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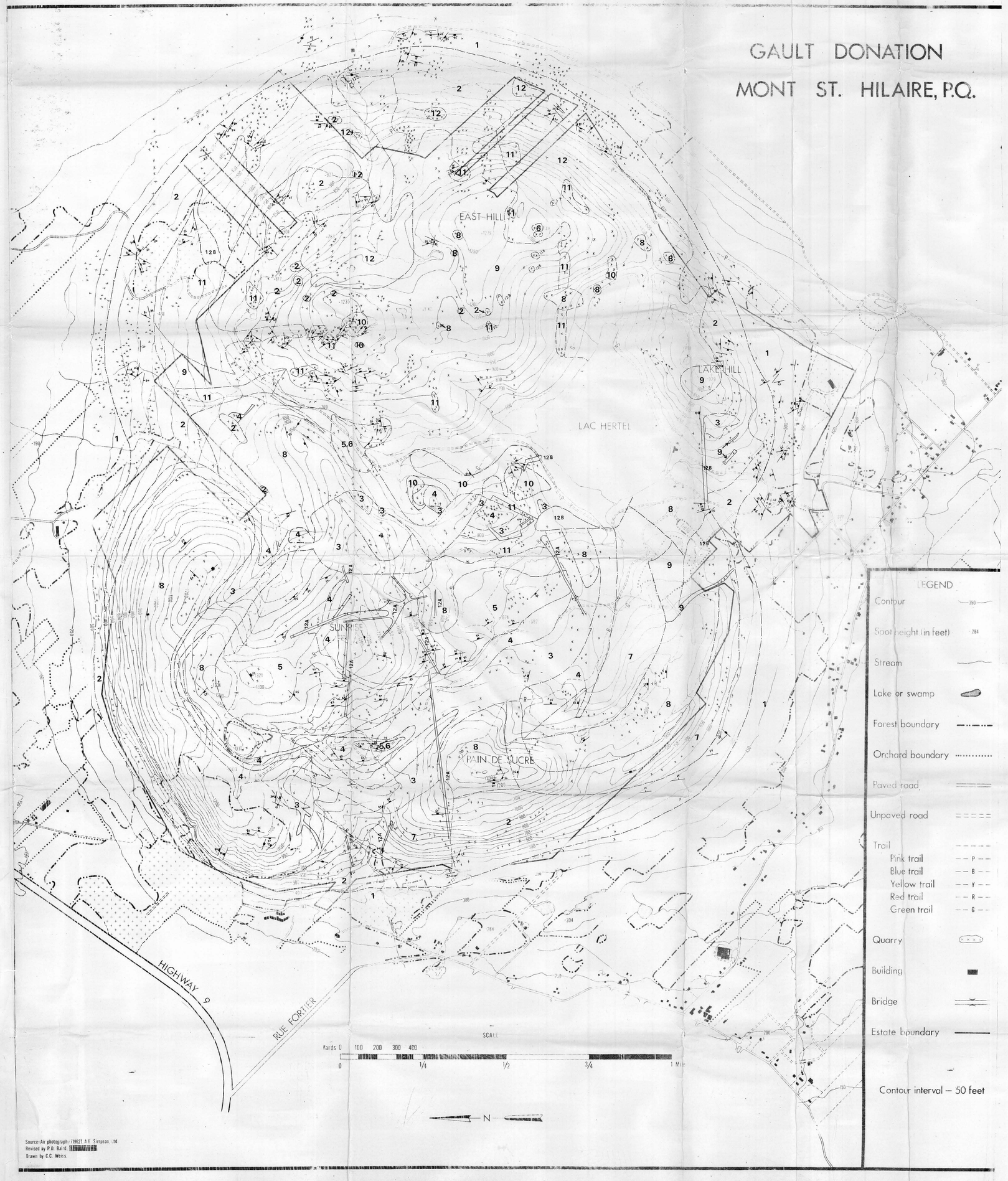
GAULT DONATION

MONT ST. HILAIRE, P.Q.



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Drawn by C.C. Wells.

