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PRELIMINARY STUDY OF MANICOUAGAN STRUCTURE

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MINES BRANCH

GEOLOGICAL EXPLORATION SERVICE

PRELIMINARY STUDY

of

MANICOUAGAN STRUCTURE

PREPARED IN COOPERATION WITH THE GEOLOGICAL SURVEY OF CANADA

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Quebec Department of Natural Resources

and

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Geological Survey of Canada

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QUEBEC DEPARTMENT OF NATURAL RESOURCES

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SAGUENAY COUNTY

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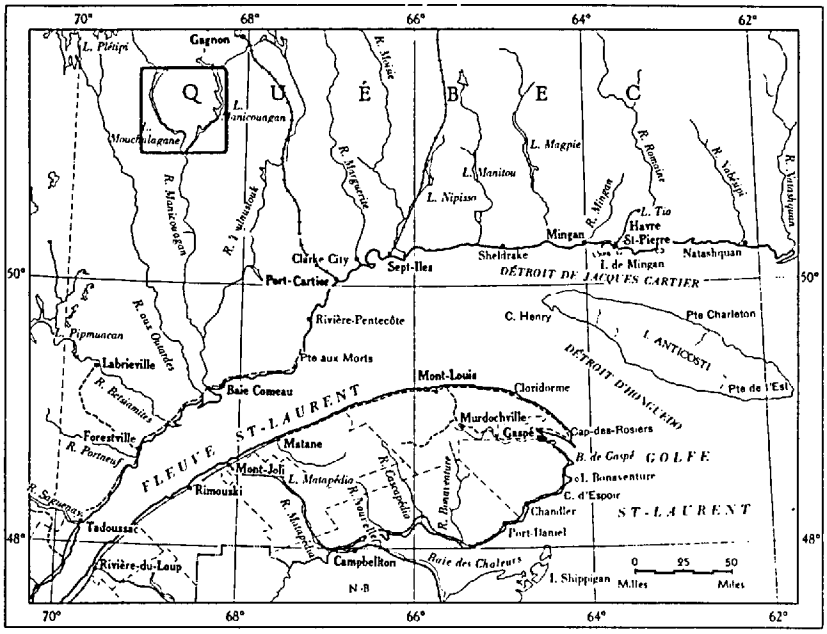

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A PRELIMINARY STUDY

OF THE

MANICOUAGAN STRUCTURE, QUEBEC

by

J.G. Murtaugh* and K.L. Currie**

The Manicouagan structure, a polygonal depression filled with unusual rocks which could be either an extensively reworked impact scar or an aberrant igneous complex, is easily reached by aircraft from Gagnon or Manicouagan, or by boat from Manicouagan. The accompanying map shows the topography and geology as of 1963. Since that time filling of the reservoir behind the high Manicouagan-5 dam has raised the water level above 1,200 feet, submerging much of the outcrop shown on the map. The terrane is rugged and heavily wooded, except the areas more than 2,600 feet above sealevel, these being barren. Outcrop is good on the barren hills and fair elsewhere.

An octogon about 38 miles across defined by Manicouagan and Mouchalagane lakes bounds the most spectacular parts of the structure, but the diameter of the structurally

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disturbed area may exceed 65 miles. The hinterland is underlain by Precambrian rocks cut by narrow curvilinear belts of fracturing. Just inside the deep marginal canyon, largely occupied by Manicouagan and Mouchalagane lakes, is an outer lowland underlain by disturbed Precambrian and Ordovician rocks cut by dikes and pipes of igneous material and brecciated Precambrian rocks. This lowland is locally veneered by thick glaciofluvial deposits. An annular plateau composed of near horizontal sheets of igneous rocks rises several hundred feet above this lowland, locally attaining a width of 10 miles. Between this plateau and the central mountain is a lowland of variable width underlain by igneous material and Precambrian rocks strongly metamorphosed at the time of igneous activity. The central mountain, an altered anorthosite massif, rises abruptly 1,500 feet above the surrounding lowland.

The Precambrian rocks examined (units 1-10) are of amphibolite or granulite grade of metamorphism. Granulite facies rocks (units 1-2) were identified by the presence of honey-yellow or greasy green (antiperthitic) plagioclase and two coexisting pyroxenes (hypersthene and augite).

