THE PETROLOGY AND GEOCHEMISTRY OF SOME GRENVILLE SKARNS

PART I: GEOLOGY AND PETROGRAPHY*

D. M. SHAW, R. L. MOXHAM, R. H. FILBY AND W. W. LAPKOWSKY
McMaster University, Hamilton, Ontario

Abstract

Coarse-grained skarns are abundant throughout the Grenville province wherever marble is found, and are the most common in regions of high metamorphic grade. The principal minerals present are pink calcite, clinopyroxene, scapolite, amphibole, mica and sphene: some varieties are rich in potash feldspar and plagioclase, fluorite, quartz, apatite, allanite, zircon, pyrite, thorian uraninite and uranothorite.

Mineralogical composition varies widely, and over short distances (a few cm.). Nevertheless, 5 main assemblages can be recognized: scapolite-pyroxene, pyroxenite, pink calcite rich, pyroxene-feldspar-quartz, purple fluorite rich. At numerous localities in S.W. Quebec and S.E. Ontario it may be demonstrated that these skarns show petrographic transition to normal Grenville amphibolites, marbles, granites, gneisses and pegmatites, which therefore have in part contributed to the formation of the skarns. Other contributory processes include in situ metasomatism, metamorphic differentiation, vein and pegmatite deposition, bulk flowage and injection. In most cases skarn formation was the last event recorded in the Precambrian history of the region, but some of the skarns have been affected by later shearing.

Many radioactive deposits are located in the skarns or in related granitic and syenitic pegmatites. However, some were clearly emplaced by fracture control and show no evident relationship to the host rocks. It is therefore difficult to relate all the radioactive deposits to the processes of skarn formation.

Chemical analyses were made of 6 scapolites, 6 pyroxenes and 2 feldspars. Spectrographic trace element analyses were made for numerous elements in 40 scapolites, 38 pyroxenes, 29 calcites, 5 amphiboles and 2 feldspars.

The elements Ca, B, Be, Ga, Li, Mn, Y, Sr, Pb are commonly enriched in the skarn minerals. To these may be added F, Cl, S, P, Zr, RE, Ti, U, Th, in many cases. B is always richer than in the crust, and the same is probably true of Cl, Be, Li, Mn, Y, Sr and Pb.

The assemblage scapolite-diopside-sphene is the most widespread. It formed under upper amphibolite facies conditions, and is sufficiently common in many parts of the world to justify its retention as a new metamorphic facies characteristic of environments rich in CO_2 and Cl but lower in H_2O.

Evidence for the environment of formation of the skarns is scanty and difficult to interpret, but a temperature of 300–400° C. and a depth of 20–25 km are reasonable. It is probable that the skarn-forming fluids were produced by remobilization of crustal materials by plutonic metamorphism.

Introduction

Coarse-grained pegmatitic assemblages of pink calcite and silicates are common in many parts of the Precambrian Grenville province of Quebec,

*Part II. Geochemistry will appear in the following issue: The Canadian Mineralogist, Vol. 7, Pt. 4 (1963). Tables 2 to 13 are included with Part II.

Ontario and New York State. Not infrequently they contain concentrations of less common elements and minerals which are interesting from both economic and academic standpoints. This paper is concerned with the field relations, petrographic and geochemical features of a number of these deposits, mostly in Quebec but also including some examples from Ontario. A synthesis of the results is attempted to try to account for the origin of these rocks, which will be referred to as the Skarn Series. The major emphasis of the present paper is on the scapolite-pyroxene-calcite skarns, although other varieties are discussed and a general interpretation is made. Another paper will, however, be devoted to additional mineral series.

Most of the deposits studied show significant radioactivity and it is clear that the conditions of formation allowed the concentration of U and Th. Although a considerable number of the minerals were analyzed for rare elements, the methods available to the writers did not permit analysis for U and Th, nor for small amounts of rare earths. This aspect of the skarns therefore has not been adequately studied.

Most of the material in Quebec was collected during the summers of 1954 and 1955, while the first author was working for the Quebec Department of Mines. The summer of 1954 was spent mapping part of Calumet Island (Grand Calumet Twp.) in the Ottawa river, and the summer of 1955 in mapping numerous radioactive deposits in Quebec. A detailed account of these properties has been published (Shaw, 1958). No general discussion of Grenville geology is necessary here, but brief descriptions of the more important properties are given: for convenience these will be referred to by abbreviations denoting the companies prospecting or developing the deposits at the time, although the status of many may have subsequently changed.

Samples from Glamorgan and Monmouth townships in Ontario were collected at various times, with the advice of Dr. H. S. Armstrong, University of Alberta, who has mapped the area for the Ontario Department of Mines (unpublished). The samples prefixed "A" were donated by Dr. Armstrong; a few additional specimens were taken from university collections.

From the geochemical standpoint the skarn rocks are too inhomogeneous to analyze directly. Accordingly the constituent minerals were separated and analyzed individually, by chemical and spectrographic methods. Six scapolites, six pyroxenes and two feldspars were analyzed in the Rock Analysis Laboratory of the University of Minnesota, by Mr. C. O. Ingamells* under the direction of Dr. S. S. Goldich.† The spectrographic analyses were carried out at McMaster University, and

*Now at Pennsylvania State University.
†Now at the National Bureau of Standards, Washington, D.C.

division of the work with graduate students allowed special attention to different aspects of the geochemistry. Thus Filby studied several major elements in the scapolites (1957), Moxham studied the minor elements in pyroxene (1960) and Lapkowsky studied minor elements in the calcites (1959). The principal mineral series examined were scapolite, pyroxene and calcite: in addition, a few amphiboles and feldspars were analyzed. However, the micas were not studied geochemically, although phlogopite is fairly abundant in some of the rocks: future work will examine mica, sphene, fluorite and apatite.

All rock names in this paper are used in a descriptive, non-genetic sense.

Acknowledgments

The Geological Survey of Canada and the National Research Council of Canada contributed generous research grants to help finance this work; the Penrose Fund of the Geological Society of America defrayed the cost of the chemical analyses; the Quebec Department of Mines permitted publication of data gathered during surveys carried out on their behalf. The writer is indebted to these organizations. Several graduate students, in particular J. N. Weber, O. C. Wickremasinghe and C. C. Yip, gave great help and valuable discussion.

Geology of Individual Deposits

General accounts of the Grenville province can be found in Adams & Barlow (1910), Hewitt (1956), Osborne (1956), Dresser & Denis (1944), Satterly (1957), Engel (1953) and various other references included in those works. The geology of some of the more important properties is outlined in the following paragraphs: further details have been published elsewhere (Shaw, 1958).

It should be pointed out that there is no direct proof that the rocks considered, coming from widely separated localities, are coeval and cogenetic. This is, however, considered to be the case for the following reasons: (*a*) the assemblages are petrographically identical; (*b*) the ages of the radioactive minerals determined by various authors are similar; (*c*) in every locality studied the genesis of the skarns has been the last event recorded in the Precambrian geology, except in some cases for later shearing; (*d*) geochemical features of the minerals are similar.