A GEOLOGICAL MAP OF THE MONT SAINT HILAIRE PLUTON, QUEBEC

INTRODUCTION

Mont Saint Hilaire forms a prominent landmark 30 km east of Montreal, a steep, roughly circular massif about 2 km in diameter which rises 350 m above the surrounding lowlands. The mountain consists of alkaline igneous rocks of the Cretaceous Monteregian petrographic province ranging from gabbroic to dioritic rocks in the west half to peralkaline nepheline syenite and phonolite in the east half. A famous mineral collecting site, the De Mix quarry, from which many beautiful specimens of rare minerals have been recovered, lies on the northeast flank of the mountain. Despite a voluminous mineralogical literature, the geology and petrology of the pluton remain imperfectly known. The whole of the mountain was mapped in 1971-72 at a scale of 1:6000 using the extensive network of paths and systematic east-west traverses at intervals of about 100 m. The present map also incorporates work by H.M. Aarden in 1969-70 (unpublished) and K.C. Rajasekeran (1966), and the petrographic observations are based extensively on Aarden's collections.

GEOLOGY OF THE PLUTON

The Mont Saint Hilaire pluton intrudes calcareous shale, siltstone and limestone of the Upper Ordovician Lorraine and Richmond Groups (Clark, 1955). A hornfels collar varying in width from 10 to 150 m surrounds the pluton. The pronounced valley extending northward from Lac Hertel divides the pluton into a mafic western portion and a salic eastern portion, but mapping shows that the pluton consists of three rather than two, presumably related, suites of rocks. The oldest suite, here termed the Sunrise suite after the prominent hill northwest of Lac Hertel, comprises melanocratic to ultramafic amphibole-bearing rocks which lack olivine, potash feldspar and nepheline. The younger Pain de Sucre suite, which locally intrudes the Sunrise suite, comprises more mesocratic and alkaline rocks ranging from biotite trachygabbro to nepheline diorite. These rocks consistently contain olivine, nepheline and potash feldspar. The East Hill suite, which intrudes the other two consists of leucocratic, peralkaline undersaturated rocks ranging from coarse, sodalite-rich syenite and pegmatite through phonolite to various types of igneous breccias. All the suites exhibit, at least locally, good igneous layering and a remarkable range of textures. Much of the pluton consists of medium-grained massive igneous rock, but indefinite nebulous pegmatitic patches occur in all units, and contacts between units tend to be marked by coarse to pegmatitic zones.

DESCRIPTION OF UNITS

The Ordovician sedimentary rocks (unit 1) surrounding the Mont Saint Hilaire pluton can be examined in quarries northeast of the mountain and in rare outcrops elsewhere. At distances of more than 150 m from the pluton the rocks are undisturbed, more or less horizontal, fissile thin-bedded to medium-bedded calcareous shale and siltstone. In the immediate vicinity of the pluton the sedimentary rocks have been converted to a very tough, homogeneous brownish black to grey hornfels (unit 2). On the western half of the mountain the contact of hornfels and pluton can be examined on steep rock faces. Hornfels tends to dip inward toward the pluton at angles of 15-30°, with local dips as steep as 70°. The contact with the igneous rocks is sharp, but the igneous rocks rarely display chilling, and locally become pegmatitic against the contact. The grade of the hornfels appears no higher than biotite zone on the west side of the pluton. On the east side the grade appears to be albite-chlorite zone, but metasomatic phenomena in the form of arfvedsonite needles and local occurrences of narsarsukite and neptunite occur as far as 300 m from the contact (Rajasekeran, 1966). In thin section all hornfels specimens consist of a fine-grained quartz mosaic with varying amounts of albite, muscovite, chlorite, biotite and calcite.

The hornfels collar contains a bimodal dyke suite of green tinguaite similar to unit 12, and mafic to ultramafic dykes similar to units 3 and 5. Hornfels also occurs as large blocks or enclaves in the complex breccia zones north of Lac Hertel, and as inclusions in the igneous breccias of the East Hill suite. High alkali contents of these inclusions suggest that they have been metasomatized (Rajasekeran, 1966).

