THE ORIGIN OF THE HOLLEFORD CRATER BRECCIA*

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Abstract

This paper reports the results of a petrographic and geochemical study undertaken to evaluate the possibility that the polymict breccia discovered in drill core from Holleford, Ontario, is the product of meteorite impact. The breccia lies in a bowl-shaped depression on the Proterozoic (Grenville) land surface and is overlain by Palaeozoic rocks. The coarse fragmental constituents have been derived from the Proterozoic rather than the Palaeozoic rocks. The arenaceous fraction of the breccia exhibits a very limited variety of mineral constituents, wholly of local derivation, and grain forms which indicate little or no transportation. Clay minerals from the matrix of the breccia are typical of normal sediments. No meteoritic materials have been identified microscopically and the nickel content of the breccia is only slightly above average for sedimentary rocks. The bowl-shaped form of the breccia, as indicated by diamond drilling and geophysical data reported by Beals (1958), is the principal criteria favouring genesis by meteorite impact. Other data neither refute nor confirm this hypothesis.

Introduction

The Holleford Crater is approximately 16 miles north of Kingston, Ontario, in latitude 44° 27′ north and longitude 76° 38′ west (*see* Fig. 1). The characteristic circular depression was first recognized as the result of a systematic search of aerial photographs Beals *et al.* (1956), (Fig. 4). A comprehensive study of the structure, directed by C. S. Beals† included three diamond drill holes. The borings penetrated successively Palaeozoic limestone, consolidated breccia (Figs. 2, 3), and Grenville lime silicate rocks and gneisses. Specimens from the drill cores were provided for use in the present study.

The profile in the section of the drill holes (Fig. 5) suggests that the breccia lies in a basin-shaped depression on the surface of the Proterozoic rocks and is overlain by undisturbed Palaeozoic rocks. Geophysical studies corroborate the shape of the breccia.

This study was made to determine, if possible, the genesis of the breccia and particularly to evaluate the possibility that it is the product of meteorite impact. The study comprised: (1) comparison of the petrology of the breccia with that of the surrounding rocks, to discover whether the breccia may have been derived from one or more of these; (2) identi-