Quebec Metallurgical Industries Ltd., Clarendon Township, Pontiac County, Quebec (QMI)

This property is about 11 miles north of Shawville and consists of a complex of skarns at a granite-marble contact. The skarns include pyroxenite, scapolite-diopside rocks of various kinds and pink calcite-silicate assemblages. They outcrop over a length of about 900 feet, structurally beneath the granite, which appears to form a sheet overlying marble. There is no clear evidence that the skarns have formed by action of granite on marble; they could just as well have formed by later ascending solutions whose effects were localized by the impermeable granite sheet. Cubes of uraninite are scattered through the pyroxenite.

Grand Calumet Township, Pontiac County, Quebec

On the northern end of Calumet Island (Grand Calumet Township) there is considerable variety of rock types and the geology is complex. Most of the rocks are, however, related to the marble, amphibolite, biotite schist, gabbro and granitic rocks which are abundant in the region, but which have commonly been altered or hydridized. Of several radioactive deposits three have been extensively explored.

Calumet Uranium Mines Ltd. (CUM) have explored radioactive showings of two main kinds. One consists of a coarse pink calcite skarn with abundant purple fluorite, green apatite and minor uranothorite. This occurs as numerous small pods and lenses enclosed by rocks of all kinds, and is commonly associated with pyroxenic hybrids of syenitic or granitic composition. The other is a more normal marble, though commonly pink, containing diopside, phlogopite and other common silicates together with minor thorian uraninite and uranothorite. This rock occurs as a thin (4 feet) sheet near the base of a normal marble which is intercalated in a succession of marble, amphibolite and various gneisses. The strike is generally N60°E and the structure is an overturned syncline which has been cross-folded. The average of 48 company assays on the radioactive zone gave 0.14% U_3O_8 and 0.49% ThO_2.

Adjacent on the west is the Calumet Contact Uranium Mines Ltd. (CCUM) property. Although here again there are numerous fluorite-rich pods and veins, the main radioactive zone is also in marble and is situated close to a scapolite-diopside skarn which resembles altered gabbro. The sequence is again of marble, amphibolite, gneiss and granite, in alternating bands, the amphibolites showing gradation into the scapolite-diopside rock, and scapolite amphibolite. The average of 14 company assays on the radioactive zone gave 0.10% U_3O_8 and 0.32% ThO_2.

The Struan Uranium Mines (formerly Quebec Nickel Corp. Ltd.) property a few miles further south is worthy of mention as illustrating a radioactive deposit of quite different type. There are no skarns and the main showing exposes an extensively mylonitized and tourmalinized granite pegmatite, with disseminated radioactive minerals of very fine grain size and uncertain nature. The pegmatite dyke swarm shows simple mineralogy, and the radioactivity is largely restricted to the zones of later intense shearing: the deposit has been described by Gittins (1956).

Huddersfield Twp., Pontiac County, Quebec

Of the seven localities examined in this township four are similar in character and will be described.

The Noranda Mines Ltd. (NML) option in the northern part of the township has uranothorite occurrences in an E–W striking band of marble and skarn measuring about 900 by 150 feet. The rock-types include white marble, coarse pink silicated marble, pyroxenite and scapolite-diopside rock. The body appears to be a synclinal or canoe-shaped lens persisting for only 50 feet below the surface and surrounded on all sides by granite and gneiss.

Three similar properties are adjacent to each other in the central part of the township. The Huddersfield Uranium and Minerals (HUM) and the Soma-Duverny Gold Mines Ltd. (SDGM) showings both exhibit skarn rocks and marbles resembling those mentioned in the last paragraph. As a result of the irregular, pegmatitic development, the structural patterns are uncertain, and contacts between adjacent skarns and marbles are crenulate and scalloped. Where a rock-unit shows any persistence for more than a few feet, however, the surface and drill-core information suggest a gently-dipping or flat-lying attitude. At these two properties the coarse diopside-phlogopite-pink calcite marble is locally very rich in twinned (spinel law) cubes of thorianite up to 1 cm. wide, and there are small areas very rich in allanite. Although contacts are sometimes sharp, in other cases one finds gradual transitions as follows: phlogopite marble → chondrodite-white calcite marble → chondrodite-pink calcite marble → coarse diopside-phlogopite-pink calcite marble → pyroxenite (diopsidite) → pyroxene hybrid gneiss. Outcrops are generally poor except where the overburden has been stripped, but granite and gneiss appear to be the principal country-rocks and are intimately associated with the skarns. Amphibolites are also present and some sillimanite-garnet schists were noted in drill-core sections.

The Yates Uranium Mines Inc. (YUM) property resembles the three preceding ones but has been much more thoroughly explored, both by surface excavation and diamond-drilling. The locality was originally developed for phlogopite, which occurs in association with pyroxenite and augite-scapolite rock and subsequently for radioactive minerals. The latter occur in two principal bands. The first, known as the Camp Zone, is a complex of coarse silicated pink marble, pyroxenite and augite-scapolite rock, extending for 900 feet along strike (N20°W) and varying in width from 50 to 100 feet, with variable dip. Thorianite, uranothorite and uranophane are sparsely disseminated along the band. Adjacent rocks are granite and gneiss, including varieties with green pyroxene. The band has the shape of a gently-folded (synclinal) lens whose maximum true thickness is about 70 feet. Other thinner bands lie structurally below the main mass and are roughly parallel to it.

The second zone (the Matte Zone) differs from other occurrences in the township in the abundance of purple fluorite and green apatite. The principal rock-type, is a fluorite-apatite-pink calcite marble with pyroxene, scapolite and minor uranothorite. The zone has been exposed over a strike-length of 800 feet (N25°W) and appears to form a sheet dipping regularly at 20 to 30°W, enclosed by granite. The true thickness is about 20 feet. Drill-cores show the ore-zone to be bordered by hybrid granitic rocks which are very variable but generally contain pyroxene or dark green-blue hornblende (pseudomorphing pyroxene). Further away are biotite granites and leucogranite. About ½ mile to the northwest (along strike) a similar but smaller zone has been found and may be an extension of the Matte Zone.

There are other radioactive occurrences on the same property. The Belanger showing closely resembles the Camp Zone but is smaller, and the Belisle showing is characterized by abundant very coarse apatite but no fluorite.

At all the showings there is extensive variation in lithology over short distances, a considerable variety of skarns and marbles being present. The grain-size is also very variable, from medium and coarse marbles to very coarse vein or pegmatitic skarn.

Gatineau Uranium Mines Ltd., Baskatong Twp., Gatineau County, Quebec (GUM)

A pyroxenite complex is situated on a small island in Lake Baskatong. Rocks are only exposed at periods of relatively low water. In addition to uranium-thorium minerals there is also some lead-zinc mineralization.

The rocks exposed are a conformable series of marble, granite gneiss, schist, quartzite and pyroxenite. The strike averages N45°E with dips mostly in the range 35 to 70°E. The regular banded structure persists throughout adjacent islands but is probably of tectonic rather than sedimentary origin, since drag-folds abound in the marble. At various places in the two pyroxenite bands are patches rich in galena and, more rarely, sphalerite. Uranothorite is common both in the pyroxenite and in the marble at the footwall. Although contacts mostly appear sharp, fragments of drill-core show facies transitional from pyroxenite to marble.