The Sunrise suite of the pluton (map units 3-6) outcrops in an elliptical area elongated from northwest to southeast, at a high angle to the east-west axis of the pluton as a whole. The suite underlies an area about 1700 by 1000 m, truncated to the east and southeast by an intricate maze of breccias of the East Hill suite, and elsewhere by the younger ring intrusion of the Pain de Sucre suite. Rocks of the Sunrise suite can be readily recognized by their melanocratic, moderately to strongly foliated, character. With the exception of some rare (cumulate) leucocratic gabbro, the colour index of the suite exceeds 50, and in some cases approaches 90. However very few of the specimens are truly ultramafic (C.I. >90), and the suite is best described as melanocratic gabbro. The most mafic parts of the complex (map unit 3) consist of pyroxene melagabbro grading to jacupirangite (titanaugite-magnetite pyroxenite). Rocks of this type form a continuous fringe around the Sunrise suite, and occur as large inclusions in the East Hill suite. Dikes of similar rocks cut the hornfels collar west of the pluton. In hand specimen the rocks commonly display a felted or trachytoid texture with distinct foliation. They tend to be relatively fine-grained (less than 2 mm) and dark brownish-black in colour, commonly with rusty tinges. In thin section, pyroxene forms tabular euhedra, which in some specimens are cracked or granulated. The mineral exhibits the typical pinkish pleochroism, anomalous bluish extinction and low extinction angle typical of titanaugite. Unzoned plagioclase, commonly in the range An_{65-75} with occasional grains of An_{90} according to the Michel-Levy method, form clusters of interstitial elongate lathes noticeably finer grained than the mafic minerals. Trace amounts of olivine occur in only two of 36 sections examined. An amphibole with distinctive brown pleochrism and the optic properties of kaersutite occurs sparsely as adcumulus overgrowths on pyroxene. Opaques presumed to be titaniferous magnetite, occurs as large euhedra, locally reaching 25 per cent by volume. Apatite euhedra are included in or clumped with opaques. Sphene occurs in large euhedra only in three specimens, all of which appear to be altered with corrosion of pyroxene, loss of the characteristic pink titanaugite colour, and clouding of feldspar. These observations suggest some deuteric reaction, perhaps

$$3\ CaFeTiSiO_6 + \tfrac{1}{2}O_2 = 3\ CaTiSiO_5 + Fe_3O_4$$

Chemical analyses (Currie, 1984) show this unit to be ultrabasic, containing less than 40 per cent SiO_2, more than 5 per cent TiO_2, up to 17 per cent CaO and very high P_2O_5 contents. Presence of fine-grained dikes of similar composition demonstrates that these features corresponded to a liquid, although some of the scatter observed probably results from varying degrees of cumulation of minerals during crystallization of the coarser-grained rocks.

The melagabbro grades by increase in the amount of amphibole into amphibole-pyroxene gabbro with roughly equal amounts of amphibole and pyroxene (unit 4). Such rocks form a more or less continuous fringe between the melanocratic gabbro and the amphibole gabbros of unit 5, and locally form the outer fringe of the Sunrise suite. The rocks tend to be more coarse-grained and less melanocratic than the melanocratic gabbro. Mesoscopic trachytoid or radiating textures with bluish plagioclase lathes up to a cm in length are common. In many specimens poikilitic clots of amphibole can be readily identified in hand specimen. Microscopically, the rocks exhibit euhedra of both titanaugite and kaersutite, but the titanaugite euhedra are surrounded by thick mantles of amphibole, and adcumulus (?) amphibole may form large clots up to several cm across including pyroxene and plagioclase. Plagioclase occurs in euhedral, unzoned lathes. Optical determinations suggest compositions slightly less calcic than the melanocratic gabbro, generally in the range An_{55-65}. A thin selvedge of biotite occurs on some amphibole clots, but biotite is rare. Apatite and titaniferous magnetite occur abundantly, in some specimens forming major components, but overall these minerals are less abundant than in the melanocratic gabbro. Chemically the rocks are ultrabasic (Currie, 1984) with high contents of TiO_2 and P_2O_5, but the Al_2O_3 and Na_2O contents are noticeably higher than in the melanocratic gabbro, and the CaO and MgO contents marginally lower. No dikes of unit 4 were found during this study, so it cannot be positively stated that these analyses represent liquids.