Granulitic gabbro and anorthositic granulitic gabbro (map-unit 1) form a massif extending east from Manicouagan lake. The rock is a coarse hypidiomorphic aggregate of plagioclase (An_{50-55}), hypersthene, and diopsidic augite. Biotite and amphibole may be present locally (unit 1a), together with green charnockite gneiss and charnockite. The rock varies from igneous-looking gabbro to yellowish, moderately gneissic, strongly lineated rocks. Gneissosity, when present, is roughly parallel to that in the charnockites, but the boundary of the massif cuts across the gneissosity. The massif terminates abruptly just west of Manicouagan lake, possibly by faulting. Vague, linear remnants of sillimanite-bearing gneisses and calc-silicate rocks (b) represent relicts of older metasedimentary rocks. Buff or greenish charnockites (unit 2) are coarsely granoblastic and homogeneous with erratic gneissosity. Subunit 2 (b) is characterized by tabular clots or shiny black biotite on parting planes. Plagioclase (An_{37-43}), perthite hypersthene and diopsidic augite are the essential minerals. Alkali feldspar is present as antiperthite in metamorphosed pegmatite lenses. Quartz and wine-colored garnet are commonly present in minor amounts.

The massive charnockites (2a) grade toward charnockitic rocks with biotite on parting planes (2b) and finally to strongly gneissic rocks with biotite on parting planes and hornblende in place of pyroxene (unit 3). These gneisses may contain lenses or strips of biotite gneiss and granite gneiss.

This hybrid gneiss complex grades rather abruptly to quartz-biotite-feldspar gneisses of Unit 4.

Amphibolite facies metamorphic rocks (units 4 and 6) appear to truncate the granulites east of Manicouagan lake and may represent younger rocks resting on an older basement.

Unit 4 is pale gray, erratically foliated gneiss containing varying amounts of quartz, perthite, plagioclase (An_{22-30}) and biotite (and/or hornblende). Distinctive varietal minerals, such as garnet or (rarely) kyanite and/or sillimanite, are locally present. Gneisses of Unit 4 are characterized by white or gray plagioclase readily distinguished from the honey-yellow plagioclase of the granulites of Map-units 1 and 2.

Granite and granite gneiss (unit 5) comprise fine-grained to medium-grained, commonly alaskitic pink rocks, containing aplitic portions. Biotite and hornblende are the common mafic minerals, but pyroxene is locally present, particularly near the charnockitic rocks (2) southeast of Manicouagan lake. Strongly gneissic and/or lineated margins are common on the granite masses northeast of Manicouagan lake. South of Gabriel river, granite grades to migmatite at the margin of the biotite gneisses.

Recognizable metasedimentary rocks (unit 6) are found as thin lenses along Mouchalagane lake. Iron-formation (6c) consists mostly of grunerite-orthopyroxene-quartz-magnetite rocks, with quartz-magnetite-hematite rocks in the southwest corner of the area. The marbles (6b) are coarse grained, massive, white to blue rocks and generally contain 10 to 50% colorless diopside and/or tremolite. The quartzite (6a) is tough, well bedded, white to gray, and vitreous.

The mafic gneiss complex (map-unit 7) is a dark-colored, coarse-grained, faintly gneissic rock composed of roughly equal amounts of hornblende, plagioclase (An_{27-32}) and orange-red garnet. Along Hart-Jaune and Mouchalagane rivers, it occurs as a margin around anorthosite and gabbro.

Leucocratic anorthosite (map-unit 8) is believed to intrude the granulites and amphibolite-grade gneisses of Map-units 1 to 6 but grade to hornblende-garnet-plagioclase gneiss (7) and interband with it. Anorthosite (map-unit 8) forms the massifs of Mont Brillant and Mont de Babel and occurs as a granulated margin around a coarse-grained anorthosite massif in the Tetepiska Lake area in the southwest corner of the map-area.

These homogeneous, medium-grained white rocks are composed of plagioclase with accessory amounts of diopsidic augite and wine-colored garnet. Hypersthene is rare. Plagioclase from the Tetepiska and Mont Brillant massifs gives An values 52 $\pm$ 5, but plagioclase from chemically and petrographically identical rocks of Mont de Babel gives (anomalous) optical data corresponding to An_{40-45}. Gneissosity in the anorthosite is commonly pronounced, and results from the alignment or lenticular segregation of mafic minerals. Leucocratic anorthosite can be traced from Mont Brillant across Lac du Chaunoy, onto Mont de Babel, and to the mouth of Memory creek. This belt truncates all Precambrian formations to the north and south.