Stratmat Ltd., Masham Twp., Gatineau County, Quebec (SL)

This molybdenite property has been known for about 40 years and has been developed by various companies from time to time. It is located at the north end of Indian Lake.

The rocks exposed are a complex of paragneiss, marble, pyroxenite and pegmatitic granite with irregular bands and pockets containing pyrite, marcasite, pyrrhotite and molybdenite. The sulphides occur most commonly in the pyroxenite and are frequently accompanied by strong radioactivity, due to uraninite or thorianite.

Duvex Oils & Mines Ltd., Mitchell Twp., Gatineau County, Quebec (DOM)

These localities occur on the west side of the Gatineau River a few hundred feet below the Mercier Dam, north of Maniwaki. Marble, quartzite, hornblende-biotite schist and various hybrid gneisses and granites are abundant in the district and in the vicinity of the radioactive showings.

The principal rocks of interest here are a series of pegmatitic granites varying from leucocratic to mesotype varieties. The latter are rich in green pyroxene and locally have abundant sphene, zircon and allanite. Thorite-uranothorite is present in all.

Alta Mines and Nemrod Mining Co. Ltd., Sicotte Township, Gatineau County, Quebec (ANM)

At this locality a pegmatite is exposed for about 70 feet along the shore of the Gatineau river, below a sand terrace. The pegmatite is leucocratic, consisting chiefly of quartz, white plagioclase and microcline. Accessory minerals occur in clots and include green pyroxene, schorl, zircon, sphene and uraninite. Allanite is probably present also and a little uranophane was found.

The attitude of the pegmatite is uncertain but on either side is a gneiss striking N30°E and dipping 45°E, carrying narrow bands of chondrodite marble. Exposures are poor but drill-core fragments revealed a wide variety of rocks, including sillimanite-garnet gneiss and pyroxene granite.

General Geology and Petrography

There is a wide variety of rock types to be found in the Grenville province, and the majority are to be found at the different radioactive deposits. It is not necessary here to repeat the petrographical descriptions which are given in so many papers and reports (*e.g.*, Adams & Barlow, 1910; Satterly & Hewitt, 1955; Engel & Engel, 1953; Dresser & Denis, 1944). The common rocks can be divided into five main groups: (*a*) marble and associated rocks; (*b*) amphibolite, hornblende gneiss, metagabbro; (*c*) quartz-feldspar schist and gneiss, syenite, granite; (*d*) leucogranite, pegmatite, aplite; (*e*) quartzite. This division is based primarily on lithology and composition. Of these rocks, the last group has little importance in connection with the skarns, but occurs at one locality (GUM). Of the other varieties, only the marble will be described in a little detail, since it is closely related to the skarns.

The rocks of the Skarn Series vary widely in composition, as indicated in the Introduction, sometimes within a single specimen. They consist mainly of calcium-bearing silicates with calcite and a few other minerals, and do not show the range of exotic mineralogy found in many younger contact skarns. In spite of variations from point to point, which make them difficult to map, they can be classified on the basis of certain common mineral assemblages as follows: (*a*) scapolite—diopside skarn; (*b*) pyroxenite; (*c*) pink calcite skarn; (*d*) pyroxene syenite, granite, pegmatite; (*e*) fluorite skarn; (*f*) miscellaneous pegmatitic facies. After first discussing the marbles, these skarn types will be described.

Marble

Calcite is the major constituent of the marbles, and is usually white, grey or buff: it may form up to 99 per cent of the rock but is usually in the range 50–90 per cent.

The accompanying minerals are mostly silicates, although dolomite, graphite, sulphides, iron oxides and apatite are also common.

Phlogopite is the most common silicate, forming small amber flakes; in some rocks a colourless mica is also found. Talc, chlorite and serpentine are also common, either as primary metamorphic minerals or, more usually, as alteration products of mafic constituents: they also are abundant in shear zones. Clinopyroxene varies from a dead-white variety, through pale green translucent diopside and salite to darker green ferrosalite: the latter is restricted to hybrid facies, as a rule. Similarly the clinoamphiboles are represented by white and grey tremolite, greenish actinolite and aluminous varieties. Colourless forsterite and orange chondrodite are less common, but usually occur together and are often somewhat serpentinized. Spinel is found in silica-poor marbles, quartz in silica-rich ones, the latter being much more common. Microcline and sodic plagioclase are widespread but are seldom abundant constituents: scapolite is common in some regions. Small amounts of sphene are very common.

The grain size varies from medium to very coarse and textures are usually dominated by the rhombohedral habit of the calcite grains. Banding and layering of silicates or graphite frequently give a clear foliation: with thicker banding the rock becomes less homogeneous and passes into a layered sequence. The thickness of individual marble layers varies from inches to hundreds of feet, and the intervening bands may be amphibolite, biotite gneiss or schist, quartzite, aplite, pegmatite or various other rocks. To what degree these sequences represent sedimentary bedding is often uncertain, not only because some of the interstratified rocks may be intrusions, but also because many marble contacts are tectonic as a result of flowage. Frequently the bands are parallel and show regular dip over wide areas, but elsewhere there has been extensive folding. As the degree of folding becomes more intense, the effects of shearing and flowage are seen (drag-folds, boudinage, axial migration, etc.), and massive bands within the marble break up and "float away." Continued flowage may lead to highly contorted bands of marble between apparently conformable layers of silicate rocks.

Flowage of this kind is presumably deep-seated in origin: surficial shearing commonly leads to the formation of grey seams of fine-grained marble, which are seen in thin section to be mylonites.

Veins and sills of granite, aplite and pegmatite are commonly seen in the marbles. Often there is no sign of contact metamorphism or assimilation and in these cases some of the "sills" of medium-grained rock represent arenaceous sediments. Elsewhere, there are thin zones of contact alteration, and in some cases there is very complex intermingling of pegmatite and marble. Good examples of the latter can be seen in Monmouth township, Ontario, in the road-cuts on Highway 121 just north of the village of Tory Hill.

Scapolite-Diopside Skarn

The principal minerals are scapolite, diopside and sphene. The proportion of the first two minerals varies widely, but averages about 45 per cent each. Sphene forms from 2 to 10 per cent. Among other minerals present are calcite, amphibole, phlogopite, chlorite, quartz, feldspars, epidote, molybdenite and uraninite. The rocks are usually very fresh.

Scapolite occurs in several colours, of which an opaque grey-white and a translucent buff-amber are the most common: pale shades of yellow-green are not uncommon, and a pink-brown glassy variety was found at one locality (Q30, QMI). In thin section the scapolite is usually fresh, with very slight carbonate alteration along the cleavage cracks. The composition varies between Me_{30} and Me_{70}, according to the analyses and refractive index measurements (Tables 3, 5). Pyroxene varies from green to black in hand-specimen, and in thin section is colourless to pale green. The colourless variety has negligible dispersion, but as the colour deepens the dispersion increases: pleochroism however is slight: analyses in Table 6 show the composition to lie in the range diopside—salite. Generally pyroxene is fresh, but alteration to amphibole or chlorite is sometimes found. Depending on the colour of the pyroxene, associated amphibole varies from colourless tremolite (or sometimes pargasite) to a blue-green actinolite. Epidote occurs at some localities, for example Q31B (QMI) shows a complex assemblage of scapolite-epidote-microcline-diopside-phlogopite-calcite, with minor molybdenite and uraninite.

