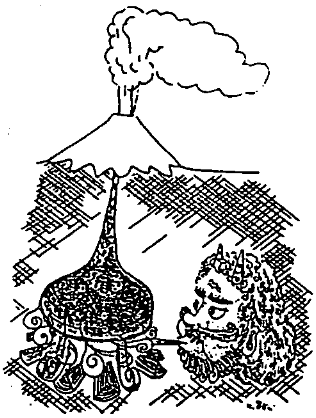


ASH FALL

Newsletter of the Volcanology Division
Geological Association of Canada

ASH FALL #25

July 1990

CONFERENCES

International Volcanological Congress (IAVCEI) Mainz (FRG) 1990, Sept. 3-8, 1990; tel (06131) 305-1/-390/-231, Dr. Gerhard Brey

GAC/MAC, Toronto, Ont., May 27-29, 1991

VOLCANOLOGY DIVISION FIELD TRIP - 1991

Members voted 14:1 in favour of Greek Islands over Kenya, California, etc.

Venue is now being considered by Les Coleman.

CONTRIBUTIONS

Contributions to Ash Fall are welcomed and should be sent to:

E. W. Grove, Editor, Ash Fall
Volcanology Division
4581 Boulderwood Drive
Victoria, B.C. V8Y 3A5 FAX (604) 658-5289

PHOTO CONTEST

There were no correct answers. No comments!

This issue of Ash Fall includes the Past President's report on activities for the year May 1989 - May 1990, abstracts of papers at Vancouver '90, a contribution on Poas Volcano (Costa Rica) and on the Onaping Formation, Sudbury, and the minutes of the May 1990 meeting of the Volcanology Division.

ANNUAL MEETING VOLCANOLOGY DIVISION, GAC
May 18, 1990; 1240 hrs.

1. The meeting called to order by Roger Laurent was held in the Hotel Vancouver and was attended by 11 members: Roger Laurent, Les Coleman, Catherine Hickson, Jarda Dostel, Tark Hamilton, Charlie Roots, Lousie Stevenson, Bob Barragar, J. Dale, Ken Ashton, and Ted Grove. Roger Laurent also held 5 proxies.

2. The agenda was as outlined in Ash Fall #24. The minutes of the 1989 meeting were discussed and approved with no amendments. It was noted that the Division Budget could withstand the increase to $250.00 for the revised Gelinas Award. No new business arose from the minutes.

3. Roger Laurent noted he had chosen the 1990 Ph.D. Thesis Gelinas Award winner who is Jon Stix, University of Toronto for "Physical and Chemical Fractionation Processes in Subaerial and Subaqueous Pyroclastic Rocks".

   (The list of theses considered is appended)

4. Copies of the abstracts of talks and posters commemorating the 10th Anniversary of Mt. St. Helens will be distributed to all Division members. More than 30 posters involved volcanic processes.

5. The short course on Pearce Element ratios was well attended and enlightening.

6. Tark Hamilton reported that the compilation on Volcanological Research will be found in Volume 42, Can. Geophy. Bull., Inserc. Publ. ($2.00 GSC, 10 chapters) No Vol. 41 because of lack of response.

7. Treasurer reported Division still afloat. It was suggested that at future general meetings of Volc. Div. members be given a free beer to increase attendance.

8. The future of the 1991 field trip was discussed. As a result of polling the Greek Islands trip was favoured by 14:1 with support by members' wives. A pre 1991 Toronto venue was favoured. It was also noted that a post Toronto Meeting '91 trip to the Caribbean will be led by Sigurdsson & Carey. This does not conflict with the Division's Greek trip (more to come).

9. New officers were elected:
   Chairman: Les Coleman
   Vice-Chairman: Catherine Hickson
   Sec.-Tres.: Ted Grove
   Editor Ash Fall: Ted Grove
   Past Chairman RogerLaurent
   Special Councillor on Research: Tark Hamilton
   Councillors: East - Scott Swindon, West - Paul Wodjak
   Center - Karen Stamatelopoulou-Seymour

The meeting was adjourned at 1500 hours.

Roger LAURENT
Past-chairman, Volcanology Division
Department of Geology
Laval University
Quebec (QC) G1K 7P4

Report of activities between May 1989 and May 1990

1) 3 issues of Ash-Fall were prepared by Ted Grove (# 22, 23, 24) providing information on our activities, abstracts of theses and summaries of volcanology papers, e.g. on italian volcanoes visited during the Italian Field Trip of May 1989.

2) Testing a new formula for the Volcanology Division Award. This new formula consists of alternating rewards for M.Sc. theses one year, and Ph.D. theses the year after. In 1989, the award was given to a M.Sc. thesis; the winner was F. Brissette from Université de Montréal. This year the competition was open to Ph.D. theses defended in 1988 or 1989. The four following Ph.D. theses were selected:

M. Berrahma: Etude pétrologique des laves récentes du massif du Siroua (Anti-Atlas Central, Maroc), Université Laval, Québec.

H.L. Gibson: The mine sequence of the Central Noranda volcanic Complex: geology, alteration, massive sulphide deposits and volcanological reconstruction. Carleton University, Ottawa.

J. Stix: Physical and chemical fractionation processes in subaerial and subaqueous pyroclastic rocks. University of Toronto, Toronto.

M.-C. Williamson: The Cretaceous Igneous Province of the Sverdrup Basin, Canadian Arctic. Dalhousie University, Halifax.

....../2

The four works represent very useful contributions deserving our interest. Authors and their Ph.D. supervisors must be complimented. However, because of its outstanding physical, chemical and experimental approach in volcanology, the thesis of John Stix came first. So the 1990 Leopold Gelinas award of the Volcanology Division was attributed to John Stix with our special congratulations and a reward of 250.00 $.

3) At Vancouver'90, the Mount St. Helen's, 10th Anniversary special symposium, sponsored by our division and organized by Catherine Hickson (GSc) and Donald Peterson (USGS), was a real success.

A booklet regrouping the abstracts of the symposium will be distributed to the members of the volcanology division.

4) Next field trip. According to a survey most members favor a volcanology field trip to the Greek Islands (over Kenya or Philippines). Since a volcanology field trip in the West Indies, organized by H. Sigurdsson and J. Carey, is planned for the next GAC meeting in Toronto'91, we may have to postpore the Greek Islands. A decision must be taken soon about this.

5) An annual compilation of volcanology research in Canada has been compiled by Tark Hamilton.