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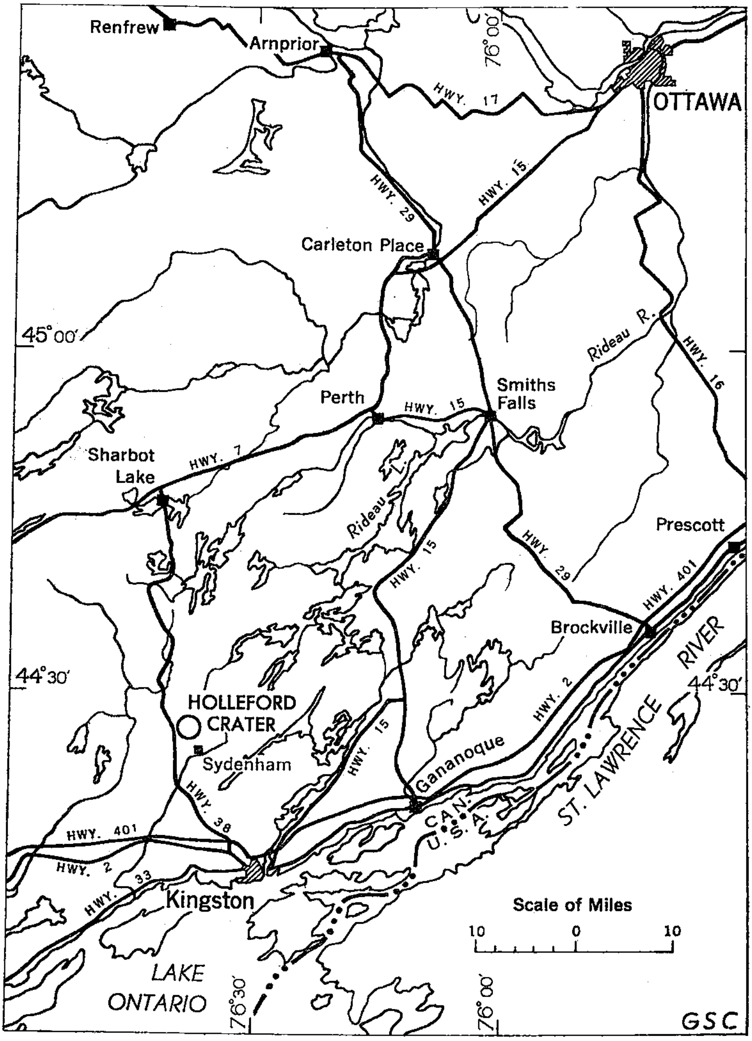
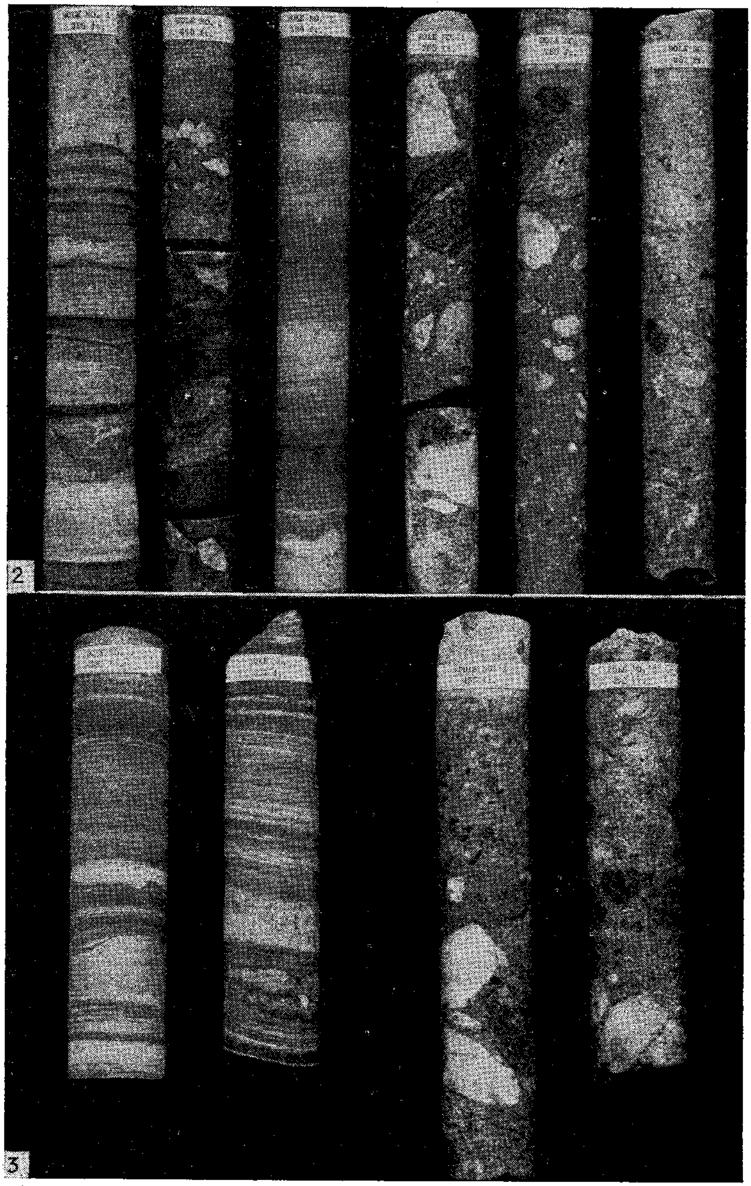


FIG. 1. Index map of Eastern Ontario showing the location of the Holleford Crater.

fication of the clay minerals in the matrix as an aid in deciphering the paragenesis; (3) interpretation of the transport mechanism of the breccia from the shape of the fragments; (4) comparison of suites of heavy minerals; (5) comparison of the nickel content of the breccia and other rocks; (6) comparison of properties of this breccia with equivalent properties of breccias of known origin.



FIGS. 2 AND 3. Photographs of drill core from holes 1 and 2 showing from left to right the interbedded shale and sandstone and the underlying breccia.