Sphene is the principal accessory constituent, forming brown or red-brown, grains. The nearly total lack of opaque oxides is striking: occasional grains of pyrite are present.

The grain-size is usually coarse to very coarse. Many specimens are quite massive and show no foliation. Others show a sub-parallel alignment of scapolite prisms, and commonly a segregation of pyroxene gives a slight foliation. The texture is usually granoblastic or granulitic, but in some varieties the pyroxene forms subhedral grains enclosed poikiloblastically by scapolite. Sphene often shows euhedral shape and the grains are commonly aligned in strings or trains, conforming to the foliation. However, these strings are usually interstitial to other grains and sphene is seldom enclosed by the other minerals: it is therefore unlikely that this texture is an original one (palimpsest).

These rocks commonly occur in conformable sequences with marble and amphibolites or pyroxenites, and appear therefore to have been derived from the pre-existing series. They are the most widespread of the Skarn Series, and may be found outside the high-grade metamorphic rocks in which most radioactive deposits have been found. For example, they occur in Chandos township, Ontario, to the south of the Haliburton-Hastings Highlands, unaccompanied by pink calcite skarns or radioactivity, and are also well-known in other parts of the world, as will be discussed later. They are nevertheless most typically to be seen in association with the other skarn rocks described here.

Pyroxenite

Rocks consisting mainly of green diopsidic pyroxene have long been known in Quebec and Ontario (and other parts of the world), owing to their common association with mica, apatite and molybdenite deposits. Wilson (1924) proposed that such rocks be called "metamorphic pyroxenites," to distinguish them from igneous varieties.

Pyroxene constitutes more than 80 per cent of these rocks, occurring either as a very pale green sugary granular aggregate, or as a darker green mass of subhedral prismatic grains. In thin section it is colourless or very pale green, non-pleochroic and non-dispersive: the optical characteristics are identical with pyroxene in the scapolitic skarns, and two analyses (Q19DS14 and Q31A, Table 6) show the composition to be diopside. Usually the grains are very fresh, but in some examples there is partial alteration or intergrowth with phlogopite and amphibole, the latter being colourless or pale green. Calcite is usually present, together with a few per cent of feldspars or scapolite, phlogopite and amphibole. Opaque oxides are seldom found, but small amounts of pyrite and sphene may be present.

Textures have already been mentioned: if the proportion of calcite exceeds a few per cent it usually forms a poikiloblastic matrix enclosing subhedral diopside grains. Scapolite behaves in the same way. In one pyroxenite studied (Q34, SL) the diopside showed abundant polysynthetic twinning, bent twin lamellae, fragmented grains and very irregular extinction, all of which indicated considerable shearing. In addition the most highly sheared portions were rich in epidote, biotite and green amphibole, together with a little purple fluorite and uraninite. However, another example which was strongly radioactive is Q73 (GUM), which contains blood-red grains of uranothorite: this rock showed no shearing, but is notable for containing galena in cubes up to 2 cm. wide and a little sphalerite.

The pyroxenites commonly occur in lenses, sheets or tabular bodies conformable with the foliation of associated marbles and scapolitic skarns (*e.g.*, QMI, YUM, GUM, HUM, SDGM, etc.). These range in size from aggregates (segregations ?) a few inches wide and long occurring sporadically in pink calcite skarns (as in some of the HUM exposures) to the tabular body at the north end of the GUM deposit which outcrops over an area measuring 600 × 50 feet, dipping east at 45°.

Pink Calcite Skarn

In these rocks the characteristic constituents are calcite, which usually has a bright salmon-pink colour, green pyroxene and pale brown mica. Less abundant minerals include amphiboles, scapolite, feldspars, quartz, apatite, chondrodite, sphene, opaque oxides, fluorite, allanite and other radioactive minerals.

The salmon-pink colour in calcite is probably caused by the presence of Mn and Fe (see later): in some rocks the colour varies to a pale brown or flesh colour or to white. Since the same colours occur in diamond drill-core, it is not likely that they are of surficial origin. Adjacent to radioactive minerals the pink colour may be either bleached or darkened. Pyroxene closely resembles the variety in the pyroxenites, but is darker when fluorite is abundant (these skarns are considered separately). Colourless tremolite is commonly present but is seldom clearly visible in hand-specimen. Mica forms crystals of translucent amber phlogopite which is nearly colourless in thin section (X, colourless; $Y = Z$, pale straw). The prism faces are very smooth and well-developed, seldom showing the serrated "book-edge" so common with mica. A little colourless mica, presumably muscovite, may be present.

In some facies dark orange chondrodite grains are abundant. Tremolite, forsterite and flesh-coloured calcite are usually present, and the rocks appear to be transitional to normal marbles. Among the minor constituents only the radioactive minerals need be considered here. In most of the other skarn rocks the principal radioactive mineral is uranothorite: although this also occurs here, in reddish-black rounded grains up to 5 mm. wide, thorian uraninite is more common. The latter occurs as black equant grains with submetallic lustre, up to 1 cm. wide. Many grains are euhedral cubes which are almost always twinned on the spinel law. The latter is characteristic of thorium-rich members of the ThO_2–UO_2 series, according to Robinson & Sabina (1955). These authors also give a graph relating the unit cell edge to the Th content: measurement of the cell edge by *x*-ray powder diffraction methods gave a value of 5.55 Å, corresponding to about 50 per cent ThO_2 and 35 per cent U_3O_8. In one deposit (SDGM) local concentrations of up to 10 weight per cent thorianite occur in the skarns.

In addition to thorianite and uranothorite, allanite is also common: specimens rich in radioactive minerals commonly contain some yellow-green secondary uranophane on fracture surfaces.

The grain size is coarse to very coarse: sometimes these rocks are called "calcite pegmatites." The grain size may vary within a hand-specimen, however, and finer-grained patches are common. Calcite is usually interstitial to other minerals, but may also form rhombohedral porphyroblasts, which sometimes are rich in inclusions. The diopside may form sugary granular masses or large subhedral crystals, the two occurring not uncommonly side by side. The coarser-grained rocks may show irregular gneissic banding with alternate bands rich and poor in calcite.

Generally these rocks occur in irregular pockets or pods, enclosed by a variety of other rocks. Larger bodies, such as the Camp Zone at YUM, are conformable to lenticular masses, when adjacent to marble (e.g., HUM, SDGM) gradual transitions may be found. Although transcurrent relations are rarely found, one example occurs at the DOM deposit, where a vein cuts through quartzites. The bodies nevertheless have the irregular shape, variable nature and coarse grain size characteristic of veins, cavity-fillings and replacement deposits. It is probable that their mode of origin includes all three, with flowage effects also, but will be discussed later.