6) Toronto'91. A special session on **Komatiites** will be organised by S.-J. Barnes and R. Laurent and sponsored by the GAC Volcanology Division.

7) New officers have been elected to the executive of our division:

Chairman: Les Coleman, Saskatoon
Vice-chairman: Catherine Hickson, Vancouver
Secetary-treasurer: E.W. (Ted) Grove, re-elected, Victoria

...../3

Their term of office is for two years, between May 1990 and May 1992. The "decision" center, then, has been moved from East- to West, from old volcanic centers to active new ones!

05.06.90 [signature]

CONTRIBUTION TO ASH FALL

FROM: Gerardo J. Soto, Sección de Sismología e Ingeniería Sísmica, Dpto de Geología, Instituto Costarricense de Electricidad, Apdo 10032-1000 San José, Costa Rica.

PHOTOGRAPH Nº 1:
Big breadcrust bomb from the 1963-65 eruption of Irazú Volcano (Central Costa Rica). The eruption began with a phreatic and phreatomagmatic phase, followed by a strombolian phase and a vulcanian phase (probably, the bomb was ejected during the vulcanian event), and small phreatic-strombolian activity closed the eruption.

POAS VOLCANO (CENTRAL COSTA RICA): SULFUR-HYDRO-THERMAL ACTIVITY

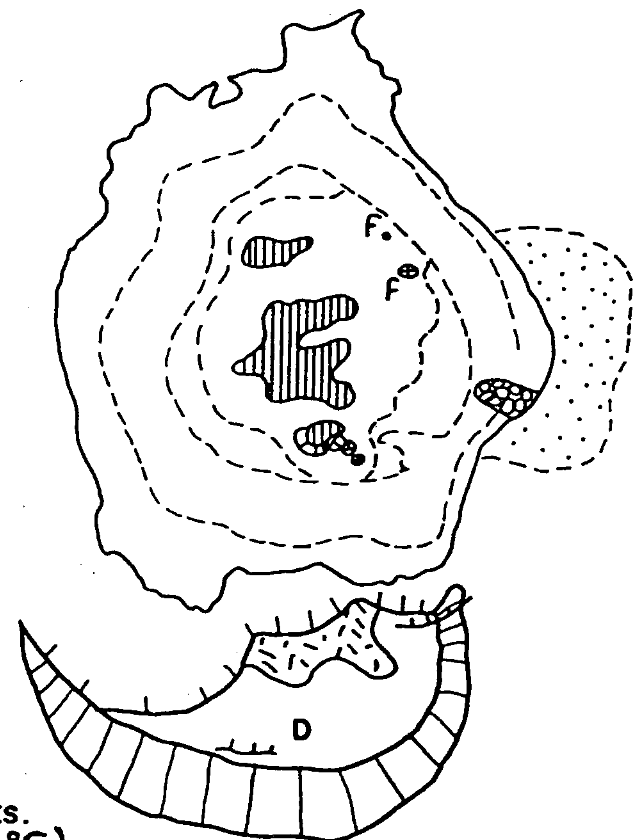
Since its last eruption in 1953-55, Poás volcano have had an exhalative activity. A hot acidic lake was inside a pit crater in the principal big crater (1,3 km in diameter) since centuries ago, but it dissapeared during strombolian-phreatomagmatic activity in 1953-55. The lake appeared again in 1965 and it has been the focus of hydrothermal activity, with geysering plumes of mud and contouring fumaroles. In 1980-81, fumaroles in the lava dome extruded in 1954, had high temperatures (960º C). In 1985, the hot acidic lake began a strong evaporation phase. On the same way, temperature of the lake rose from 40º C to 85º C i 1988-89, and pH was close to 0.0. Since mid January 1989, appeared in the bottom crater, sulfur lakes and cones. The lake dissicated in April 1989, and hot fumaroles appeared in the previous bottom lake (temperatures at least 460º C), which expeled ash (evaporite sediments and lithics) to atmosphere. This kind of activity is ongoing now (mid April 1990: fumarole temperatures close 800º C).

Contemporaneous to lake dissication, evaporite sediments (silica, gypsum and sulfur) formed terraces inside pit crater. Close to terraces, mud-sulfur cones and lakes were installed (see figure based on photograph). The cones and small lakes are continuosly recycled, with fumaroles inside, characterizing a conspicuous sulfur-hydro-thermal activity.

Sulfur compounds come from vesiculation of a hot magma body which stay below the crater, at 200-500 m depth. The sulfur has formed probably subaqueous sulfur deposits. When the groundwater and lake are almost totally evaporated, sulfur crops out as lakes, and the continuous bubbling and pluming form the cones (see figure: Observations on Poás Crater, April 18, 1990).

RED SISMOLOGICA NACIONAL.
(R.S.N : ICE-UCR)

CRATER POAS.
OBSERVACIONES DEL 18 DE ABRIL 1990.
(G.J. SOTO)



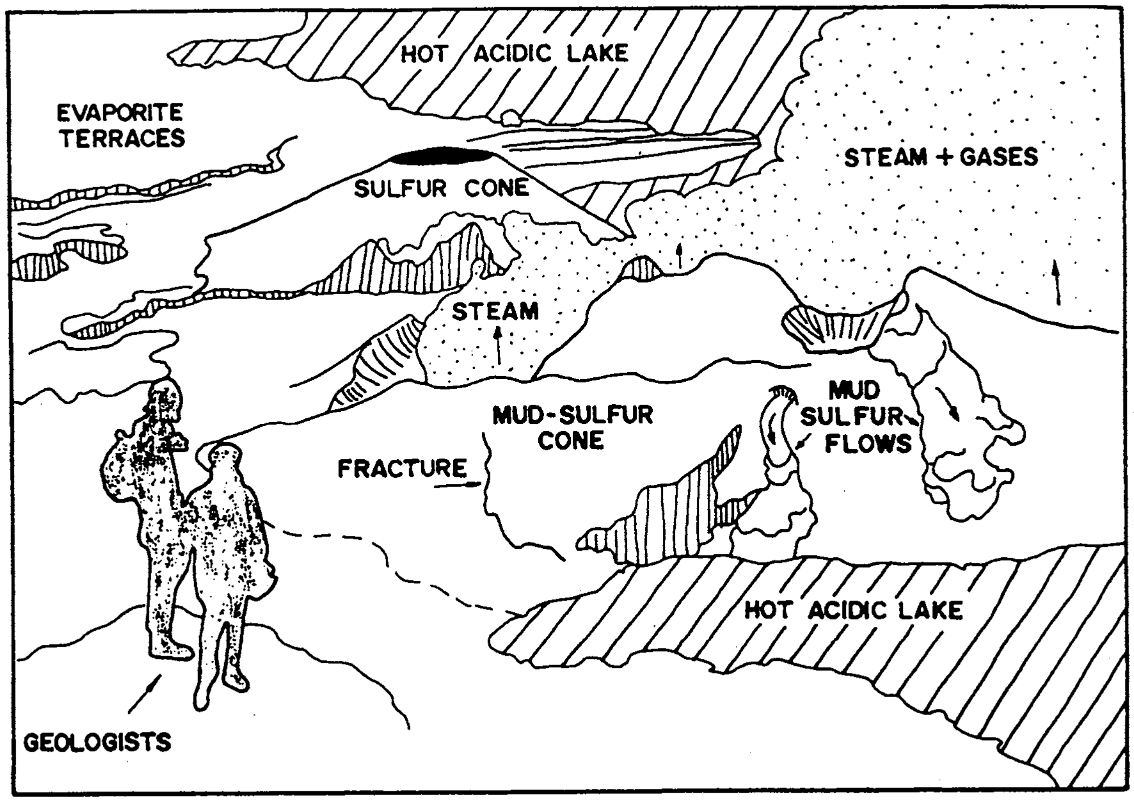
SIMBOLOGIA.

