Earth Sciences Report 2001-04

Petrographic, Mineralogical and Lithogeochemical Study of Core from Three Drillholes into the Steen River Structure, Northern Alberta

Alberta Energy and Utilities Board

Alberta Geological Survey

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Acknowledgments

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Summary

The Steen River Structure (SRS) has been the focus of research studies and exploration programs since its discovery in the 1960s. Situated in northwestern Alberta, the SRS lies about 115 km north of High Level along the western border of NTS map area 84N. Lacking a surface expression, the SRS is buried by more than 200 m of Cretaceous to Recent sedimentary units.

The origin of the SRS has been somewhat equivocal. In general, the similarity of its structural geometry, stratigraphy and breccia unit to other known meteorite impact features has supported an extraterrestrial (astrobleme) origin. However, some prior workers have suggested, based on geophysical surveys and magmatic-appearing core from drilling programs, the possibility the structure is, in whole or in part, a volcanic cryptoexplosion feature.

In early 2000, New Claymore Resources Ltd. drilled three diamond-drill holes into the SRS to test three discrete aeromagnetic anomalies that were possibly related to kimberlitic or ultramafic diatreme emplacement. The generalized stratigraphy of the SRS comprises a thin (up to 18.3 m thick) layer of overburden, underlain by undisturbed Cretaceous strata ranging from 224.0 to 275.6 m in thickness, that in turn nonconformably overlies a heterolithic, green to reddish-green breccia that is up to 140 m thick. Granitic basement underlies the breccia in one of the three drillholes.

Although the SRS breccia in the core visually resembles a kimberlitic diatreme breccia, the results from the detailed mineralogy, petrography and chemical composition obtained in this AGS study indicate that it is primarily a meteorite impact breccia, or suevite. In places, the suevite breccia comprises a melt phase, but this magmatic-appearing rock type is a result of impact shock and heat, and not deep-seated intrusive magmatic activity. In addition, newly formed magnetite was discovered at variable depths within the breccia. The position of the magnetite in the core appears to directly affect the aeromagnetic signature of the SRS.

The SRS is well known as an attractive target for hydrocarbon exploration, and exploitable hydrocarbon resources have been found in several places. However, the economic potential of the SRS to host or have spatially associated metallic-mineral deposits or diamondiferous kimberlites remains uncertain.

1 Introduction

The Steen River area hosts an unusual geophysical anomaly known as the Steen River Structure (SRS). Since its discovery in the early 1960s, numerous drilling, geophysical and exploration programs have been conducted in the region to determine the origin of the feature and its potential to host economic deposits of hydrocarbons, base and precious metals, and, more recently, diamonds.

The origin of the SRS is still equivocal. Buried by Cretaceous marine sedimentary rocks and Quaternary glacial sediments, the feature has no apparent surface expression. As a result, data collected from the structure is restricted primarily to drillcores and geophysical surveys. Interpretation of the data has suggested either volcanic activity associated with the Peace River Arch or extraterrestrial impact as possible origins.

1.1 Objective and Scope of Study

Drilling conducted by New Claymore Resources Ltd. in early 2000 provided new information about the SRS. The purpose of the Alberta Geological Survey (AGS) study was to describe and analyze these new cores, in particular the brecciated unit, to determine whether the SRS represents an impact structure or volcanic activity associated with regional tectonism. Close attention was paid to the potential of the SRS to host precious metals, hydrocarbons and diamonds.