Pyroxene, Syenite, Granite and Pegmatite

This group comprises rocks which in hand-specimen are best classed as syenite, granite or pegmatite. Feldspars, pyroxene and sometimes quartz are the major constituents, and smaller amounts of sphene, zircon and purple fluorite are prominent accessories which are usually evident in hand-specimen. The following minerals are sometimes present: amphibole, epidote, biotite, chlorite, allanite, scapolite, iron oxides, sulphides, apatite, calcite, thorite-uranothorite.

The feldspars include both plagioclase and potash feldspar. In leucocratic rocks both feldspars are usually light-coloured in shades of grey and pink: pyroxene-rich varieties usually have dark brownish-yellow and red feldspars. Potash feldspar usually shows microcline cross-hatched twinning. Some varieties are microperthitic, while others which show wavy extinction are probably cryptoperthite. Variation in $2V$ (see later) suggests that in addition to a triclinic variety, a phase intermediate between triclinic and monoclinic symmetry may be present. The composition of an analyzed specimen recalculates to $Or_{88}Ab_{12}An_0$ (Table 11).

Plagioclase varies between sodic oligoclase and albite, and extinction angle measurements usually show a composition close to $Ab_{85}An_{15}$. An analyzed specimen from the same rock as the analyzed microcline (Q3, CUM) has a composition $Ab_{87}An_9Or_4$ in weight per cent (Table 11) and was shown by *x*-ray methods to be a low temperature modification. Fluid inclusions are common, and the dark shade of red observed in some specimens appears to be caused by abundant minute rod-like opaque inclusions. Peristerite is very common.

Pyroxene is dark green or black and weathers to a grass-green colour. In thin section it is strongly coloured and slightly pleochroic (X, green; Y, yellow-green; Z, yellow or yellow-green), and shows marked dispersion. Analysis of the pyroxene from Q3 (Table 6) shows the composition to lie in the ferrosalite range ($Ca_{47}Mg_{21}Fe_{32}$): other specimens with lighter colour are probably richer in Mg. Irregular compositional variations lead to variable optical properties within grains, as discussed later.

Quartz forms irregular white or grey grains which are commonly rich in planes and zones of fluid inclusions. Fluorite is common and occurs interstitially and as inclusions in pyroxene: it is dark purple in hand specimen but rather mottled in thin section. Sphene and zircon are interstitial and usually show euhedral shape: allanite is also common but forms irregular grains. At one locality (Q69, DOM) there are pegmatitic schlieren rich in euhedral sphene crystals up to 5 cm. wide, platy black allanite crystals up to 5 cm. wide, and black-brown prisms of zircon up to 3 cm. long, doubly terminated with two tetragonal bipyramids. Similar schlieren rich in sphene, allanite and zircon were found at other localities, and are well-known in Ontario (Satterly & Hewitt, 1955).

Amphibole, biotite and chlorite are found in intergrowth with pyroxene and may in part be alteration products. The amphibole is commonly a dark blue-green variety which resembles ferrohastingsite. Opaque constituents include magnetite, ilmenite and pyrite, but the oxides are not common except as minute inclusions in other minerals.

Apart from allanite, the principal radioactive mineral encountered in these rocks is uranothorite. In rocks rich in pyroxene and fluorite it forms grey-brown needles of square cross-section, up to 2 mm. wide and 3 cm. long. In other facies uranothorite forms rounded or irregular grains, varying in colour from translucent yellow, green and orange to blood-red: where fresh the lustre is vitreous. The yellow, green and orange varieties are most common in the schlieren rich in sphene, allanite and zircon, whereas the red material is usually in leucocratic rocks. These minerals were identified on the basis of *x*-ray powder photographs: after heating to restore the structure, the pattern conformed either to huttonite or to uraninite-thorianite plus weak silica lines. It is possible that other minerals may also be present.

The textures are commonly allotriomorphic granular or granitic: however, porphyroblasts of plagioclase, microcline or pyroxene are common. The latter shows a strong tendency to form glomeroporphyroblastic aggregates, often rich in inclusions of fluorite: where these aggregates are distributed in lenticular fashion the rock shows a gneissic foliation. In several cases (e.g., CA44, CUM; Q69, DOM) the presence of prominent undulant extinction and sutured boundaries in quartz, curved and bent twin lamellae in feldspar and mortar texture throughout, testify to cataclastic action.

In the field these pyroxenic rocks are characterized by very variable mode and fabric: some are leucocratic, with only occasional grains of the dark pyroxene, whereas others are melanocratic and consist mostly of pyroxene and fluorite: some are massive and granitic in appearance, others are gneissic or streaky. Similarly their distribution is variable and sporadic, and they are interspersed with more normal granites and gneisses. No regions of extensive outcrop where the rocks were of constant lithology were encountered. They are always found in the vicinity of other skarns or marbles. Individual occurrences often are irregular in shape, but at some localities the bodies are sills or dikes. In these cases the texture is commonly pegmatitic, and a rough zonation may be seen, in which pyroxene is concentrated in the border zone, adjacent to the surrounding gneisses: the core is more leucocratic. Similar relations have been mentioned by Satterly & Hewitt (1955, p. 7).

At one locality (Lot 28, Range VII, Grand Calumet Twp.: CA44, CUM) there is clear evidence of replacement origin. About 1600 feet south-west of the range-line road the country rock on a low hill in the pasture is leucogranite and pegmatite. Steeply-dipping fractures trend at N65°W and N-S and have localized the emplacement of radioactive veins a few inches wide: the veins consist mainly of pyroxene and fluorite and show abrupt contacts with the adjacent granite. The latter, however, is rich in both pyroxene and fluorite for several feet on either side of the veins, the proportion of these minerals decreasing to zero further away. Somewhat similar relations are seen on Lots 38/39, Range V, Egan Twp., Quebec (Maniwaki Kid Uranium Mining Co. Ltd.), where stripping has revealed a mass of leucocratic granite and syenite, overlying a zone of pink calcite skarn. Abundant pyroxene has developed in the granite at the contact. The age relations here are not clear, but the skarn has a vein-like form and in any case it is clear that pyroxene is formed by reaction between the two rocks or related solutions.

Fluorite Skarn

Fluorite has already been mentioned as occurring in several of the rock types discussed. It is, however, convenient to distinguish those rocks in which it is a major constituent. These rocks are of rather diverse mineralogy, texture and mode, but show some distinctive features. After fluorite, the principal minerals are calcite, pyroxene, apatite and scapolite, but other more or less abundant minerals include amphibole, quartz, feldspars, mica, sphene, allanite, dolomite, pyrite, pyrrhotite, uranothorite and uraninite.