- F — FUMAROLAS CALIENTES. (T: 300-800°C)
- AREA DE FUMAROLAS DEL DOMO (T= 90°C)
- TERRAZAS DE SEDIMENTO (EVAPORITAS).
- HERVIDEROS DE LODO.
- ⊕ — CONOS DE AZUFRE-LODO.
- FRACTURAS MAYORES EN EL DOMO.
- AREA DE CAIDA DE AZUFRE-LODO PIROCLASTICO.
- D — DOMO.
- DESLIZAMIENTO DE ROCAS.

125 100 50 0 62,5 125 m

ESCALA GRAFICA.

POAS SULFUR CONES AND FLOWS.



DRAWING BASED ON A PHOTOGRAPH, LATE OCTOBER 1989.
(PHOTO AND DRAWING BY G.J. SOTO)

IRAZÚ VOLCANO
Bomb

J. Grove

POAS Volcano - 1990

John Grove POAS VOLCANO - 1990

John Grove POAS VOLCANO - 1990

Tectonophysics, 171 (1990) 249–257
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

The volcanic origin of the Onaping Formation Sudbury, Canada

JOHN S. STEVENSON

Department of Geological Sciences, McGill University, Montreal, Que. H3A 2A7 (Canada)

(Revised version accepted February 2, 1989)

Introduction

Ever since the controversy about the meteoritic origin of the Sudbury Basin began, it has been held that the nature and origin of the Onaping Formation are central to the Sudbury problem. Is the Onaping Formation of meteoritic fall-back origin or is it of volcanic origin? I would like to present some data that support a volcanic origin.

The Sudbury Structure (Fig. 1) is a NE-trending elliptical feature with long and short axes of 60 and 27 km respectively in which the Onaping Formation forms an oval ring 2.4–4.8 km wide. This formation overlies and is intruded by the

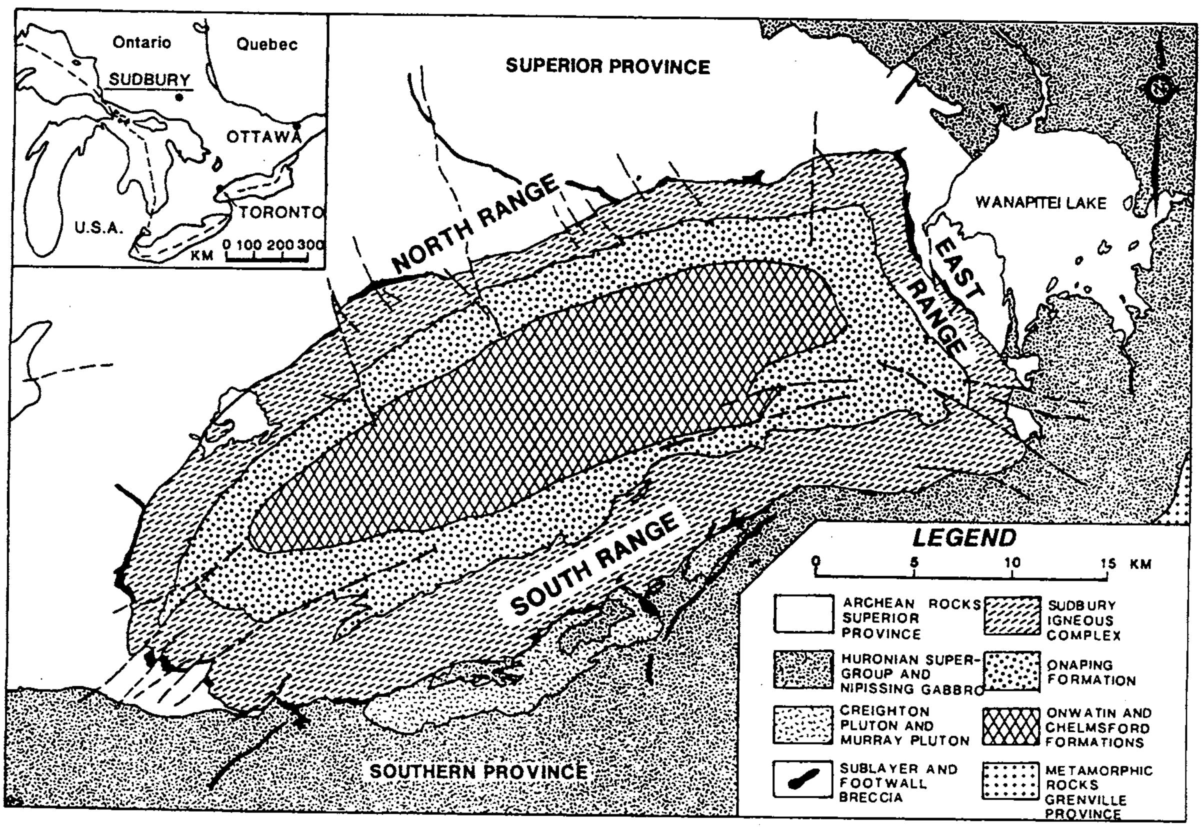


Fig. 1. General geology and location of the Sudbury Structure. The Basal Member, including the quartzite breccia, is at the base of the Onaping Formation. (Figure supplied by B. Dressler, Ontario Geological Survey.)