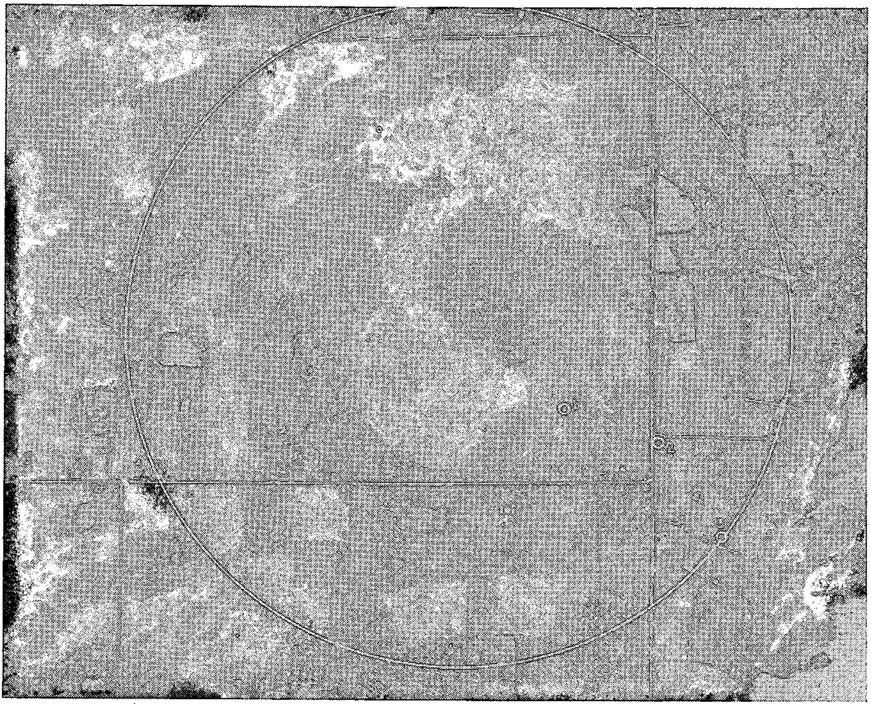


FIG. 4. A vertical aerial photograph showing the outline of the crater and the sites of the three drill holes.

SPECIMENS FROM THE HOLLEFORD CORE

Drill Hole No. 1

Footage	Remarks
616	Palaeozoic sandstone with thin shale partings. Both the sandstone and the shale are geen in colour due to their high content of clinopyroxene.
690	Palaeozoic monomict breccia derived from the green sandstone and shale and interbedded with the former.
730	Palaeozoic green sandstone with shale interbeds, and graded bedding.
765	Polymict breccia with arenaceous green matrix and angular fragments of biotite gneiss and granite. Most fragments less than 2 inches in diameter.
780	Polymict breccia with fragments of gneisses embedded in a green arenaceous matrix.
861	Polymict breccia. The breccia is made up of white to black angular fragments varying in size from 1 inch down. The matrix is green, fine-grained, porous sand, which consists of fragments of clinopyroxene, potash feldspar, biotite flakes, and quartz cemented by mica-illite, and kaolinite. No primary structures were observed.
909	Polymict breccia. The breccia consists of angular fragments of biotite gneiss and granite in a friable green sand matrix. The matrix consists of fresh fragments of potash feldspar, plagioclase, clinopyroxene, quartz, hornblende, and biotite cemented by mica-illite and kaolinite. No primary structures observed.

952 Polymict breccia. The fragments include angular pieces of gneiss, granite, and marble. The matrix is friable, green, fine-grained sand consisting of brown mica flakes, and fragments of quartz, clinopyroxene, and feldspar cemented by mica-illite and chlorite. No suggestive structures observed.

957 Polymict breccia. The fragments include altered gneiss and quartz grains. The matrix is a green, friable sand consisting of grains of potash feldspar, quartz, plagioclase, clinopyroxene, biotite, chlorite, and calcite cemented by mica-illite and kaolinite.

1035 Polymict breccia. The angular fragments consist of leucocratic gneiss and lime silicate rocks. The matrix is a mottled green, friable sand consisting of clinopyroxene and minor calcite.

1120 Polymict breccia. The fragments are mainly pieces of leucocratic gneiss. The matrix is a structureless friable, green sand consisting of fragments of potash feldspar, clinopyroxene, and plagioclase with accessory quartz, sphene, and calcite.

1128 Lime silicate rocks. The rock is characterized by white and green bandings. No fragments or evidence of brecciation has been detected. In thin section the rock is seen to consist mainly of inequigranular aggregate of potash feldspar, quartz, and clinopyroxene with accessory pyrite, sphene, and calcite.

Drill Hole No. 2

269 Calcareous sandstone. This is grey, fine-grained sandstone with disseminated fragments of carbonaceous material. Bedding is weakly developed. The major constituents, quartz, and potash feldspar, are cemented by calcite. Shell fragments, and disseminated accessory grains of magnetite are also present.

354 Calcareous sandstone. The stone is grey, fine-grained with alternating beds of sandy and argillaceous material. Quartz, plagioclase, and potash feldspar, the major constituents, are cemented by calcite. Accessory amounts of carbonaceous material, iron ores, and apatite are disseminated through the thin section.