The most spectacular rocks of the Sunrise suite occur among the amphibole gabbros (map unit 5), consisting of plagioclase lathes up to 2 cm in length displaying moderate to perfect alignment, with interstitial coal black amphibole. The most spectacular parts appear on Sunrise hill, but essentially similar, though finer-grained and less perfectly foliated rocks form the core of the Sunrise suite. In outcrop, these rocks appear to be fairly typical gabbro, with roughly equal amounts of plagioclase and mafic, and a pronounced ophitic texture. Microscopically the rocks consist of about equal subordinate augite euhedra rimmed by kaersutite, biotite rims on kaersutite, and magnetite. As with all rocks in this suite, the plagioclase is essentially unzoned, and potash feldspar, nepheline and olivine are absent. Rocks of very similar mineralogy occur commonly as fine-grained dikes in the hornfels west of the Sunrise suite. Chemically the amphibole gabbro resembles other members of the Sunrise suite, although the SiO_2, Al_2O_3 and Na_2O values tend to be slightly higher, and the TiO_2 and MgO values somewhat lower. There are reasonably systematic changes with SiO_2 content, and plots against other variables, such as MgO and CaO, do not significantly reduce the scatter, which probably results from varying degrees of crystal accumulation in the coarse grained rocks. Leucocratic gabbros (map unit 6), similar in all respects to units 4 and 5 except for a content of plagioclase of 70-75 per cent, form mappable lenticles at two places within the Sunrise suite, and smaller lenticles of calcic plagioclase occur throughout the suite. These occurrences appear to represent extreme examples of crystal accumulation, and hence were not analyzed.

The foliation within the Sunrise suite defines a well-marked pattern, dipping inward at shallow to moderate angles in the northern parts of the suite and at steeper angles to the southeast. The pattern suggests a pipe-like feeder to the north of Lac Hertel, with a scoop-like protrusion to the northwest forming much of the presently visible part of the outcrop.

The Pain de Sucre suite (units 7-8), named from the prominent hill west of Lac Hertel, almost completely encircles the Sunrise suite, forming a high-standing outer ring around the western part of the mountain. The Pain de Sucre suite clearly intrudes the older Sunrise suite on the southern slopes of Sunrise hill, and in the valley north of Lac Hertel as evidenced by variously assimilated blocks of the older suite in the younger, and dykes of the Pain de Sucre suite cutting the Sunrise suite. Alteration of the older rocks in the form of large euhedra of alkali feldspar occurs along the contact. However dikes of melanocratic gabbro also cut the Pain de Sucre suite, suggesting that the two magmas may have coexisted at depth. No dikes of the Pain de Sucre suite have been found in the hornfels collar of the intrusion, a remarkable observation considering that almost 50 per cent of the contact is between hornfels and rocks of the Pain de Sucre suite.

The older part of the Pain de Sucre suite consists of biotite trachygabbro (unit 7) exposed along the outer edge of the suite in the southwestern part of Mont Saint Hilaire. These rocks are essentially mesocratic, massive, medium to coarse grained gabbro, distinguished by low colour index from the melanocratic parts of the Sunrise suite, and by the lack of poikilitic amphibole from the more leucocratic members of that suite. In outcrop the unit rarely shows any foliation, which if present is crude and faint. Microscopically the rocks consist of coarse-grained, strongly zoned (from about An_{50-30}) plagioclase with rims of alkali feldspar. Characteristic flesh-coloured titanaugite and biotite occur in about equal amounts as independent but associated euhedral grains, while magnetite and apatite form the principle accessories. Olivine occurs in accessory amount as partly altered granules. Amphibole locally forms thin selvedges on pyroxene. Nepheline does not occur. Chemically the rocks exhibit higher SiO_2 contents than the Sunrise suite, along with higher alkali content and lower TiO_2 and MgO contents. They approach the average alkali gabbro of Nockolds (1954), but because of the presence of alkali feldspar, I prefer the name trachygabbro.