0040-1951/90/$03.50

granophyre of the Sudbury Igneous Complex, which is approximately 1850 m.y. old, and is overlain conformably by the Onwatin Formation and the Chelmsford Formation. The lower contacts of the Sudbury Igneous Complex generally dip 35°–50° inward but in the south may be vertical or dip steeply outward.

The Onaping Formation consists of the Basal Member, overlain by the Gray Member and the upper Black Member. All these members consist of heterolithic breccias.

Basal Member

The Basal Member (Fig. 2) has been termed *quartzite breccia* (Stevenson, 1961) in the South Range. In the North Range the Basal Member is heterolithic in character containing fragments of granitic, gneissic, metavolcanic and metasedimentary rocks. The quartzite breccia consists of close-packed angular pieces of quartz arenite, some of them arkosic, that show a considerable range in size. The largest seen measured 75 m by 23 m, grading down to a few millimeters in size. A continuous layer of coarse breccia, the Gray Member of the Onaping Formation, with a great variety of fragment types overlies the Basal Member, but is distinct from the latter. Muir and Peredery (1984) describe the quartzite breccia as part of the Basal Member of the Onaping Formation. Peredery (1972) interprets it as the earliest fall-back breccia analogous to the Bunte Breccia of the Ries

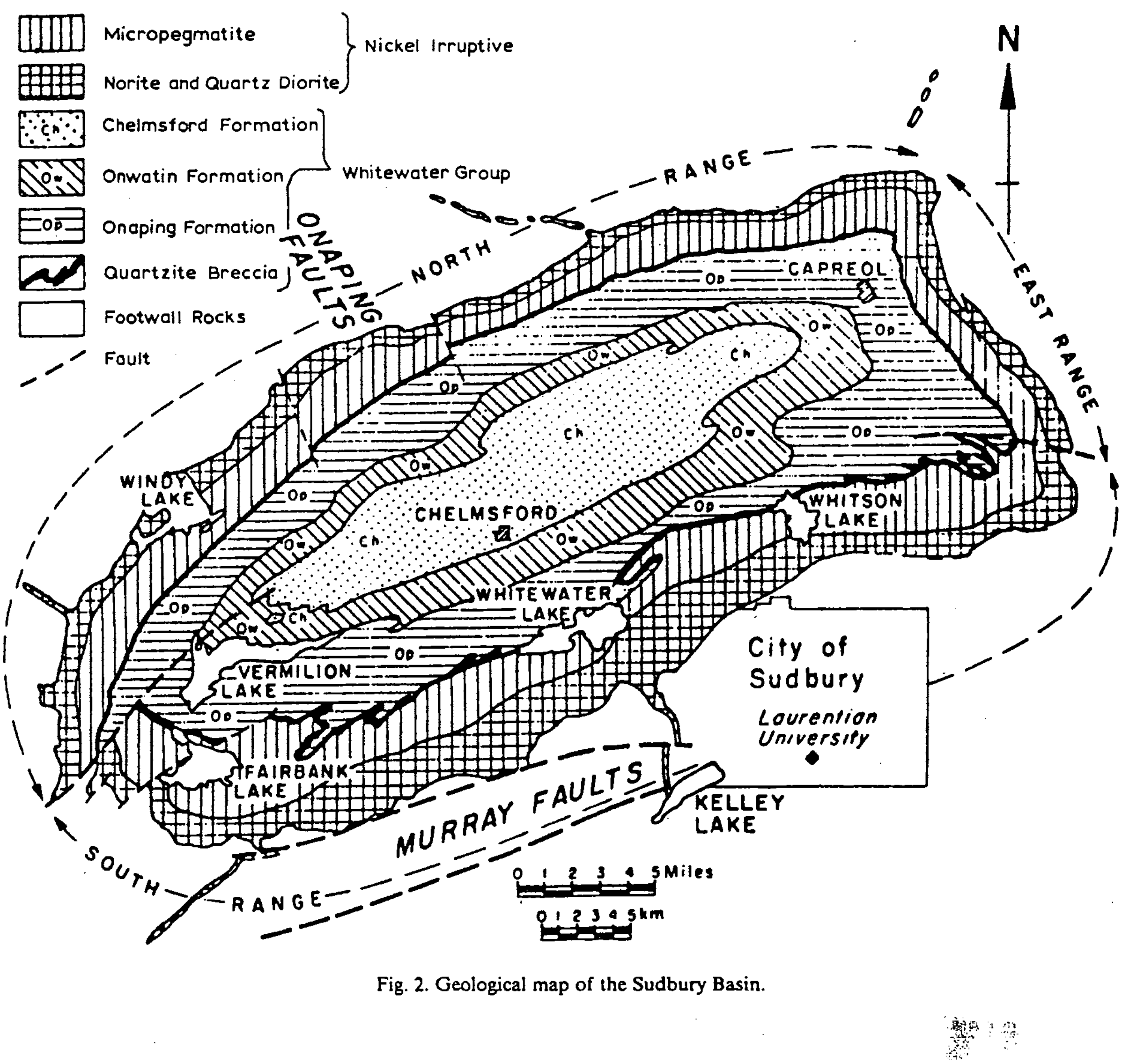


Fig. 2. Geological map of the Sudbury Basin.

crater in Germany. I prefer to think of the quartzite breccia as a tectonically brecciated, recrystallized quartz arenite and arkose; structurally much of it has been deformed by drag folding and disrupted by later tectonic transport.

The Gray and Black Members of the Onaping Formation

I consider the Gray and Black Members of the Onaping Formation to be volcanic in origin and consequently will use volcanic terminology in describing the two units and their components.

The two members consist principally of pyroclastic material and possess all the features of ignimbrites.

Lithologically the two members possess a gross size grading of fragments. In general the lowermost 150 m consist of coarse lapilli tuff and blocks of quartz arenite and basement complex granites. These blocks are, in places, gathered together into lenses of breccia and elsewhere are widely scattered throughout the lower part of the Gray Member. Above this are about 900 m of coarse lapilli tuff with uncommon blocks of quartz arenite. This is overlain by about 600 m of finer lapilli ash tuffs with no blocks and finally by about 150 m of ash tuff with uncommon pumice lapilli.