Fluorite is dark purple, but fades on long exposure to sunlight: some specimens decolourize completely in a few days but others need years. A strong odour of ozone is emitted when the fresh fluorite is crushed. In the Grenville province these characteristics are always associated with nearby concentrations of radioactivity. Calcite usually has the salmon-pink colour previously described, but local patches may be light brown or grey. These rocks generally resemble closely the pink calcite skarns: pyroxene, however, is richer in iron (see analysis Q87, Table 6) and is green-black in hand-specimen. It shows euhedral habits, dominated by prisms with a single termination consisting of the basal plane and narrow dome faces: this end is adjacent to calcite, whereas the other end is commonly obscured. Apatite is abundant, thereby differing from the pink calcite skarns; it generally forms green prismatic crystals simply terminated with a hexagonal bipyramid, but red varieties are also common in radioactive zones: the red variety is strongly fractured, and all varieties show abundant parting traces oblique to the basal plane. Large crystals, up to 25 by 5 cm. for example, are common in the Matte zone at YUM. Scapolite occurs in at least two varieties. One is deep yellow-brown and occurs in granular aggregates; the other is buff-grey and occurs as crystals up to 15 cm. long by 10 cm. wide, commonly showing tetragonal prisms terminated by bipyramids and sometimes in parallel growth aggregates.

Among the less abundant constituents, amphibole is usually deep green and is associated with pyroxene. Microcline forms pink-white translucent crystals up to 10 cm. long, euhedral on one side only. Plagioclase has not been found in any of the deposits examined by the writer. Allanite is widespread in black plates or wedge-like crystals up to 5 cm. wide. Other radioactive minerals include uranothorite, uraninite, and associated alteration products. Uraninite is not as typical of the Quebec deposits of this kind (it has been identified however, in concentrates) as in Ontario deposits such as the well-known Richardson property near Wilberforce. Uranothorite occurs either as irregular grey-black masses, or as thin (2 mm.) tetragonal crystals up to 2 cm. long: the latter are brown-black and occur as irregular clusters within fluorite grains, often showing a rim of grey-white alteration products. Another alteration product which occurs on joint-surfaces throughout the more radioactive rocks forms scaly yellow-green aggregates; powder-diffraction photographs identify it as uranophane (Gorman & Nuffield, 1955). Uranothorite also forms inclusions in apatite and scapolite. Other minerals present need no further discussion.

As with the other skarn rocks, the mode is variable and cannot be measured by thin section methods. However, a fairly representative figure may be obtained from a mill-test on a 500-lb. sample from the Matte zone, YUM (courtesy Yates Uranium Mines Inc.):

Mode		Assay	
Calcite	45–50 Wt.%	U_3O_8	0.089 Wt.%
Fluorite	25	ThO_2	0.32
Apatite	10	CO_2	20.4
Pyroxene, mica	7	F	15.0
Scapolite	4	P_2O_5	4.49
Quartz, sphene, pyrite, uranothorite	tr	S	0.19

The fabric is dominated by the euhedral tendency of apatite, pyroxene, scapolite, mica and feldspars, and the interstitial matrix of calcite and fluorite. Foliation is commonly seen in the finer-grained matrix, by alternation of bands rich in one or other mineral. The foliation is often sinuous and flows around eyes composed of the euhedral minerals, or of lenticular or subhedral aggregates of fluorite or calcite. In addition to these streamline features, thin sections commonly show cataclastic effects in the calcite and fluorite.

These complex fabric features are, however, only seen in the larger bodies, such as the Matte zone, which forms a tabular, concordant body exposed over a length of 800 feet and about 20 feet thick, dipping west. Most of the occurrences are small pods or lenses a few feet long occurring as "tumours" in gneiss of various kinds. These small bodies often show a zonation, with a core of fluorite and calcite and an outer shell rich in pyroxene, amphibole and sometimes phlogopite.

An interesting pocket of fluorite skarn occurs on Lot 32, Range VIII, Grand Calumet Twp. (CCUM), which is characterized by a very heterogeneous appearance. Inclusions of gneiss are present and the bulk of the deposit consists of pink calcite carrying lenses and streaks rich in fluorite, apatite and a little uranothorite, commonly with thin (1 cm.) zones of buff dolomite between calcite and fluorite: dolomite is otherwise rarely encountered. The original nature of the inclusions is uncertain but they show a zonary reaction with the skarn. One studied in detail has a core (5 cm.) of pink aplite, consisting of fresh microcline, untwinned plagioclase and aggregates of quartz: an aggregate of ferrohastingsite (X, yellow-green; Y, dark green; Z, dark blue) and a few fluorite grains are also present. The ensuing zone is ill-defined but consists of microcline, poikiloblastic scapolite and subhedral grains of salite and sphene. There is no evidence that pyroxene has replaced amphibole, nor that scapolite has replaced plagioclase, but plagioclase is absent. The ensuing zone is waxy green, of medium grain, and about 5 cm. wide. It contains poikiloblastic salite (about 50 per cent), enclosing granular scapolite (40 per cent), quartz, sphene and calcite. Enclosing this zone is a 5 mm. rim of fluorite and apatite, then the main pink calcite-fluorite skarn. These zones appear to represent partial reaction of a granitic (?) inclusion with fluorite skarn and will be referred to later.

Miscellaneous Pegmatitic Facies

Several diverse rocks are grouped together here, characterized by abundant calcic minerals of coarse grain. Several specimens (e.g., CA51, CA83) were mainly composed of sphene, forming red-brown euhedra or irregular masses. Associated minerals were greenish scapolite, calcite, dark green pyroxene, phlogopite and purple fluorite. A few rocks and several diamond drill-core intersections consisted mainly of black lustrous allanite accompanied by calcite, pyroxene and scapolite. Two specimens contained 50 per cent of brown-red garnet, together with scapolite, quartz and minor calcite, oligoclase and pyroxene.

One small deposit (Q26) contained vuggy, radiating groups of scapolite crystals associated with smoky quartz, sphene and pink calcite, and traces of uranothorite. The mass is well exposed, near water's edge on a cliff of granite-gneiss rising out of Otter Lake, Pontiac County, Quebec, and forms a pod 20 feet long which appears to have been completely surrounded by gneiss.

Rocks containing coarse phlogopite are also commonly associated with the skarns. One such deposit is near the Camp Zone (YUM) and consists of large phlogopite crystals set in calcite and associated with a scapolite-diopside skarn. Another at the same property is the Belisle showing, where coarse phlogopite occurs with apatite crystals up to 40 cm. long, in a pink calcite rock which is slightly radioactive. The many phlogopite deposits throughout the Grenville province do not usually show any notable concentration of uranium and thorium, as far as the writer is aware, but they are almost always associated with skarn rocks and must be genetically related.

Transitional Facies

As mentioned earlier, the division of the Skarn Series into different lithological types is not rigid, although it was possible to map them on this basis. Transitional types are, however, common: some have already been mentioned and others will now be discussed.

Scapolite-diopside skarns, pyroxenites, pink calcite skarns and silicated marbles can readily be found which are mineralogically identical, differing only in the proportion of the three minerals and consequently in textures also. These are well-represented on the HUM, SDGM and GUM deposits, and on numerous road-cuts in the vicinity of Tory Hill. Nevertheless it is rare to find an exposure where continuous transitions can be seen; the rock types are somewhat distinct although commonly interbanded.