The bulk of the Pain de Sucre suite consists of relatively leucocratic coarse-grained massive rocks containing significant amounts of nepheline and olivine (map unit 8). Traditionally these rocks have been called essexite, or rouvillite in the case of the more nepheline-rich rocks, but the strong objections to these names have been outlined by Gold (1963), and I have elected to term them nepheline diorite and monzonite. In outcrop these rocks are quite variable, ranging from fine-grained to pegmatitic within a few metres. Typically however they are leucocratic, pale grey, coarse-grained rocks with a distinct bluish cast and visible lathes of alkali feldspar. Locally textural variations give a crude, vertical to steeply dipping foliation to the rock, but in general the unit is quite massive. In thin section the rocks are dominated by large tabular feldspar lathes, often radially arranged, passing gradationally from labradoritic cores through about An_{32} to thick potash feldspar rims which may be perthitic. Though separate grains of potash feldspar are rare, the amount of potash feldspar excedes plagioclase in many specimens. Nepheline occurs as large interstitial grains, commonly partly to completely altered to cancrinite. Mafic minerals tend to occur as complex polymineralic aggregates involving olivine, titanaugite, kaersutite and biotite. In most rocks titanaugite appears partially replaced by kaersutite and/or biotite, while olivine, although partially altered, seems not to have reacted with other mafic minerals. Magnetite and apatite occur in accessory amounts associated with the mafic clots. Chemically the unit forms a homogeneous group of analyses (Currie, 1984), like unit 7 but richer in SiO_2 and alkalies and poorer in CaO, FeO and MgO. When plotted on variation diagrams against SiO_2 (Fig. 2), the trends within the Pain de Sucre suite appear to continue those of the Sunrise suite, but with a marked SiO_2 gap from 41 to 47 per cent. The major minerals, with the exception of alkali feldspar and nepheline, resemble those of the Sunrise suite. The reason for the SiO_2 gap is obscure.

Structurally the Pain de Sucre suite appears to have formed a complete steeply dipping ring dike. The portion missing from the southeastern sector can be reconstructed from inclusions in the younger East Hill suite.

The contact between the mafic to intermediate alkaline rocks of the western part of Mont Saint Hilaire and the peralkaline syenites of the eastern part lies in the median valley running north from Lac Hertel, among poorly exposed, complex breccias involving a fragment-charged component (unit 9) which appears to be a hybrid between the mafic alkaline rocks and younger syenites, and a younger suite of diatreme-like breccias which essentially lack igneous matrix (unit 10). The igneous breccia of unit 9 appears to grade continuously into phonolitic to fine-grained syenitic rocks (unit 12). Fragments of phonolite and syenite (units 11, 12) occur locally in the breccias, but elsewhere dikes of tinguaite and sodalite pegmatite clearly cut the breccia. One dike of gabbro 20 m wide, similar to unit 7, cuts breccia north of Lac Hertel. Because of these complex relations, an exact age sequence for the East Hill suite cannot be determined, but all units appear to be of closely similar age.

Igneous breccias (unit 9) form fine-grained to aphanitic rocks in hand specimen, charged with myriads of inclusions best seen on weathered surface. Inclusions may be stretched and contorted along flow banding, and in many cases appear to be disintegrating. The larger inclusions consist exclusively of older mafic alkaline rocks. The matrix locally shows good flow banding, but strong contortion reduces its value for determining structure. In thin section, the matrix consists of trachytoid microlites of sodic plagioclase (albite or oligoclase) charged with minute opaque dust. Pyroxene occurs as equant granules, pale green in rocks most resembling phonolite, and colourless to pale grey in rocks charged with older inclusions. The matrix is charged with cracked and corroded xenocrysts of titanaugite, kaersutite and calcic plagioclase clearly derived from older mafic alkaline rocks. Meaningful chemical analyses from such rocks are difficult to obtain, but one analysis from an unusually homogeneous matrix suggests that it represents slightly hybridized peralkaline phonolite. The high TiO_2, MgO and CaO contents probably result from incorporation of older mafic alkaline rocks either as inclusions or by assimilation. The occurrence of a dike of unit 7 in the breccia suggests that some of the older mafic alkaline rocks remained molten at the time of emplacement of the breccias.