Garnet amphibolite and dunite, troctolite, and pyroxenite (map-unit 9) form a typically coarse-grained, greenish black rock consisting of roughly idiomorphic olivine, pyroxene, hornblende and orange-red garnet, with minor plagioclase. They form small, equant masses or dikes cutting the gneiss complex (4).

Black, fine- to medium-grained dikes (map-unit 10) up to a few meters wide are found intermittently east of Manicouagan lake trending northeast, or north-northwest. They appear very similar to some of the Manicouagan andesite (15), but a whole rock K/A age gives a date of 665 $\pm$ 74 million years.

Ordovician rocks (map-unit 11) are found as tilted and deformed outliers. The number of these fragments is probably large, for they have been discovered in virtually every creek draining into the major lakes from the interior, and probably form a more or less continuous girdle roughly coincident with the outer edge of the Manicouagan Group. Ordovician rocks have not been found in the interior of the structure, and only one outcrop has been found outside the major lakes, near the mouth of Mouchalagane river. In the southern half of the structure, carbonate rocks with rare Precambrian cobbles at the base grade rapidly upward into fossiliferous limestone, whereas farther north sandstone appears at the base of the section. Fossiliferous shales found locally may underlie the carbonates. The total Ordovician section probably does not exceed 75 feet. The fauna is transitional between the 'Arctic Ordovician' and more southerly Ordovician, and is closely correlative with the fauna of Ordovician formations of the Lac Saint-Jean area. In some outcrops the rock is composed of fine recemented fragments, so that at first glance it appears that the rock has not been affected.

Perhaps the most spectacular outcrops in the Manicouagan structure are the altered and reconstituted Precambrian rocks (map-unit 12) commonly found in close association with igneous material. Specimens may contain single or multiple planar features (12a) (deformation lamellae) on quartz and feldspar, kink bands in biotite, partially vitrified, or completely recrystallized quartz, feldspar and amphibole, glass veins, and related phenomena collectively termed 'shock metamorphism'. The mafic minerals are progressively and pseudomorphously converted to hematite (12c). Biotite is most susceptible, followed by hornblende, garnet and pyroxene in that order. Vesicles tend to develop in the hematized mafics (12d), perhaps because a little water is concentrated there. The vesicles begin at pinhead size and range up to irregular cavities more than a centimeter across. In highly vesiculated rocks, vaguely resembling ignimbrites, substantial amounts of brownish glass are present, the felsic minerals are vitrified or recrystallized, and spectacular flow banding may be present, presumably because of the fluidity of the glass. These rocks occur mainly in biotite gneiss, but at this stage the parent rock is unrecognizable. Unit 12c is wide-spread at the base of the igneous sequence (units 14, 15, 16), Units 12a and 12b are less common but still abundant, whereas Unit 12d is a rarity found only as irregular zones a few yards in extent.

Hornfelsed anorthosite (map-unit 12f), common north and east of Mont de Babel, displays a hornfelsic texture preserving original banding and color in some instances. In many cases, the rocks display unusual brecciation, jumbling together fragments of different degrees of recrystallization into a brown to gray aphanitic rock. Hornfelsed anorthosite occurs near igneous contacts and forms an indicator of the presence of igneous rock. Zeolites (12e) are widely developed on Mont de Babel, to a lesser extent on Mont Brillant, and in other Precambrian rocks within the structure. Thomsonite is the principal species in rocks remote from known occurrences of igneous rocks and forms patches of radiating fibers, together with orthoclase, which gives the rock a characteristic pink color. Spectacular occurrences of zeolites are found near igneous rocks on the lower slopes of Mont de Babel. Breccias have been recrystallized into dodecahedra of analcite up to an inch across, with interstices filled by chabasite, thomsonite and possibly other zeolite species. Some parts of the recrystallized anorthosite have been entirely converted to a felted mass of analcite and thomsonite. Maskelynite (unit 12b) (plagioclase glass retaining the crystal shape of plagioclase) is readily recognizable by its vitreous transparent character. The mineral is most abundant on the east peak of Mont de Babel, but is widely distributed in microscopic amounts, in a fashion

not apparently related to structural or compositional features. Maskelynite has not been found outside the structure, but on Mont Brillant the abnormally low birefringence of plagioclase characteristically associated with it is wide-spread. In most occurrences, the degree of conversion of plagioclase to maskelynite is less than 10% in fragments of hand-specimen size, but, on the southeast spur of Mont de Babel, conversion is nearly 100% at several localities.