384 Sandstone. This rock is characterized by alternating well-sorted, fine- and very fine-grained sand weakly cemented by calcite and clay. Organic fragments are present. Quartz is the major salic constituent in the fine-grained beds and it is associated with accessory biotite and magnetite.

429 Coarse-grained sandstone. Very friable, coarse-grained rock, green in colour and without apparent bedding. Calcite and clinopyroxene grains are abundant and hematite dust is disseminated through the thin section.

432 Polymict breccia. The breccia consists of angular fragments from 2 inches down which include pieces of amphibolite, lime silicate rock embedded in a massive matrix. The matrix consists of clinopyroxene, carbonate, quartz, biotite, microperthite and potash feldspar grains cemented by montmorillonite, mica-illite, kaolinite, and talc.

438 Polymict breccia. The breccia consists of fragments of biotite gneiss and lime silicate rocks from 2 inches down embedded in a friable matrix of clinopyroxene, quartz, and biotite. The clay fraction consists of montmorillonite, kaolinite, mica-illite, and talc.

455 Polymict breccia. The breccia consists of fine-grained fragments ($<1''$) of granite, lime silicate rocks, and mineral fragments. The matrix is a friable aggregate of plagioclase, quartz, clinopyroxene, biotite, and chlorite with disseminated calcite. The clay fraction consists of montmorillonite, mica-illite, and talc.

466 Biotite gneiss. A fragment of this rock occurs in the breccia at this point. The rock consists mainly of biotite, quartz, and feldspar with accessory potash feldspar and perthite, apatite, and magnetite.

484 Polymict breccia. The fragments consist mainly of biotite gneiss and lime silicate rocks. The matrix is a friable, green sand consisting of plagioclase, quartz, clinopyroxene, and biotite. The clay fraction consists of montmorillonite, mica-illite, kaolinite, and talc.

490 Pyroxene gneiss. Specimen taken from the breccia. Massive rock which consists mainly of clinopyroxene grains in granitoid texture with minor quartz, plagioclase, tremolite, and chlorite.

513 Biotite gneiss. Fragment from the breccia. The gneiss is a granular foliated aggregate of biotite, pyroxene, quartz, and feldspar. The quartz, which is the major constituent, is somewhat fractured. Mineral banding has been developed. Accessory apatite and magnetite are present.

534 Biotite, pyroxene gneiss. The gneiss is melanocratic with a weak orientation due to the mica flakes and some white and green veinlets. Biotite, quartz, plagioclase, and clinopyroxene are the major constituents. Grains of magnetite are sparsely disseminated through the thin section.

538 Pegmatitic gabbro. Mainly coarse-grained clinopyroxene partly replaced by biotite and hornblende. Minor interstitial plagioclase and microperthite grains occur with disseminated accessory pyrite and a few calcite veinlets.

557 Lime silicate rocks. This rock is massive, and variable in colour from white to green. Clinopyroxene is the dominant constituent with accessory disseminated plagioclase, quartz, potash feldspar, sphene, calcite, and magnetite.

572 Lime silicate rock. The rock is white, fine-grained with disseminated grains of pyrite.

611 Muscovite gneiss. This rock is characterized by strong foliation due to abundant oriented flakes of muscovite.

675 Breccia. The breccia is characterized by white fragments embedded in a green matrix. Calcite is a major constituent with accessory pyrite.

750 Lime silicate rock. This rock is white and is partly kaolinitized. Some quartz veins are present and clinopyroxene is the major constituent.

771 Crystalline limestone. The rock consists mainly of calcite, lime silicates, with disseminated pyrite. There is no evidence of bedding or brecciation.

840 Lime silicate rocks. The rock is weakly consolidated and consists mainly of clinopyroxene. Accessory disseminated quartz is present.

883 Biotite gneiss. The specimen is very friable. Biotite, perthite, potash feldspar, hornblende occur with accessory garnet and magnetite.

1060 Biotite pyroxene gneiss. This gneiss exhibits crude mineralogical banding. Clinopyroxene and biotite are abundant. Minor quartz and accessory pyrite are also present.

1325 Lamprophyre. This rock is black and very fine-grained. Biotite, pyroxene, plagioclase, and quartz have been identified.

Drill Hole No. 3

64 Monomict breccia. The breccia consists of rounded fragments of white granite embedded in a black, fine-grained calcite and clay matrix.

