M. Evans.

The hypothetical injection gneiss would plot on the von Wolff diagram (Fig. 9) in the area between points 1 and 2, and 12 and 13 well away from the field where the actual *lit-par-lit* gneisses plot. The analyses of the less siliceous dyke rocks (10 and 11) plot fairly near to the point (8) representing the granitic material in the *lit-par-lit* gneisses. Thus the injection gneiss resulting from intrusion of this material would plot close to the hypothetical *lit-par-lit* gneiss (point 9) already discussed above and well away from the field where the actual *lit-par-lit* gneisses fall. It seems therefore that injection of magmas of dyke composition cannot have been the mechanism by which the *lit-par-lit* gneisses were formed. This is in keeping with the fact that it has been shown elsewhere that these dykes are probably of metasomatic and not magmatic origin. Thus neither the field nor the chemical evidence is in keeping with the injection hypothesis. The dykes vary petrographically along their length from granitic to syenitic pegmatites, yet no similar variation has been seen in the *lit-par-lit* gneisses of the neighbouring wall-rocks. The light-coloured layers of the gneiss maintain their granitic character whether they are developed alongside granitic or syenitic pegmatite and show no significant variation in their quartz content. In addition it may be noted that they do not contain any of the prominent accessory minerals which characterize the dykes, such as aegirine–augite, hornblende and uranium minerals. Other important field evidence is the presence of scattered patches of incipient development of *lit-par-lit* gneiss within the pelitic gneiss (sometimes only on the scale of a hand specimen) well away from the dykes or any other igneous-looking rock which could be a source of the material forming the leucocratic layers.

A comparison of Figs. 8 and 9 shows that in the formation of *lit-par-lit* gneiss from pelitic gneiss at the Bicroft Mine, the chemical changes and trends were the same as those involved in the development of the permeation gneisses investigated by Read and Reynolds. The movement towards the L corner indicates the importance of feldspathization during the development of these gneisses. The movement away from the area intermediate between the pelitic gneiss and the field occupied by granitic rocks demonstrates that the mechanism of formation of the granitic layers in the *lit-par-lit* gneiss must have been that of metamorphic differentiation and not magmatic injection.

The cause of these developments of *lit-par-lit* gneiss at the Bicroft Mine is not clear. Though usually developed in close spatial relationship to pegmatite dykes, the occurrence of enclaves of *lit-par-lit* gneiss in the dykes testifies to its development before the dyke emplacement. This spatial relationship is not then a direct genetic one, but may well imply that both rock-types have been developed in areas of extreme metasomatic activity during the general regional metamorphism.

Interesting light is shed upon the problem by the fact that *lit-par-lit* gneiss is only developed in rocks having a pronounced schistosity and the better the development of the schistosity the more pronounced is the development of *lit-par-lit* gneiss. This is in accord with the observations made by Turner (1941) from a study of laminated schists in New Zealand.

The nature of the process which gives rise to mineral banding in homogeneous rocks possessing a good schistosity is still incompletely understood. An excellent discussion of the problem appears in Turner & Verhoogen (1960) who conclude that the process is a complex one "involving solution, crystallization and mechanical deformation, acting together or in alternating combinations as the selective agents of metamorphic differentiation". But earlier in their discussion (pp. 582–583) they go on record as considering that local gradients in chemical potential are the main driving force behind the differentiation. On the other hand Schmidt (1932) suggested that the process was entirely a mechanical one. The recognition during recent years of the importance and common occurrence of ionic diffusion on various scales in metamorphic processes makes it seem unlikely that chemical factors would play no part in the differentiation. However Sclar (1965) has drawn attention to examples where the dominant process certainly appears to have been mechanical. Many mylonitic rocks, besides those described by Sclar, show incipient to well developed mineral banding. In fact this is an obvious feature of many shear zones in metamorphic and other crystalline rocks, and it may well be that it is the mechanical factor which triggers off this whole process of the development of laminated metamorphic rocks from previously homogeneous rocks. In all the accounts which the author has read of the formation of *lit-par-lit* gneisses and other similar forms of laminated metamorphic rocks there is usually some mention of cataclastic activity having affected the rocks concerned. It may be that further investigation in the few cases where this has not been reported would reveal evidence of shearing or the existence of a later metamorphic phase which may have healed the effects of earlier cataclasis.

In the example under discussion there is ample evidence of considerable shearing movement along the schistosity surfaces after the crystallization of much or all the garnet. This has been noted above in the description of the pelitic gneiss. The continuation of this shearing during or towards the end of the *lit-par-lit* gneiss formation is indicated by the cataclastic features seen in the leucocratic layers. This shearing is believed to have initiated the metamorphic differentiation.

As noted previously, the formation of *lit-par-lit* gneiss in the Shawinigan Falls District of Quebec was ascribed by Osborne (1936) to the injection of granitic material along the foliation planes of pelitic gneiss. The writer has not had the opportunity of examining these rocks, but it is of interest to plot the analyses of pelitic (IV) and *lit-par-lit* gneiss (V) given by Osborne on a von Wolff diagram—Fig. 8. The trend revealed by this plot is similar to that recorded from the Bicroft area (Fig. 9), but the two points occur further up the diagram because the pelitic gneiss in this case is more siliceous than the Bicroft pelites. The similar geochemical trend towards the L corner and the decrease in silica content during the change from pelitic to *lit-par-lit* gneiss suggest that these gneisses too are the result of metamorphic differentiation. It is of further interest that Osborne reports a similar elongation by fracturing of the garnets and other effects of mechanical deformation in these rocks.