It is significant in terms of the concept of a volcanic origin of the upper two members of the Onaping Formation that the principal ignimbrite unit is overlain by thin beds of interlaminated pumiceous air-fall tuff and pumiceous slate of the overlying Onwatin Formation. At the western end of the basin the Onaping Formation is overlain by a thin limestone chert, the chert probably being ultimately volcanic in origin. This is the Vermilion Member of the Onwatin Formation.

The Onaping Formation above the Basal Member can be divided into a lower, gray tuff member (Gray Member), 760 m thick, and an upper, black tuff member (Black Member), 1060 m thick. These are very similar, both chemically and texturally, but the Black Member contains disseminated carbonaceous material; the Gray Member lacks this constituent and is much more recrystallized. Lenses of green tuff with conspicuous pink pumice lapilli occur near the base of the gray tuff. The green tuff is characterized by an abundance of finely disseminated actinolite.

Both the black and gray tuffs contain principally pumice lapilli, shards, varying amounts of small crystal fragments of quartz, plagioclase, and lesser amounts of fragmental lithic material, mainly quartz arenite, but occasionally granitic material similar to that found in the northern footwall of the norite.

Perhaps the most significant features of these tuffs are the bubble textures of the shards, the pectinate rims, and axiolitic textures of the pumice lapilli and even of the much smaller shards. These are features that are characteristic of ignimbrites the world over, from the Precambrian to the late Cenozoic.

Flinty green rhyolite

A minor, but widespread and very significant component of the Onaping Formation is a rock that, in mapping of parts of the Sudbury Basin, I termed *flinty green rhyolite*. This rock is of very controversial origin. It has been referred to as a fluidal glass formed as a consequence of meteoritic impact, as a lava within a volcanogenic Onaping Formation, or as a phase of the Onaping tuff baked to a hornfels by the underlying granophyre. Some of it has been likened to the fladen from the Ries crater in Germany. French (1972) has said of it: ..."The heterogeneous glassy inclusions are especially important for interpreting the origin of the Onaping Formation". My field studies suggest that it is a welded, shard-rich rhyolite ignimbrite definitely of volcanic origin.

The rhyolite is found in both the Gray and Black Members of the Onaping Formation, but principally in the Gray Member. Here, toward the base of the Gray Member long and short lenses of this rhyolite are found. Farther up in the Gray Member and in the Black Member, large broken blocks are found. In both, but particularly in the Black Member, smaller, broken lapilli-sized fragments are located as widespread but minor clasts in this tuff. The rhyolite is seen to envelope cores of quartz arenite.

In hand specimens the flinty green rhyolite appears very fine grained, much of it quite flinty

TABLE 1

Representative analyses of main rock types in the Onaping Formation; also of the uppermost granophyre of the Sudbury Igneous Complex (*N.D.* = not determined).

Wt.%	QTE	PSQTE	BLTF	GYTF	GNRHY	PS	QTZPS	MP
SiO_2	82.91	82.35	62.14	63.65	71.61	58.64	71.67	70.85
Al_2O_3	8.47	7.42	11.07	11.63	11.12	16.34	11.84	10.98
Fe_2O_3	0.17	0.38	3.34	1.35	0.45	1.70	1.21	2.24
FeO	0.62	0.21	6.37	5.76	2.73	4.54	2.71	3.10
MgO	0.26	0.29	4.51	4.10	2.79	3.39	2.39	0.79
CaO	0.07	0.39	2.89	3.24	2.11	1.97	0.91	1.27
Na_2O	5.27	0.37	2.59	4.79	5.16	5.02	4.30	3.30
K_2O	0.32	6.23	3.65	2.36	1.18	3.27	2.45	3.71
TiO_2	0.28	0.29	0.74	0.76	0.67	1.13	0.60	1.06
P_2O_5	0.04	0.01	0.13	0.18	0.09	0.16	0.08	0.15
MnO	N.D.	0.00	0.20	0.12	0.05	0.22	0.09	0.08
CO_2	0.15	N.D.	1.72	0.34	N.D.	0.41	0.76	0.05
Total	98.56	97.94	99.35	98.28	97.96	96.79	99.01	97.58

QTE = feldspathic quartz arenite, Norman Township. PSQTE = quartz arenite, spherulitic PS matrix, Norman Township; BLTF = black tuff, Dowling Township; GYTF = gray tuff, Norman Township; GNRHY = green rhyolite (intensely welded dacitic to rhyolitic tuff flows); Norman Township; PS = quartz-poor "pepper and salt rock" (trachyandesite, both extrusive and intrusive), Blezard Township; QTZPS = quartz-rich PS (dacite to rhyolite, intrusive), Snider Township; MP = quartz-rich, uppermost micropegmatite (granophyre), Norman Township. XRF (alkali elements checked by AAS).