By contrast all stages of transition between scapolite-diopside skarns and amphibolites can be found at several localities (notably CCUM and along Highway 500 several miles west from Gooderham, ON 31). In the vicinity of the CCUM property there are abundant amphibolites and metagabbros. The former are mainly composed of normal hornblende and plagioclase, with smaller amounts of quartz, biotite, sphene and sometimes opaque oxides and sulphides. Near the radioactive areas these rocks also contain pyroxene and scapolite, and sphene may form up to 10 per cent of the rock. The pyroxene is usually mantled by amphibole, and biotite may be present. Plagioclase is commonly accompanied by scapolite: in some cases the scapolite embays the feldspar and gives the impression of partial replacement, but in other cases the two minerals exist in equant grains, side by side, and appear to have crystallized together in equilibrium. Minor constituents are the same as in the amphibolite, with the addition of calcite and apatite: the latter forms from one to five per cent of the rock as is sometimes the case in gabbros. By increase in scapolite and pyroxene, the rocks become normal skarns.

One or two specimens were seen of rocks intermediate between scapolite-diopside skarn and pyroxene granite. Q24, for example, consists of 30 per cent scapolite, 30 per cent quartz, 20 per cent microcline and 10 per cent pyroxene: the latter was not as dark as in the usual pyroxene granite.

The relationship between scapolite-diopside skarn and fluorite skarn has already been referred to in the case of the zoned inclusions in the latter: also, it is common to find patches of granular scapolite and diopside within the fluorite skarn in the Matte zone.

Pink calcite skarns pass into ordinary marbles by decrease in grain size and change of colour of the calcite. As mentioned previously (SDGM deposit), chondroditic marble may be an intermediate facies in some cases. There are clearly two groups of pink calcite rocks, characterized by the absence or presence of fluorite (and other features already mentioned), but continual transitions are found between them.

Pyroxene syenite and granite skarns pass continuously into fluorite-rich rocks, as mentioned earlier. An example of the relationship between pyroxene granite and pink marble at the Maniwaki Kid property has already been given: another is seen on the range-line road on Lot 12, North Range, Grand Calumet Twp., where an exposure on the contact between the two types can be seen. The major minerals are diopside (altering to actinolite), microcline, quartz, sphene and scapolite, occurring as subhedral crystals in a matrix of flesh-coloured calcite which makes up about half of the rock. The feldspar forms porphyroblasts up to 5 cm. wide and from a distance the surface of the outcrop looks like a conglomerate.

Examples of the transition of the pyroxene syenite and granite into leucogranite, leucopegmatite and gneiss have also been given. A good example of an intermediate facies was found on Lots 24/25, Range VIII, Grand Calumet Twp., where the granite gneiss contains salite but also has abundant biotite and closely resembles the tonalite mass at whose contacts it was found.

Summary of Modes of Occurrence of the Skarn Series

The observations on the distribution, mode of occurrence and origin of the Skarn Series are summarized in the following.

Scapolite-diopside skarns occur

(i) as conformable layers, which may be either beds or segregations, in sequences of marble, pyroxenite and related rocks: the thickness may vary from less than an inch up to many feet, but it is not rare to find rapid alternation of rock type;

(ii) as the product of alteration of amphibolite or metagabbro, this being shown by the presence of partially altered rocks; these occurrences are frequently tabular and conformable also, but not always;
(iii) as granular aggregates within the fluorite skarns.

The first kind may represent simple metamorphism, if it can be shown that all the constituents of the rocks were originally present. This seems unlikely and the alternative of metasomatic replacement must also be considered, as has operated in the second case. In neither case is there evidence of vein deposition, cavity filling or intrusive action, but metamorphic differentiation may have operated.

Pyroxenites occur

(i) as conformable layers in the same sequences as the scapolite-diopside skarns;
(ii) as tabular or lens-like bodies associated with the same rocks but often showing rather sharp contacts;
(iii) as segregated granular aggregates of small dimensions within pink calcite skarns;
(iv) as host rocks for deposits of phlogopite, molybdenite, apatite, galena, sphalerite and radioactive minerals.

The smaller bodies and intercalated layers may have formed by simple metamorphism or by metasomatism, perhaps accompanied by metamorphic differentiation. The larger bodies appear too homogeneous to suggest replacement alone: they might represent original beds of a composition which could yield diopside after metamorphism, or, if they are of replacement origin it seems likely that some subsequent homogenization and recrystallization took place, for most of them are fresh and show no evidence of movement.

Pink calcite skarns occur

(i) as conformable beds or layers within a sequence of marbles and related rocks, showing gradual transition into marble;
(ii) as irregular pockets or lenses in marble, appearing to be segregations;
(iii) similar pockets in other skarns and gneisses;
(iv) as veins or fracture fillings, transecting the structures of adjacent rocks.

It would appear that normal marble is the source rock, and that the four types of occurrence indicate progressively greater degrees of transport of calcite: whether the transport was achieved by diffusion, solution, flowage or melting must be considered later.

Pyroxene syenite and granite skarns occur

(i) as irregular layers, lenses and patches within other granitic rocks or quartz-feldspar gneisses;
(ii) as streaks and zones within apparently intrusive pegmatites of a leucocratic character;
(iii) as pegmatitic schlieren, rich in sphene, zircon and allanite;
(iv) as irregular patches at the contact of quartz-feldspar rocks of various kinds with marble (especially pink calcite skarn); there is usually evidence of intense flowage, brecciation and commingling.

The first category corresponds to metasomatic replacement, in most cases. Interpretation of the second group depends on the age relations, which are seldom clear, but usually suggest an assimilation of inclusions rather than random replacement. The pegmatitic schlieren suggest that local intrusion, vein deposition or cavity filling took place. The last group suggest a diffusional reaction, no doubt aided by marble flowage.

The fluorite skarns occur

(i) as pockets and small lenses in a variety of rocks, but usually in some kind of skarn;
(ii) as segregations in pyroxene syenites;
(iii) as veins and metasomatic replacements in granites: the veins may contain inclusions of partially digested wall rock;
(iv) as tabular bodies of considerable size (thousands of tons), containing segregations of other skarns and commonly possessing gneissic and cataclastic textures indicative of shearing after emplacement.

It is clear that these rocks require introduction of uncommon elements and are in part metasomatic and in part vein and cavity fillings.

In general it should be added that the skarns are usually found in the regions of the Grenville province which have undergone the highest degrees of metamorphism, which are rich in syenitic and granitic migmatites, and are characterized by abundant flowage effects in the marbles and considerable tectonic complexity. At the same time it must be added that the scapolitic rocks are, however, more widespread, and extend into regions of slightly different metamorphic character, e.g., the Hastings Basin (Hewitt, 1956), where radioactive deposits are much less common, and scapolitic rocks of great variety are to be found.

Summary of Mineral Assemblages

To facilitate discussion of the petrology Table 1 presents the mineralogical composition of the principal members of the Grenville Series* and

*Associated granites and pegmatites are here included with the Grenville Series, although they may be in part of igneous origin.