Pseudotachylyte (pt) typically occurs in vein-like masses reaching a maximum width of 6-8 inches and having an average length to breadth ratio of about 15:1. Round, elliptical and irregular rootless pods are common near the edges of Mont de Babel. Peculiar sinuous or irregular deformation of the veinlets is locally displayed. Pseudotachylyte is found throughout the area between the major lakes, but is best displayed and probably most abundant on Mont de Babel. Three varieties can be distinguished: (a) black or red opaque glass with rare rounded inclusions, (b) pinkish aphanitic matrix with numerous subrounded to subangular inclusions, (c) intensely red anastomosing vein networks, possibly grading to red breccia (map-unit 15c). Pseudotachylyte is best developed in anorthosite and granulite facies rocks. No clear relation to structural features has been established, although many pseudotachylyte veins are found in small breccia zones. Pseudotachylyte is much more abundant in the southern and marginal parts of Mont de Babel than in the northern part.

Breccias with a clastic matrix (map-unit 13) comprise three recognizable map-units. Autochthonous breccias (13a) are found only in canyon-like radial and concentric valleys cutting the inner margin of the structure. They range from rocks fragmented and slightly rotated, but without matrix, to monomict angular breccias with moderate amounts of matrix. Fragment size is generally from 1-10 cm. There appears to be complete gradation from autochthonous breccia (13a) to suevite (13b).

Suevite (map-unit 13b) overlies or cuts basement units with a sharp disconformable contact around the inner margins of the structure. The rock, commonly red, brown or green, is composed of a gritty cataclastic matrix, locally partially melted and filled with assorted angular fragments, which may show plastic deformation. The vast majority of fragments are single crystals, or parts of crystals showing little or no deformation, but a few crystals display degrees of 'shock metamorphism' ranging up to complete vitrification. Brown to black, glassy, streak-like fragments up to a centimeter in length are characteristic. Fragments of a dense glass-rich breccia are seen in many places. Brown glass commonly rims rock fragments,

whereas clear glass is formed around quartz grains. Preliminary searching for glass-rich portions of this material has failed to discover coesite or stishovite. Suevite is found in an intermittent layer from opposite Hart-Jaune river to the Bérard Canyon area, but is rarely seen south of a line from Memory creek to Chastelard river, and has not been found in the interior of the structure. The characteristic mode of occurrence is in lenses up to 80 feet thick and a few hundred feet long, but it is also commonly observed as stacks (on the Precambrian basement (pipes?), dikes, and veinlets in autochthonous breccia (13a).

Ball fracture breccia (unit 13c) occurs exclusively inside the igneous plateau, most commonly in anorthosite. The rock is broken along rather smooth, curved fractures into a characteristic knobby breccia of rounded fragments a few centimeters in dimension. Commonly, little or no matrix is present. These rocks are particularly subject to zeolitization.

Map-unit 14 comprises a rather heterogeneous assemblage of basic and ultrabasic rocks which have in common a jet black color, in many places 'oily', a fine net-fracturing, and an association of very fine and coarse-grained rocks. The most common rocks are coarse, little altered peridotite, aphanitic vesicular, serpentinized picrite of similar composition, and quartz-bearing basalt. Breccias containing both cognate and basement fragments, and with intense hematite staining, commonly surround the occurrences of this unit. Although sheets and pipes of this material are defined in a few places, the geometric shape of many occurrences is obscure.

Trachyandesitic igneous rocks (map-unit 15 and 16) form the bulk of the annular plateau between the outer and inner lowlands of the Manicouagan structure. They are estimated to comprise more than 90% of the volume of the Manicouagan Group. Clear-cut age relations have not been established for the larvikite (16). Very few inclusions of basement rocks are found in it. Sharply gradational contacts with trachyandesite are common, but give no clear-cut evidence of different ages for the two rocks. Age relations relative to the basalt and ultramafics (14) are unknown, but the fractured character of Unit 14 suggests that it is older. The larvikite is a medium- to coarse-grained rock characterized by red-coated pyroxene laths reaching a centimeter in length and giving the rock a red, flecked appearance. Any, or all, of pigeonite, hypersthene and diopsidic augite may be present, commonly strongly corroded. Sanidine commonly rims normally zoned plagioclase (An_{50-26}) laths, but unzoned, unrimmed plagioclase may also be present. Quartz is present intersertally in minor amounts. A few

specimens of the syenodiorite are greasy gray, but most outcrops are reddish or buff owing to oxidation. Coarse-grained igneous rocks have a characteristic rounded outcrop appearance, and areas underlain by them are in many places covered by swamp. Larvikite is found as dikes and sub-horizontal sills near and on Mont de Babel.