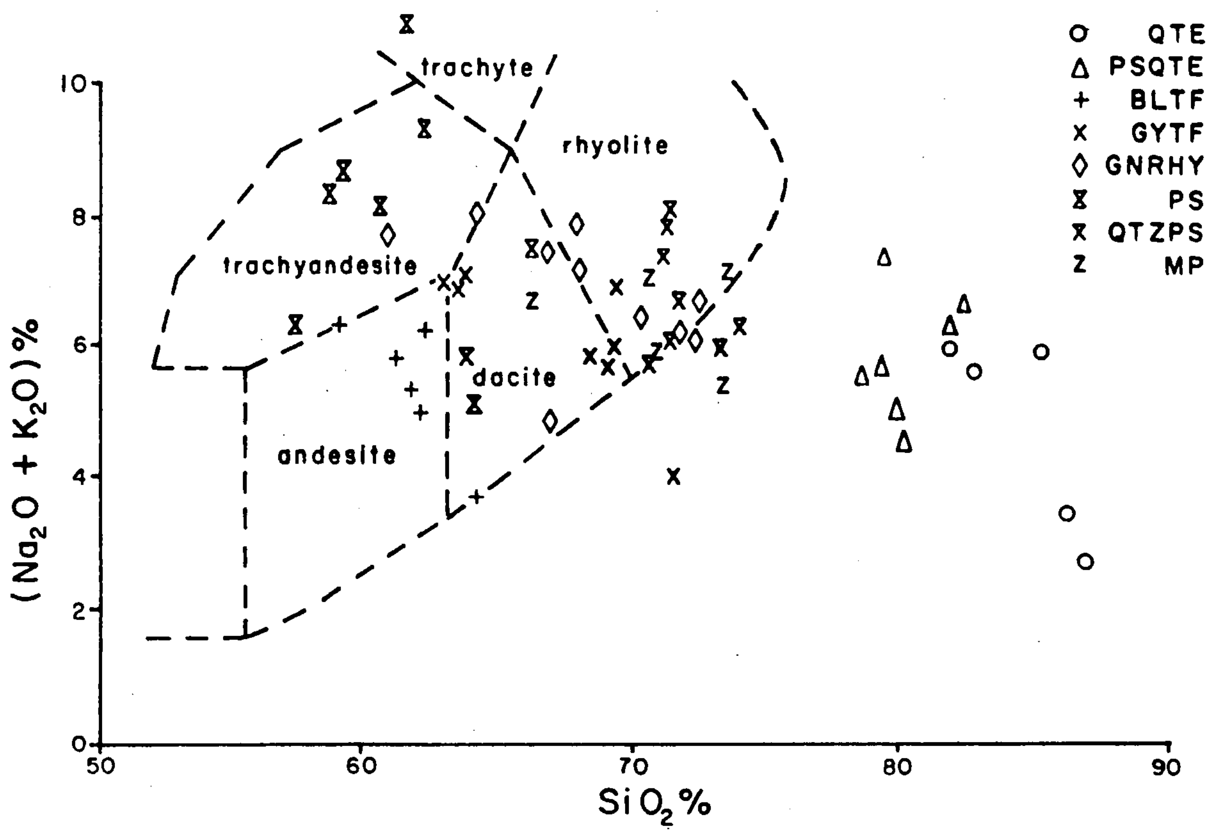


Fig. 3. (Na_2O + K_2O) versus SiO_2 diagram of rocks of the Onaping Formation (for legend, see Table 1).

with a vitreous to subvitreous lustre and with a subconchoidal to conchoidal fracture.

Although in outcrop and hand specimen this flinty rhyolite has many of the fluidal structures of a lava, it is texturally different. In thin section it is seen to consist of close-packed, shadowy, cusp-shaped and commonly bubble-walled shards which form the matrix to long, drawn-out, fiamme-like pumice lapilli. The shards are faintly outlined and their identification as shards is difficult, but with careful adjustment of the illumination their characteristic outlines, and even pectinate rims, may be recognized. A familiarity with the appearance of the small, readily identifiable shards in the Black Member, with their cusped and bubble-walled shapes and pectinate rims, is vital for the recognition of the shadowy shards in the flinty green rhyolite.

In some of the rhyolite in the East Range (Fig. 1) the close-packed shard texture has been largely replaced by striking spherulitic and axiolitic devitrification textures. Even here, however, in places where the intensity of devitrification is less, shadowy relict shard textures may be recognized. Even outlines of pumice fiamme may be reconstructed.

The comparative chemistry of these three components of the Onaping Formation just described, namely the black and gray tuff and the rhyolite, may be seen in Table 1. The black and gray tuffs are similar in composition in some components. The rhyolitic tuff differs somewhat in being higher in silica and lower in iron and magnesia. These analyses are of carefully selected material devoid of all extraneous pebbles and smaller clasts.

The comparative chemistry is illustrated in Fig. 3. According to the Cox et al. (1979) classification of volcanic rocks, the black tuffs plot in the andesite field, the gray tuffs plot in the dacite field, and the rhyolites plot in the rhyolite field.

Figure 4 is an alumina–magnesia computer plot and outlined on it can be seen a striking grouping of all three tuffs.

The flinty green rhyolite, then, does seem to have many features in common with the gray and black tuffs. It has shards, occasional pumice lumps, fragments of quartz crystals and, significantly, rare but definitely present beautifully bipyramidal quartz. These are all typical of the gray and black tuffs.

I believe that this rhyolite is a densely welded shard-rich rhyolitic ignimbrite tuff. In its mode of occurrence, texture and chemistry it is similar to the highly welded ignimbrites and rhyolitic ignimbritic obsidians found elsewhere in the world. It was indeed a Precambrian rhyolitic ignimbritic obsidian.

"Pepper-and-salt rock"

In addition to the flinty green rhyolite, a genetically very important component of the Onaping Formation is a non-pyroclastic, amygdaloidal, igneous-textured rock. This is seen in outcrops as a fine-grained rock that, because of biotite in the South Range and actinolite in the North Range, has a characteristic "pepper-and-salt" appearance. Proponents (Peredery and Morrison, 1984) of the meteorite theory refer to this as melt rock generated from the footwall by meteorite impact. I view it as igneous and endogenic in origin, part of the Onaping Formation–Sudbury Igneous Complex magmatism.

The pepper-and-salt rock occurs as lenses, dikes and tongues; the lenses and dikes are within about 600 m of the base of the formation, the tongues extend from the granophyre of the Sudbury Igneous Complex as far as 100 m into the overlying tuff. All occurrences of this important component of the Onaping Formation are interpreted as being igneous in origin and all appear to be cogenetic.

All pepper-and-salt rock is characterized mineralogically by laths of albitic plagioclase and clinopyroxene. Clinopyroxene occurs only as occasional relict material; it has nearly always been altered to actinolite in the North Range and to biotite in the South Range, but the original clinopyroxene textures are retained. The plagioclase–clinopyroxene textures are those to be expected as the result of different rates of cooling of a magmatic liquid.

In the dikes, particularly in some of the narrower, approximately 20 cm thick dikes, beautiful skeletal or dendritic clinopyroxene occurs in a matrix of embryonic feldspars. In other dikes,