65 Limestone. The rock is fine-grained, grey-coloured, with black styoliths and some white indistinguishable fragments. The limestone has been identified as Palaeozoic. Shell debris is present and some recrystallized areas of clear calcite.

78 Marble. The marble is a fine-grained, massive rock which varies in colour from white to green. No primary structures have been detected. Calcite is the dominant constituent. Talc and mica have also been identified.

123 Lime silicate rocks. This rock consists of coarse-grained, pale green clinopyroxene and minor calcite.

144 Impure talc. The rock is massive, very fine-grained, and without primary structures. The specimen has a soapy feel.

160 Lime silicate rock. This rock is massive with fine-grained, green bands and some white crystals.

210 Biotite hornblende gneiss. The rock is dark-coloured, foliated, unbrecciated, and with interbedded mafics and salics. Biotite, hornblende quartz, and plagioclase have been identified in it.

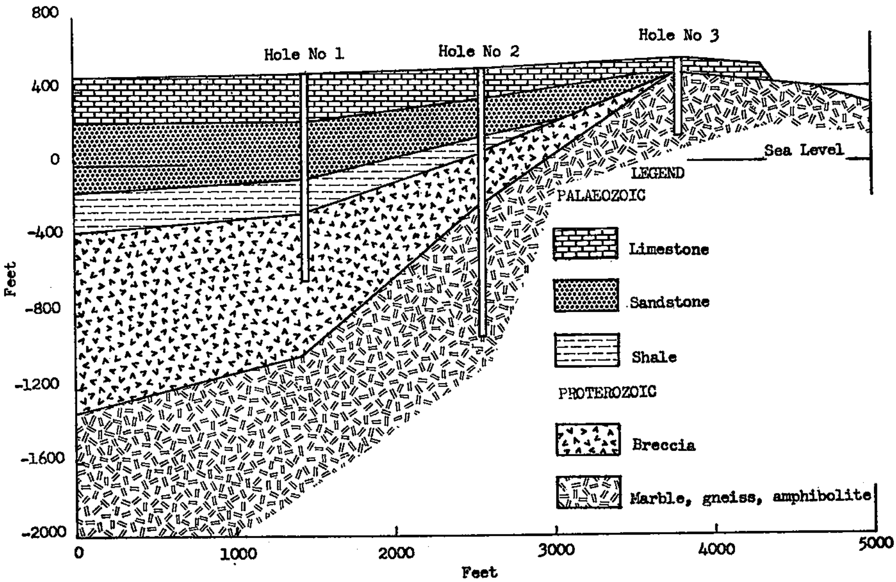


FIG. 5. A vertical section drawn through the three drill holes.

310 Gabbro. The gabbro is a melanocratic rock with weakly developed mineralogical banding. The primary pyroxene has been replaced by chlorite. Plagioclase is the most abundant salic mineral. Quartz, biotite, calcite, and potash feldspar are present.

325 Biotite hornblende gneiss. The gneiss is weakly foliated and unbrecciated. Plagioclase, biotite, and hornblende are the main constituents.

354 Amphibolite. The amphibolite is black, fine-grained, and structureless rock. Hornblende and plagioclase are the dominant constituents and quartz, biotite, chlorite, and garnet are also present.

SURROUNDING ROCKS

The overlying Palaeozoic rocks are mainly well bedded, fine- to very fine-grained, buff to grey limestones and siltstones. These are underlain immediately above the breccia by interbedded thin strata of sandstone and limy shale. The heavy mineral concentrates from this sandstone contained 50 to 59 per cent clinopyroxene, 10 to 19 per cent biotite and pyrite; and from 0 to 9 per cent garnet, magnetite, hornblende, and sphene, and one sample from the limy shale 70 to 79 per cent clinopyroxene, 10 to 19 per cent biotite; and 0 to 9 per cent garnet, magnetite, pyrite, hornblende, and sphene. This suggests derivation from nearby lime-silicate rocks and amphibolites. The overlying limestone is locally fossiliferous and by all criteria is a normal sedimentary rock which has not been metamorphosed or brecciated.

The surrounding Precambrian rocks include lime silicate rocks, gneisses, amphibolite, and pegmatitic gabbro. The lime silicate rocks vary from pale green to grey in colour. Most specimens are massive but a few showed relict bedding. They vary in grain size from medium-coarse to fine-grained. Clinopyroxene and quartz are the most widespread constituents and calcite occurs less commonly. Potash feldspar and plagioclase were identified in a few specimens as minor constituents. Pyrite, sphene, talc, and biotite or phlogopite are the usual accessory constituents. The mineralogy of these rocks is simple and is not characterized by an unusual variety of heavy minerals.