In addition to small inclusions and hybridization, large blocks of mafic alkaline rocks occur as enclaves throughout the igneous breccias, and blocks of phonolite and syenite occur locally. Some of these blocks are readily mappable. Locally the distinction between mafic rocks slightly disrupted by syenitic net veining, and igneous breccia charged with fragments, becomes essentially invisible.

Another phase of brecciation produced rounded fragments of rock densely packed together in a finely granulated matrix (unit 10). This phase of brecciation clearly locally postdates the igneous breccia, for fragments of the latter occur within it. Relations with the peralkaline syenites and phonolites of units 11 and 12 are less clear, as fragments of such rocks are rare in the breccias, and enclaves of breccia locally appear to be invaded by phonolite. The breccia is highly polymict, containing not only fragments of older alkaline rocks up to 30 m across, but also sizeable blocks of hornfels, and even of little altered sedimentary rocks. Gold (1963) pointed out that unaltered limestone blocks within the breccia contain fossil assemblages ranging in age from Lower Ordovician (Trenton) to Devonian (Helderberg), compared to the Late Ordovician age of the host rocks at the present level of exposure. These data show that vigorous vertical mixing must have taken place during the generation and emplacement of the breccias, presumably at rather low temperatures in order to preserve the fossils. Such conditions suggest diatreme-like activity, and lend a certain credibility to the traditional view of Mont Saint Hilaire as an eroded volcanic neck (O'Neill, 1914).

The syenitic rocks of Mont Saint Hilaire can be divided into coarse peralkaline syenites and fine-grained syenite to phonolite. The coarse-grained rocks (unit 11) consist of masses of moderately aligned tabular alkali feldspar lathes with varying proportions of large euhedral nepheline and sodalite, and fine-grained interstitial acmitic pyroxene. Pegmatitic patches and schlieren occur locally, commonly richer in sodalite than the surroundings. Coarse-grained syenite tends to form a kind of fringe around the eastern side of the Mont Saint Hilaire pluton, but the contacts are very poorly exposed, and the relation of these rocks to the other units are not well defined. Inclusions of the coarse-grained syenites occur in the phonolite of unit 12, and well defined, although irregular and discontinuous, dikes of coarse sodalite syenite cut nepheline diorite in the De-Mix quarry. All of the specimens examined contain small but significant amounts of interstitial trachytic matrix similar to unit 12, suggesting that the coarse-grained rocks are cumulates from, or cognate xenoliths of, the phonolite and fine-grained syenite.

Microscopically, the prominent feldspar lathes consist of fine grid perthite, commonly with a thin albitic selvedge. The pyroxene has pale green to cinnamon colour typical of high acmite content. Nepheline and sodalite look very fresh. About half the specimens contain small euhedra of a distinctive orange biotite, probably close to lepidomelane in such peralkaline rocks (Curtis and Currie, 1976). A large variety of exotic Na-rich silicate minerals have been identified optically and by X-ray in one or more specimens, most commonly eudialite, catapleiite, lavenite and astrophyllite.

Three chemical analyses of syenite are given by (Currie, 1984) in Table 1. The analyses show considerable range in SiO_2, MnO, MgO and CaO, causing Rajasekeran (1966) to give the rocks a variety of names (foyaite, litchfieldite, ditroite and others). The variation probably results mainly from cumulation of various minerals combined with variable metasomatism. The "tawite" (sodalite-rich syenite) of O'Neill (1914) represents very local cumulation of sodalite. Field and petrographic examination shows that all these rocks belong to a single unit.