TABLE 1. PRINCIPAL MINERAL ASSEMBLAGES IN THE GRENVILLE SERIES AND THE SKARN SERIES

Rock type	Symbol	pl	mc	q	am	px	bi	ph	ct	sc	fl	sph	ap	op
GRENVILLE SERIES AND ASSOCIATED ROCKS														
Leucogranite, aplite, pegmatite	P	×	×	×										
Quartz-feldspar schist, gneiss, granite	G	×	×	×	(×)		(×)							(×)
Amphibolite, meta-gabbro, hornblende gneiss	A	×		(×)	×	(×)	(×)					(×)	(×)	(×)
Marble	M	(×)	(×)	(×)	(×)	(×)		×	×					
SKARN SERIES														
Scapolite-diopside skarn	I				(×)	×			(×)	×		×		
Pyroxenite	II				(×)	×			(×)					
Pink Calcite skarn	III				(×)	×		×	×					
Pyroxene syenite, granite and pegmatite	IV	×	×	(×)	(×)	×					(×)	×		
Fluorite skarn	V				(×)	×		(×)	×	×	×	(×)	×	

pl plagioclase; mc microcline; q quartz; am amphibole; px pyroxene; bi biotite; ph phlogopite; ct calcite; sc scapolite; fl fluorite; sph sphene; ap apatite; op opaque oxides

of the Skarn Series, together with symbols to summarize them. Only the major minerals and characteristic accessory constituents have been included, and there is no attempt for example to show all the possible marble assemblages that are known to occur. The mark "x" indicates that the mineral is always present, whereas "(x)" indicates that it is sometimes found. The relationships are summarized in Figure 1, where a full line indicates that there is a continuous transition between two rock types, and a dotted line indicates that evidence of continuous transition has not been observed.

Further discussion of these relations will be deferred until after the geochemistry of the minerals has been examined.

The Problem of the Radioactive Minerals

The relationship between the genesis of the skarns and the radioactive minerals they often contain is not clear. Radioactive minerals may occur in all the skarn rocks, but are least common in the scapolite-diopside rocks. Moreover, many radioactive deposits occur in environments where skarn minerals are of minor importance or absent (e.g., Struan Uranium Mines pegmatite on Calumet Island, mentioned earlier and many deposits described by Satterly & Hewitt, 1955, Satterly, 1957, and Shaw, 1958).

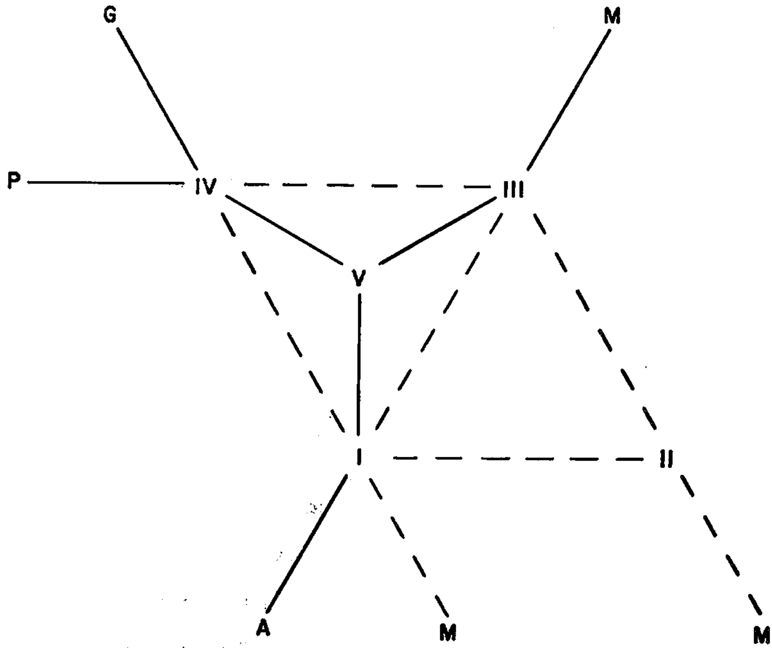

FIG. 1. Assemblage relations between Grenville Series rocks and the Skarn Series. A full line indicates continuous transition, a dotted line is an uncertain transition, while absence of a line between two members indicates no apparent relation. (See Table 1 for meaning of symbols.)

On the other hand the association of minerals which may be weakly radioactive (sphene, zircon, allanite) with uranium-thorium minerals in the pyroxene syenite-granite and fluorite skarns, strongly suggests a common parentage to both the skarn minerals and the U-Th minerals. In other words, it might be expected that the radioactive minerals were deposited by the same solutions which formed pyroxene, fluorite, pink calcite, scapolite, etc. If this were the case, why are radioactive minerals not always associated with skarns?

Further discussion of this paradox will come later. At this point however, the association of radioactivity with sheared rocks should be emphasized. Several samples have already been given (Matte zone, YUM; SL; DOM; Struan property) and many more are given by the authors cited above. In some cases the shearing might post-date the formation of radioactive minerals (e.g., Matte zone), but more usually the fractured rocks localized deposition of the radioactive minerals (e.g., Struan property). However, at several properties there is no evidence of any shearing (e.g., QMI; NML; O'Leary Malartic property, Shaw, 1958, p. 47), and it does not seem possible to entertain a hypothesis that the radioactivy was of substantially later date than the skarns, and occurs within them solely by fracture control. It is of course possible that there were several periods of radioactive mineral deposition, but in the absence of clear evidence this must at present be regarded as unlikely.

References

Adams, F. D. & Barlow, A. E. (1910): Geology of the Haliburton and Bancroft areas. *Geol. Surv. Can., Mem.* **6**.

Dresser, J. A. & Denis, B. T. (1944): Geology of Quebec. *Que. Dept. Mines Geol. Rept.* **20**, (2), 544 pages.

Engel, A. E. J. & Engel, C. G. (1953): Grenville series in the north-west Adirondack Mountains, New York, Part I, general features of the Grenville Series. *Geol. Soc. Am. Bull.* **64**, 1013–1047.

Filby, R. H. (1957): Spectrographic methods for the determination of Na, K and Ca in minerals, and their application to some scapolites. *M.Sc. thesis, McMaster University* (unpublished).

Gorman, D. H. & Nuffield, E. W. (1955): Studies of radioactive compounds: VIII—Uranophane and beta-uranophane. *Am. Mineral.*, **40**, 634–645.

Hewitt, D. F. (1956): The Grenville region of Ontario. *Roy. Soc. Canada Spec. Pub.* **1**.

Lapkowsky, W. W. (1959): Minor elements in some carbonates. *M.Sc. thesis, McMaster University* (unpublished).

Moxham, R. L. (1960): Minor element distribution in some metamorphic pyroxenes. *Can. Mineral.*, **6**, 522–545.

Osborne, F. F. (1956): The Grenville region of Quebec. *Roy. Soc. Canada Spec. Pub.* **1**.

Robinson, S. C. & Sabina, A. P. (1955): Uraninite and thorianite from Ontario and Quebec. *Am. Mineral.*, **40**, 624–633.

Satterly, J. (1957): Radioactive mineral occurrences in the Bancroft area. *Ont. Dept. Mines*, **65**, Part 6 (1956).

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

Shaw, D. M. (1958): Radioactive mineral occurrences of the province of Quebec. *Que. Dept. Mines, Geol. Rept.* **80**.

Wilson, M. E. (1924): Arnprior-Quyon-Maniwaki areas, Ontario and Quebec. *Geol. Surv. Can., Mem.* **136**.

Manuscript received January 29, 1962