Specimens of the gneisses were examined both in hand specimens and thin sections. The colour varies from grey to white and the grain size from medium-coarse to fine-grain. Some exhibit mineral banding and variable composition. The most widespread constituents are biotite, quartz, plagioclase, and less widespread hornblende, potash feldspar, clinopyroxene, muscovite, and accessory pyrite, magnetite, garnet, calcite, and apatite. Biotite-, clinopyroxene-, and hornblende-rich bands alternate with quartz- and plagioclase-rich bands. These rocks are characterized by a wider variety of heavy minerals than the lime-silicate rocks.

The amphibolites are commonly black, medium-coarse to fine-grained rocks which vary from massive to weakly banded and foliated rocks. They consist of hornblende, biotite, plagioclase, quartz, chlorite, and potash feldspar. Garnet has been identified as an accessory constituent. These rocks are also characterized by a moderately large heavy mineral suite.

One specimen of pegmatitic gabbro was also prepared as a thin section. The rock is coarse-grained and is composed mainly of clinopyroxene and minor quartz and plagioclase, potash feldspar in microperthite, and accessory pyrite and calcite.

The Breccia

Megascopic Description

The breccia is polymict with a variety of rock fragments including lime silicate rocks, micaceous gneiss, and amphibolite contained in a fine-grained matrix (Fig. 2, 3). No fragments of the Palaeozoic sedimentary rocks are present and the rock fragments seem to be randomly distributed. The angular fragments vary in size up to a few inches.

The matrix, which is dark green, is medium-grained and poorly sorted. Its weak cement allows some samples to be crushed with the fingers. It contains identifiable grains of the various rock varieties as well as quartz, calcite, and earthy white grains. One specimen of the 24 examined showed evidence of crude bedding.

Microscopic Description

Examination of the breccia in thin sections confirmed the identity of the rock species present as fragments and as bedrock from the surrounding terrain. Plagioclase, potash feldspar, calcite, quartz, biotite, clinopyroxene are usually present in the matrix. The coarse mineral grains show no evidence of rounding or frosting but are either cleavage or angular fragments. The clinopyroxene varies from colourless to white cleavage fragments with hackly ends. No evidence of secondary growth has been observed on any of the minerals identified. For example neither the quartz nor the plagioclase fragments exhibit peripheral zones. Hornblende, chlorite, sphene, and hematite are present as accessory constituents.

Clay Minerals

The matrix of the breccia was carefully crushed and the coarser fragments were hand-picked to concentrate the matrix. The concentrate was finely ground and submitted to the Mineralogy Section where the micaceous constituents were mounted on glass slides for *x*-ray diffraction identification. Abundant montmorillonite and mica-illite with lesser quantities of kaolinite, talc, calcite, quartz, feldspar, and amphibole were found. All of these occur in normal sedimentary rocks (Pettijohn, 1949, p. 105).

Heavy Mineral Suites

The Breccia

Another part of the matrix was crushed, sieved, and treated with acetylene tetrabromide to obtain heavy mineral concentrates. Specimen No. 1-957 contained 18.0 per cent, No. 2-466 contained 43.0 per cent, and No. 1-780 contained 12.0 per cent heavy minerals respectively. The suite of heavy minerals was studied optically and was found to consist of clinopyroxene, minor mica, and amphibole. Also present were sphene, pyrite, chlorite, and fluorescing calcite. The mica is either brown biotite or yellowish-brown phlogopite. The amphibole is a pale green actinolite.

The suite of minerals is characterized by a smaller variety than might be expected from a large area of highly metamorphosed gneisses. The minerals have not been rounded by transportation or altered by weathering and lack secondary rims. The clinopyroxene is usually prismatic and occurs as colourless to white cleavage fragments with hackly ends. The mica is mainly ribbon type phlogopite with a few flakes of dark brown biotite. The amphibole is hornblende. The accessory sphene is characteristic of the heavy concentrates and its identity has been confirmed by *x*-ray diffraction. Angular fragments of pyrite and in yellow fluorescing calcite are accessory constituents of most concentrates.

Surrounding Rocks

Specimens of these rocks have been crushed to 100-mesh size for heavy liquid concentrate treatment of the accessory heavy minerals. Two of these were lime-silicate rocks, one an amphibolite, and the fourth a micaceous gneiss.