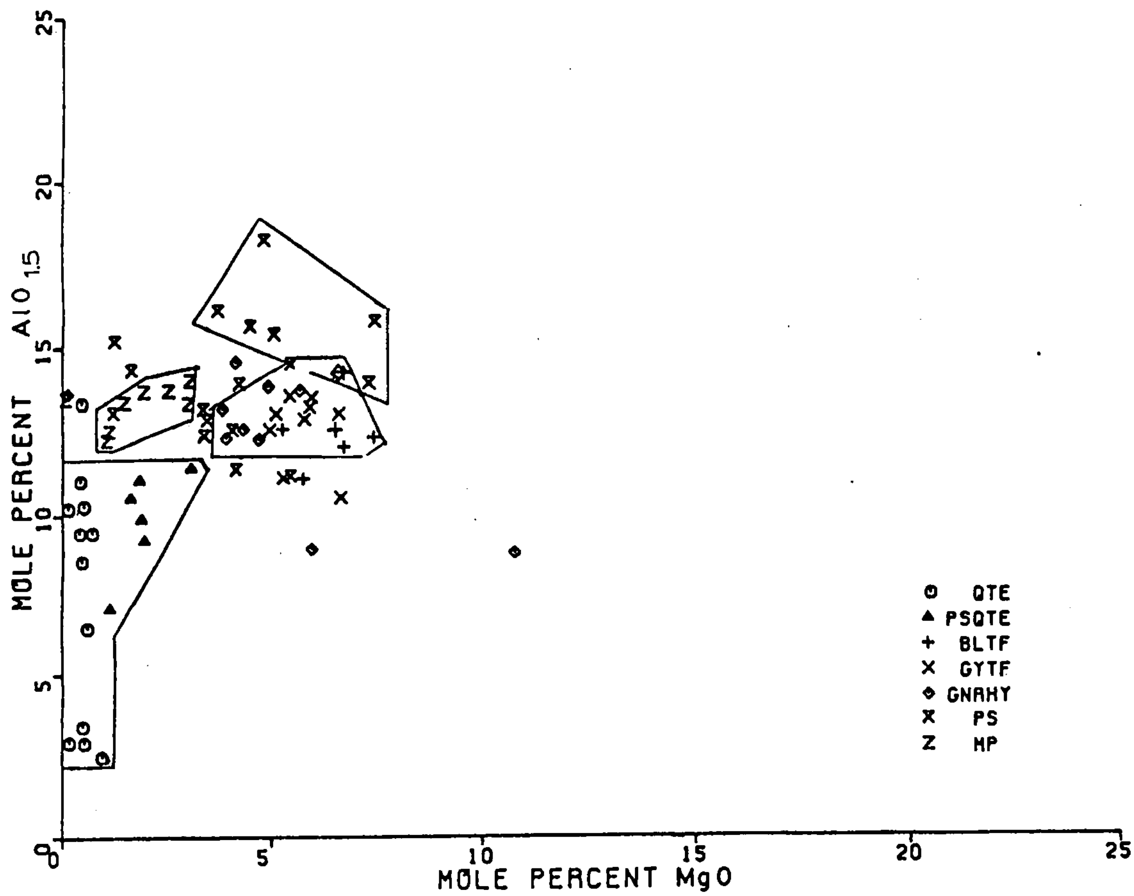


Fig. 4. $AlO_{1.5}$ versus MgO (mole %) diagram of rocks of the Onaping Formation (for legend, see Table 1).

very well developed spherulitic textures were observed. In the lenses, locally trachytic textures can be seen, but more often there are variations of felt-like or pilotaxitic textures, with which spherulitic textures are commonly associated. Plume-like to bow-tie textures consisting of a radiating array of feldspar microlites are found where tongues of pepper-and-salt rock form the matrix of the basal quartzite breccia. These textures are obviously due to rapid chilling.

Quartz, pseudomorphic after tridymite, is commonly found in the pepper-and-salt rock near the base of the Gray Member of the Onaping Formation. The tridymite formed as fringes around quartz grains outward from the pepper-and-salt matrix. Granophyric textures also begin to appear in this lower pepper-and-salt rock and may be traced, through increasing stages of development, into granophyre-like pepper-and-salt rock, and finally into the uppermost phases of the granophyre of the Sudbury Igneous Complex.

A textural continuum exists in the plagioclase, beginning in the fine spherulitic textures in the pepper-and-salt rock near the base of the Gray Member, all textures being accompanied by the progressive development of long blades or needles of plagioclase. These have fringing granophyric intergrowths. The uppermost granophyre of the Sudbury Igneous Complex is characterized by very similar needle plagioclase and fringing interstitial granophyric textures.

All pepper-and-salt rock is, in varying degrees, amygdaloidal. In some of the lenses within the tuff, quartz amygdules are so abundant that the rock can truly be called amygdaloidal. In other places the amygdules are uncommon. It is possible to recognize quartz amygdules in the uppermost granophyre.

The petrochemistry of the pepper-and-salt rock may be seen in Table 1 and Figs. 3 and 4. In Fig. 3, quartz-poor pepper-and-salt rock (PS) plots in the trachyandesite and trachyte fields, whereas the quartz-rich pepper-and-salt rock and the granophyre plot in the dacite–rhyolite fields.

Very significant groupings of the tuffs, the pepper-and-salt rock, and the granophyre of the Sudbury Igneous Complex are outlined in Fig. 4. This diagram serves to emphasize the chemical homogeneity within the rock groups outlined: the black and gray tuffs and the flinty green rhyolite in one group, the average pepper-and-salt rock in a second group, and the transitional pepper-and-salt rock and the granophyre in a third group. The quartz arenite of the quartzite breccia and samples of pepper-and-salt rock which form the matrix of the quartz arenite and which naturally have many small quartz arenite clasts understandably group together.

Lamellar quartz

Consideration must also be given to the occurrence of "lamellar quartz" (planar features), an important item used as evidence of meteorite impact. Lamellar quartz certainly occurs in the Onaping Formation, in clasts of basement origin. Here, the explosivity associated with the emplacement of the Onaping Formation was undoubtedly an influence in the development of the lamellar structures. However, an occurrence in trachytic pepper-and-salt rock from a lens in the Onaping Formation contains what I interpret to be a quartz-filled amygdule. In this amygdule a rhombohedral array of inclusions, characteristic of lamellar quartz, has developed. These lamellae are very similar to those thought to have been produced by shock waves resulting from the meteorite impact. However, the lamellae I describe are in amygdaloidal quartz in pepper-and-salt rock. This rock is interpreted to be later, not earlier, than the Onaping tuff. Thus the lamellar structures cannot be ascribed to shock waves from a pre-Onaping event such as a meteorite impact. This illustrates the fact that meteorite impact-derived shock metamorphism is not necessary for the development of lamellar structures in this quartz.

Structural state studies of Onaping Feldspars

Schandl et al. (1986) have studied the mineralogy, and particularly the structural states (degrees of order) of the feldspars in the Onaping Formation and in the norite and granophyre of the Sudbury Igneous Complex. In this study it was possible to establish an interesting pattern of vertical zonation in the degree of Al–Si order of K-feldspar. Well-ordered microcline occurs in small amounts in the norite. Widespread low microcline, together with intermediate microcline and orthoclase, occurs in the granophyre. The K-feldspar in the tuffs is poorly ordered microcline or orthoclase, and albite is almost pure and ordered. Thus the norite, granophyre and Onaping ignimbrite undoubtedly cooled as a single unit. This certainly agrees with the earlier conclusions based on field, petrographic and chemical studies.