Distinctive olive-coloured fine-grained syenite and phonolite form a large mass east of Lac Hertel (unit 12). Similar rocks occur widely as deep green, fine grained dikes (tinguaites) both in the hornfels collar, and as a radiating swarm in the Sunrise suite. The rocks consist of a fine-grained trachytoid matrix containing large phenocrysts or xenocrysts of feldspar, sodalite and nepheline up to a cm across. Some of these rocks have been termed porphyries by other workers, but most of the large crystals appear to be xenocrysts from older rocks. Polycrystalline inclusions of syenite up to 30 cm across also occur, and the phonolite grades to igneous breccia (unit 9) by increase in the number of inclusions and loss of the characteristic colour. Microscopically the rocks consist of a felted mass of alkali feldspar microlites and granular greenish pyroxene. Some specimens contain small amounts of orange biotite. The same "exotic" Na-rich minerals have been identified in phenocrysts as seen in the coarse-grained rocks. Sodalite, nepheline and natrolite occur interstitially. Large crystals of these minerals are badly cracked, severely altered, and commonly granulated on the edges. They appear to be xenocrysts from slightly older syenites.

Chemically, the phonolites are rather more homogeneous than the syenites (Table 1), with extreme Fe^3/Fe^2 ratios (but no oxide in the mode) and lower Na/K ratios than the syenites. The latter may be due to loss of Na by metasomatism, as suggested by arfvedsonite hornfels and the presence of (metasomatic) sodalite in mafic alkaline rocks in contact with the phonolites. When plotted on variation diagrams the phonolites and syenites show a chemistry distinctly different from that of the older nepheline diorites and monzonites of similar SiO_2 content.

The phonolites exhibit well developed flow banding which converges toward a centre just north of Lac Hertel, that is toward the same region defined by foliation in the mafic rocks. The data would be compatible with a cone sheet type of intrusion dipping inward at angles of 70-80°.

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LEGEND

CRETACEOUS

MONT SAINT HILAIRE PLUTON (units 3-12)

East Hill suite (units 9-12, not necessarily in order of emplacement)

12 Fine-grained nepheline syenite, nepheline syenite porphyry and phonolite with trachytoid feldspar, nepheline and sodalite xenocrysts and phenocrysts; locally contains enclosures of units 3-8 and 11. Grades to unit 9 by increase in proportion of inclusions. 12a- tinguaite and white to grey syenite dykes, 12b- red to purple porphyry dikes.

11 Coarse-grained peralkaline nepheline syenite and pegmatite with feldspar, nepheline and sodalite phenocrysts. Commonly fractured with interstices filled with phonolite.

10 Breccia, predominantly of units 2-8 with minor amounts of 9, 1 and 12. Fragments are well rounded and locally altered. May be significantly younger than other units.

9 Igneous breccia; rounded to contorted fragments and xenocrysts of units 3-12 in a trachytoid, opaque-charged matrix similar to 12.

Pain de Sucre suite (Units 7-8)

8 Nepheline diorite and monzonite; medium to coarse-grained rocks with tabular to granular plagioclase rimmed by alkali feldspar, interstitial nepheline and mafic clots containing titanaugite, kaersutite, biotite and olivine.

7 Biotite trachygabbro; lath-like plagioclase with minor alkali feldspar rims, intergrown titanaugite and biotite, minor olivine and kaersutite.

Sunrise suite (units 3-6)

6 Leucogabbro; labradorite-rich, foliated titanaugite-magnetite gabbro.

5 Amphibole gabbro; strongly foliated coarse-grained rocks with minor titanaugite and biotite.

4 Amphibole-pyroxene gabbro; moderately to weakly foliated granoblastic rocks with sub-equal amounts of kaersutite and titanaugite.

3 Pyroxene melagabbro and jacupirangite; moderately to strongly foliated medium-grained rocks with colour index greater than 60 and abundant magnetite. Minor pyroxenite and perknite.

2 Hornfels and metasomatized hornfels; fine grained to aphanitic grey to black quartz-rich rocks, commonly containing abundant dykes. Locally contain arfvedsonite and/or narsarsukite and neptunite.

ORDOVICIAN

RICHMOND GROUP

1 Calcareous siltstone and shale, siltstone, minor limestone.

Strike and dip of bedding, inclined, tops uncertain.

Strike and dip of igneous foliation, inclined.

Strike and dip of joints, inclined.

Geological contact, defined, approximate.

Geology by K.C. Rajasekeran (1966), H.M. Aarden (1970), K.L. Currie (1971, 1972). Geological compilation and interpretation by K.L. Currie.