Trachyandesite (map-unit 15) commonly underlies syenodiorite (11) with an abruptly gradational contact. Trachyandesite forms cliffs at the edge of the annular plateau where contacts with other formations are well exposed, except with basalt (14). The trachyandesite is black, brown or red, and very fine grained at the Precambrian contact, but grades up to a medium-grained compact rock (15a) distinguished from larvikite (16) by lack of pyroxene laths and a more compact texture. Hypersthene and pigeonite, together with zoned plagioclase laths (An_{45-28}), are the major constituents, with quartz and sanidine present in minor amounts. Inclusions are ubiquitous, generally of the basement, rarely of maskelynite, or other members of the Manicouagan Group. Mainly in rocks near the edge of the plateau, vesiculation is locally present, but sporadic, and is without notable orientation. Many dikes are found throughout the area between the major lakes and composed in many places of pale gray aphanitic to fine-grained rocks with sharply cross-cutting contacts, characterized by finely spherulitic texture, and ranging from 0.5 to 2.0 m. in width. Similar rocks are exposed in places at the base of trachyandesite sheets. Red andesite, either as dikes or sheets, is associated with strong alteration of the basement, in the form of brecciation, hematization and pseudotachylyte, whereas the gray and brown andesite is not normally associated with these effects.

A breccia (15c) is very commonly associated with the base of the trachyandesite sheets, particularly the red variety. The fragments may range from micron size up to huge blocks many meters in length, but in any one occurrence the fragments all appear monomict. This may be in part due to a high degree of alteration and/or shock metamorphism. The matrix ranges from intensely altered fragmental material, with a slight igneous component, to slaggy red aphanite.

Pleistocene material (13) occurs largely in the form of well-bedded lacustrine and fluvial deposits of sand and clay. Lake beds 200-300 feet thick occur along the northern part of Mouchalagane lake. Well-banded, alternating layers of light and dark silt with prominent channelling are most common. Slight amounts of drift are present on the igneous plateau, but drift is not abundant in this region. Post-glacial swamps and soils have developed in the igneous rocks.

Systems of radial and concentric features cut the rocks inside and outside the major lakes. The former are markedly curved and radial near the lakes, but bend to regional trends in a few kilometers. A poorly defined drainage divide some 15 kilometers west of Mouchalagane lake may mark the outer boundary of structural disturbance. The marginal trench largely occupied by Manicouagan and Mouchalagane lakes is composed of markedly linear segments, probably representing faults of substantial displacement. The occurrence of limestones of shelf facies at the bottom of a 2,500-foot canyon suggests downdropping of the interior of the structure. The corners of the structure, at the mouths of Hart-Jaune and Mouchalagane rivers, are complex fault blocks. The structures in the marginal lowland and at the edge of the plateau are complex in the extreme. In Bérard canyon, thrust and normal faults are present together, drag-folds are numerous, and huge blocks of rock have been displaced in very complex fashion. Parts of the rock have been broken up into fragments and recemented into autochthonous breccia (13a). The rapid increase in the number of joints and the change from planar to irregular joint facies are notable in this sector. By contrast, the inner lowland does not show any evidence of major rock movement other than shattering. The peculiar conical features known as shatter cones are abundant but generally poorly developed. Mont de Babel is a notably rectilinear block, and discrepancy in the elevation of the larvikite (16) on the mountain and in the lowland to the south suggests that it is a horst that resulted either from tectonic faulting or readjustment subsequent to extra-terrestrial impact. Within each of the several parts of the Mont de Babel horst the strike of the rocks is continuous and undisturbed.

This investigation suggests the following preliminary conclusions: (1) The Manicouagan structure belongs to that group of equant structures which displays both igneous and shock metamorphic phenomena, including the Clearwater Lakes, Sudbury and Carswell structures in Canada, and the Vredefort ring in South Africa. The geometry of these structures is not that of either a normal igneous complex or an unaltered impact scar. (2) The igneous rocks characterizing the Manicouagan structure are at least partially intrusive. The bulk of these rocks are unusually homogeneous, but very diverse lithologies do occur. The volume of igneous material is very large compared to volume of breccia. (3) Precambrian rocks within the structure are characterized by wide-spread and highly developed "shock metamorphism". Unlike other similar structures, all stages of "shock metamorphism" are found <u>in situ</u>, as well as in fragments of allochthonous breccia.