Onaping tuffs are compositionally zoned, from Na-rich at the base to K-rich at the top. This zonation reflects the operation of an ion-exchange process with associated metasomatism during cooling of the Onaping ignimbrite sheet.

The structural changes in the feldspars and the ion exchanges and metasomatism that have occurred indicate that the Onaping Formation no longer contains an original magmatic assemblage —it has no feldspar of pristine composition.

The change in the feldspars occurred as the complex cooled. Extensive development of the new assemblage required the mediation of an interstitial, mobile aqueous fluid. The very widespread nature of the transformations in the Onaping Formation suggests that the water was largely magmatic in origin and did not filter in from outside the basin. The author believes that impact material, fall-back breccia or melt would not be sufficiently saturated with water to provide the amount of hot aqueous fluid necessary for the exchange reactions involved in the zonation of Na and K in the thick section of cooling Onaping ignimbrite. Ignimbrites are characteristically saturated with water and their emplacement would supply the amounts of hot aqueous fluid necessary for the feldspar transformations that have taken place in the Onaping ignimbrite.

Conclusions

When studied in detail in the field and the laboratory, the Onaping Formation is seen to possess all the features of ignimbrites, and ranks in extent and volume with the large extrusive sheets of Precambrian ignimbrites of the Northwest Territories of Canada (the Wopmay Orogen), the Paleozoic ignimbrites of England and Wales, the Cenozoic rocks of the southwestern U.S.A., and the extensive Cenozoic ignimbrites of North Island, New Zealand. As with many of these sheets, the magma source or sources have not yet been identified. However, in the Onaping Formation we have some clues that the ignimbrite may have come from a linear zone of vents, comparable to that of the linear 200 km long Taupo–Tarawera volcanic zone of North Island, New Zealand. Specifically, the situation may be more comparable to the 16 km long Tarawera section of closely spaced vents from which the repeated eruptions of 1886 occurred progressively over a very short period of time. This would account for the localization and contemporaneity of volcanism that the Onaping Formation illustrates.

The Sudbury Structure is asymmetrical in several ways, and one regional asymmetric feature that has not been stressed is the much greater extent in continuity and width of the quartzite breccia in a matrix of pepper-and-salt rock in the South Range, particularly at the southwest end of the basin. This pepper-and-salt rock is related to both the Sudbury Igneous Complex and the Onaping Formation. This indicates that the area of the South Range could be a linear source for the magma and for its attendant ignimbrite-producing explosivity.

Geophysical studies by Gupta et al. (1984) also suggest an asymmetry for the deeper features of the basin. Indeed, their modelling suggests the presence of a hidden body or bodies of mafic/ultramafic rocks beneath the Sudbury Igneous Complex. If, as I suggest, the Onaping volcanic activity is coeval with this complex, then the combined magmatic activity could have been generated by differentiation of magma from this reservoir of mafic/ultramafic rocks. In the case of the Onaping ignimbrite, vent evisceration could have occurred from a southerly line of water-saturated apical parts passing into a line of vents from this reservoir. The attendant explosivity could have produced the shock-metamorphosed material, such as the quartz lamellae seen in the Onaping Formation. It would also have produced the shatter cones around the basin. It is interesting to note that shocked quartz produced by violent volcanic explosions has been described from the Toba caldera by Carter et al. (1986).

The author believes that two upper members of the Onaping Formation have been proven to be volcanogenic and, since the nature and origin of the Onaping Formation are generally accepted as central to the Sudbury controversy, the case for an endogenic origin for the Sudbury Structure is a strong one.

Note

After the untimely death of the author, this paper was edited by B. Dressler and T. Muir (Ontario Geological Survey). The editors took much care not to change the content of the paper. Changes, however, were made to the Sudbury terminology used by the author to make it conformable with the terminology agreed upon by the Working Group on Sudbury Geology (Giblin, 1984).

References

Carter, L., Officer, B., Chesner, A. and Rose, I., 1986. Dynamic deformation of volcanic ejecta from the Toba Caldera: Possible relevance to Cretaceous/Tertiary boundary phenomena. Geology, 14: 380–383.

Cox, K., Bell, J.D. and Pankhurst, R.J., 1979. The Interpretation of Igneous Rocks. George Allen and Unwin, London, 450 pp.

French, B.M., 1972. Shock-metamorphic features in the Sudbury Structure, Ontario: a review. In: J. Guy-Bray (Editor), New Developments in Sudbury Geology. Geol. Assoc. Can. Spec. Pap., 10: 19–28.

Giblin, P.E., 1984. Glossary of Sudbury geology terms. In: E.G. Pye, A.J. Naldrett and P.E. Giblin (Editors), The Geology and Ore Deposits of the Sudbury Structure. Ont. Geol. Surv. Spec. Vol., 1: 571–574.

Gupta, V.K., Grant, F.S. and Card, K.D., 1984. Gravity and magnetic characteristics of the Sudbury Structure. In: E.G. Pye, A.J. Naldrett and P.E. Giblin (Editors), The Geology and Ore Deposits of the Sudbury Structure. Ont. Geol. Surv. Spec. Vol., 1: 381–410.

Muir, T.L. and Peredery, W., 1984. The Onaping Formation. In: E.G. Pye, A.J. Naldrett and P.E. Giblin (Editors), The Geology and Ore Deposits of the Sudbury Structure. Ont. Geol. Surv. Spec. Vol., 1: 139–210.

Peredery, W.V., 1972. Chemistry of fluidal glasses and melt rocks in the Onaping Formation. In: J. Guy-Bray (Editor), New Developments in Sudbury Geology. Geol. Assoc. Can. Spec. Pap., 10: 49–59.

Peredery, W.V. and Morrison, G.G., 1984. Discussion of the Sudbury Structure. In: E.G. Pye, A.J. Naldrett and P.E. Giblin (Editors), The Geology and Ore Deposits of the Sudbury Structure. Ont. Geol. Surv. Spec. Vol., 1: 419–512.

Schandl, E.S., Martin, R.F. and Stevenson, J.S., 1986. Feldspar mineralogy of the Sudbury Igneous Complex and the Onaping Formation, Sudbury, Ontario. Can. Mineral., 24: 747–759.

Stevenson, J.S., 1961. Recognition of the Quartzite Breccia in the Whitewater Series, Sudbury Basin, Ontario. Trans. R. Soc. Can., Ser., 3, 60: 57–66.