Conclusions

It is concluded that the formation of much *lit-par-lit* gneiss at the Bicroft Mine was the result of metamorphic differentiation of pelitic gneiss accompanied by an accession of sodium and potassium. The chemical evidence when investigated by the use of von Wolff diagrams reveals a different trend during the transformation from pelitic to *lit-par-lit* gneiss than would be expected from the magmatic injection hypothesis. The similarity of silica content in the pelitic and *lit-par-lit* gneisses also militates against the injection hypothesis. The geochemical changes were dominated by feldspathization and a severe desilicification of that part of the original pelitic gneiss now represented by the dark layers. The location of zones of *lit-par-lit* gneiss in areas of more pronounced schistosity within the pelitic gneiss is believed to indicate that mechanical deformation played an important role in the differentiation process.

Similar geochemical changes accompanied by mechanical deformation suggest that the *lit-par-lit* gneisses of Shawinigan Falls, Quebec may also have been formed by metamorphic differentiation.

Finally, it is considered worthwhile reiterating Harry's plea that the genetic term injection be dropped from descriptions of *lit-par-lit* gneiss unless it has been shown that the gneisses were indeed formed by this mechanism.

Acknowledgments

Much of the research for this paper was carried out at Queen's University under the supervision of the late Dr. J. E. Hawley to whom the author is most grateful for his help and continual interest in the progress of the work. The author would like to thank Messrs J. G. MacDonald and S. E. Brett for the rock analyses determined in the Miller Research Laboratories of Queen's University. The award of an R. Samuel McLaughlin Fellowship and a National Research Council Studentship is gratefully acknowledged.

During the field work the author received much help from Dr. D. F. Hewitt, who introduced him to the area and from Mr. and Mrs. L. Kelly without whose help and hospitality this work could never have been attempted.

References

Barrell, J. (1921): Relation of subjacent igneous intrusion to regional metamorphism, *Am. J. Sci.*, **1**, 225 *et seq.*

Bateman, J. D. (1955): Recent uranium developments in Ontario, *Econ. Geol.*, **50**, 361–372.

Evans, A. M. (1962): Geology of the Bicroft Uranium Mine, Ontario, *Ph.D. thesis, Queen's University.*

Fenner, C. H. (1941): The mode of formation of certain gneisses in the highlands of New Jersey, *J. Geol.*, **22**, 594 et seq.

Francis, G. H. (1956): Facies boundaries in pelites at the middle grades of regional metamorphism, *Geol. Mag.*, **93**, 353–368.

Greenly, E. (1903): The diffusion of granite into crystalline schists, *Geol. Mag.*, **10**, 207 et seq.

Harry, W. T. (1954): The composite granite gneiss of western Ardgour, Argyll, *Quart. J. geol. Soc. Lond.*, **109**, 285–308.

HEWITT, D. F. (1957): Geology of Cardiff and Faraday Townships, *Ont. Dept. Mines Ann. Rept.*, **66**, pt. 3.

KELLY, L. (1956): The Bicroft pegmatites, *Can. Mining J.*, June 1956, 87–88.

——— (1958): Geology; in the Bicroft Operation, *Western Miner.*, **31**, 81–84.

MICHEL-LÉVY, A. (1887): Sur l'origine des terrains cristallins primitifs, *Bull. Soc. géol. Fr.*, ser. 3, **7**, 857 et seq.

MIYASHIRO, A. (1953): Calcium-poor garnet in relation to metamorphism, *Geochim. et Cosmochim. Acta*, **4**, 179–208.

OSBORNE, F. F. (1936): Petrology of the Shawinigan Falls District, *Geol. Soc. Amer. Bull.*, **47**, 197–227.

PERRIN, R. & ROUBAULT, M. (1937): Les Réactions à l'état solide et al géologie, *Bull. Serv. Carte géol. Algérie*, ser. 5, Petrographie, No. 1.

——— (1939): Le granite et les réactions à l'état solide, ibid, No. 4.

READ, H. H. (1931): The geology of Central Sutherland, *Scotland Geol. Surv. Mem.*

——— (1948): A commentary on place in plutonism, *Quart. J. geol. Soc. Lond.*, **104**, 155–205.

REYNOLDS, D. L. (1946): The sequence of geochemical changes leading to granitization, *Quart. J. geol. Soc. Lond.*, **102**, 389–446.

ROBINSON, S. C. (1958): A genetic classification of Canadian uranium deposits, *Can. Mineral.*, **6**, 174–190.

——— (1960): Economic uranium deposits in granitic dykes, Bancroft District, Ontario, ibid, **6**, 513–521.

SATTERLY, J. & HEWITT, D. F. (1955): Some radioactive mineral occurrences in the Bancroft Area, *Ont. Dept. Mines. Geol. Circ.*, **2**.

SATTERLY, J. (1956): Radioactive mineral occurrences in the Bancroft Area, *Ont. Dept. Mines Ann. Rept.*, **65**, pt. 6.

SCHMIDT, W. (1932): *Tektonik und Verformungslehre*, Berlin.

SCLAR, C. B. (1965): Layered mylonites and the process of metamorphic differentiation, *Geol. Soc. Am. Bull.*, **76**, 611–612.

SRIRAMADAS, A. (1957): Diagrams for the correlation of unit cell edges and refractive indices with the chemical composition of garnets, *Am. Min.*, **42**, 294.

TURNER, F. J. (1941): The development of pseudostratification by metamorphic differentiation in the schists of Otago, New Zealand, *Am. J. Sci.*, **239**, 1–16.

——— & VERHOOGEN, J. (1960): *Igneous and metamorphic petrology*, New York.

Manuscript submitted September 3, 1965, resubmitted July 22, 1966