Heavy mineral concentrates from the lime-silicate rocks consist of clinopyroxene, calcite, sphene, pyrite, and muscovite. The amphibolite concentrate consists of green hornblende, brown biotite, pyrite, and apatite, whereas the gneiss concentrate consists of phlogopite, pale green amphibole, pyrite, and apatite.

These results suggest that the breccia matrix was derived from the lime silicates beneath the structure. The fluorescing calcite is present both in the matrix and in the lime-silicate rocks studied. The strong similarity between the suites is indicative of a common origin.

Nickel Analyses

Five samples of the drill core were crushed in a jaw crusher, pulverized in a ceramic disc pulverizer, and split into two fractions each. The magnetic constituents were removed by hand magnet from both fractions. One residue was treated in a Carpco separator set at 0.05 amp. and the second was treated on the Haultain superpanner. The hand-magnetic fractions have been combined and three concentrates per specimen; the hand-magnetic concentrate, Carpco, and superpanner concentrates have been analyzed spectrographically for their nickel content. The results for the hand-magnet concentrate have been corrected by the subtraction of a blank consisting of filings from the jaw crusher combined with three parts of G-1 standard.

Specimens 1348 and 1349, which are abnormally magnetic lengths of core from drill holes 1 and 2 respectively, were collected from the breccia and the underlying rocks. Samples 1350, 1353, and 1354 inclusive consist of 6-inch lengths of core cut every 5 feet across selected lengths of core. Specimen 1350, which was collected between 739 and 751 feet in

Table 1. Spectrographic Analyses of Drill Core Specimens for Nickel

	No. 1348, Ni		No. 1349, Ni		No. 1350, Ni		No. 1353, Ni		No. 1354, Ni	
	gm.	ppm	gm	ppm	gm.	ppm	gm.	ppm	gm.	ppm
Spec. wt. concentrate	3484.0		3454.0		3500.0		7884.0		6332.0	
Hand magnet	1.7	200*	2.1	200	2.4	200	2.1	200	2.8	200
Carpco	0.5	500	2.6	500	11.7	100	2.4	500	35.0	−100
Superpanner	20.2	700	26.5	700	18.2	500	20.9	800	28.0	600

Analyst W.H. Champ.

*The hand-magnet concentrates have been reduced by the blank value 600 ppm.

TABLE 2. COMPARISON OF THE MAIN CRITERIA FOR THE IDENTIFICATION OF MANY COMMON VARIETIES OF BRECCIA

Type	Rock fragment characteristics: Size range	Shape	Roundness	Markings	Lithology	Fabric	Packing	Matrix	Underlying surface	Bedding	Form
Intraformational breccia	Limited	Tabular	Angular	Nil	Local derivation, limited	Heterogeneous unoriented	Slight	Mud with coal fragments	Undisturbed beds	Thin conformable horizon	Tabular
Orthoquartzite breccia	1 inch or less	Well-rounded	Rounded	Nil	Quartz, chert, vein quartz in quartz sand	Unoriented	Variable	Quartz sand silica cement	Conformable or not	Poor	Tabular or thin lenses
Polymict conglomerate	Sand+pebbles +cobbles	Well-rounded	Well-rounded	Nil	Wide variety rock types	Unoriented	Variable	Quartz or feldspar sand wide variety of cements	Conformable	Variable, locally present in sandy parts	Lenses or wedges
Tillite	Mainly clay+ fragmental material all sizes	Angular to subangular facetted	Subangular	Striae on facets	Wide variety	Locally oriented parallel ice flow	Variable	Clay size rock flour	Unconformable polished and striated	Unstratified & unsorted	Tabular sheets
Scree (fossil)	Very coarse grain size, variable	Angular	Angular	Nil	Cognate limited	Unoriented heterogeneous	Poor	Small fragments with various cements	Unconformable	Unstratified	Wedge shaped bodies
Outwash fan gravel	+2mm. to cobbles	Rounded	Rounded	Variable depending on rock type and transportation mode	Highly variable	Imbricate structure	Poor	Sand and a variety of cements	Conformable or not	Gross scale good, or none	Wedge shape, lense, channel fillings
Volcanic breccia	Wide	Angular to rounded	Angular to rounded	Round fragments vesicular and ropy on exterior	Cognate or non-cognate, glass	Unoriented	Variable	Mud or tuff volcanic origin	Discordant diatreme or volcanic neck	Unstratified	Tabular sheets, or cones or cylinders
Cataclastic breccia	Wide	Tabular to flattened ellipses	Subangular	Slicken-sided	Cognate or non-cognate	Oriented	Variable	Gouge or shaly material	Unconformable or not, slicken-sided	Unstratified	Sheets variable thickness
Fold breccia	Limited	Tabular or lozenge	Angular	Nil	Cognate	Unoriented	Slight	Powdered rock local derivation	Folded sediments, passes into unbroken strata	Poor	Folded sheets
Meteorite explosion breccia	Wide	Angular	Angular	Nil	Local derivation, silica glass, Ni-Fe fragments	Heterogeneous unoriented	Poor	Powdered rock local derivation	Zone of breccia passing into massive rock	None	Crater shaped body thinning at limbs
Holleford breccia	−1 inch to several feet	Angular	Angular	Nil	Cognate lime-silicate, biotite gneiss amphibolite	Unoriented	Variable	Green sand quartz, feldspar, hornblende, clinopyroxene plus mica illite & montmorillonite	Zone of breccia passing into massive rock	Mainly absent short sections of bedded sand	Crater shaped body

drill core No. 2, represents the Palaeozoic sandstone and limestone immediately above the breccia. Specimen 1353, which was collected between 440 and 1045 feet in drill core No. 1, represents the Holleford breccia. Specimen 1354, which was collected between 404 and 495 feet in drill core No. 2, represents the Holleford breccia.

The preparation technique was designed to produce three concentrates analagous to the nickel-iron, silicate, and sulphide phases of stony meteorites. The hand-magnet concentrate, which is correlated with the nickel-iron phase shows no similarity in nickel content (Rankama & Sahama, 1949, p. 101). The nickel content obtained before the subtraction of the blank was significantly less than that for meteoric iron. On the other hand, there is a similarity to the nickel content of magnetite from basic rocks (Sen *et al.*, 1959, p. 71, 72). The Carpco concentrate, which is correlated with the silicate phase of stony meteorites, is an order of magnitude less than the average for meteorite material (Vinogradov, 1956, p. 31). On the other hand, these values are similar to those published by Snyder (1959, p. 355) for the pyroxenes of basic rocks. The superpanner concentrate, which is characterized by abundant pyrite and minor accessory silicates, contains far less nickel than the sulphide phase of meteorites (Mason, 1952, p. 17) but is approximately the same order of magnitude as for accessory pyrite in igneous rocks (Rankama & Sahama, 1949, p. 101). In conclusion, none of the concentrates analyzed contains sufficient nickel to indicate the presence of meteoric material.

Discussion—Comparison of Breccia Types

The first four of the 11 varieties of breccia listed in Table 2 are characteristically products of contemporaneous sedimentary processes. The intraformational breccias are the products of shoaling water above recently emplaced sedimentary beds which have been exposed, mudcracked, and re-cemented by additional mud. Orthoquartzite breccias are products of a transgressive beach overlying a low-lying land surface. Polymict breccias are thick, wedge-shaped accumulations derived from nearby sharply elevated highlands. Tillites are extensive tabular accumulations deposited from melting glaciers. Scree and outwash fan gravel are sedimentary products having highly localized development. Volcanic breccias are products of volcanic eruptions rather than normal sedimentary processes. Fault and fold breccias are products of fragmentation taking place at some time after normal sedimentary processes have been terminated. Fault breccias sharply localized along tabular zones of structural displacement and they have associated with them slickensides and gouge. Fold breccias are the product of disruption of thin brittle beds enclosed within more plastic beds. Thin chert beds in shale often give rise to this type of breccia in folded areas of rock. Type 8 is a description of an identifiable meteorite breccia (Thornbury 1954), and Type 9 is a description of the Holleford breccia.

Summary

The bowl-shaped form of the breccia body as indicated by diamond drilling and geophysical data (Beals, 1958) are characteristic of meteorite impact breccias. Other characteristics that are in accord with such a genesis are: local derivation of the constituents of the breccia, lack of sedimentary bedding, and lack of rounded arenaceous material. No glass or coesite were found, but it is quite possible that devitrification and recrystallization of a probably metastable mineral would have taken place in the long interval since the crater was buried. There is no significant difference between the nickel content of this breccia and that of normal ingeneous rocks. However, anomalous concentrations of nickel in known meteorite craters has yet to be demonstrated as a significant criterion.

Results of this study lend weak additional support to the hypothesis that the Holleford breccia is a product of meteorite impact. More significantly perhaps, none of the results refute such a hypothesis.

Acknowledgments

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