1.2 Geographic Location

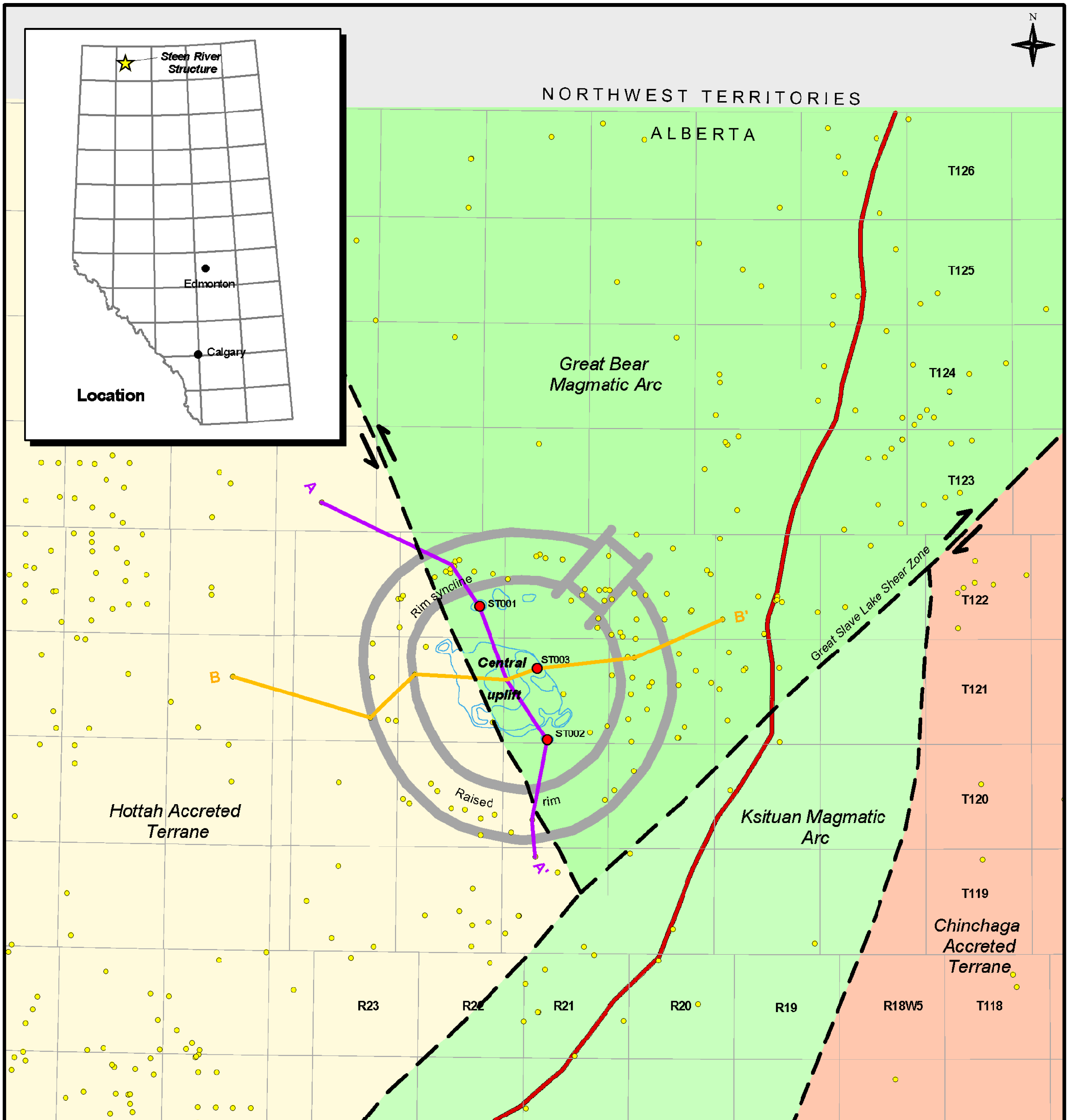
The SRS is located in northwestern Alberta, approximately 115 km north of High Level and 710 km north of Edmonton. Centered at approximately 59°31'N latitude and 117°38'W longitude (twp. 121, rge. 21–22, W 5th mer.), the SRS lies along the western edge of and within NTS 1:250 000 scale map area 84N. Geophysical studies have indicated that the SRS has an approximate diameter of 24 km along its longest axis (Figure 1). Elevation in the area ranges from 350 m in the south to 700 m near the Cameron Hills.

The majority of the region is poorly drained and covered by swamps and muskeg. The Steen River, lying southeast of the SRS, and its tributary, Jackpot Creek, drain the region by flowing north into the Hay River.

1.3 Regional Geology

1.3.1 Basement and Structure

The SRS is an elliptical to subcircular basement high that lies near several major structural features, including the Great Slave Lake Shear Zone (GSLSZ) and the McDonald Fault to the southeast. The study area is underlain by a major northwest-trending lineament that reflects the basement contact between the Proterozoic Hottah Terrane and the Great Bear Magmatic Arc. These lie to the southwest and northeast, respectively. Drilling of the SRS has indicated maximum and minimum depths to basement of 1477 m below sea level (bsl) and 167 asl respectively, in the center of the SRS. Numerous normal faults along the basement rim of the SRS form a complex pattern of horsts and grabens, with throws across the faults on the order of tens of metres. Rim relief varies from 30 to 80 m compared to the surrounding basement (McCleary, 1997).



New Claymore drillhole
Steen River structure (after Burwash et al., 1994)
Magnetic anomaly outlines (Bird Geophysical, 1999)
Terrane boundary (Ross et al., 1994)
Oil/gas well
Township grid
Hwy. 35

Cross-Section Lines (see Figure 24)
A - A'
B - B'

Figure 1

Location of study area, showing wells, diamond-drill holes, magnetic anomaly outlines and structural setting

10 0 10 20 km

1:500000

October, 2001

1.3.2 Generalized Stratigraphy

Basement in the Steen River area is overlain by a thick (1200 to 1500 m) succession of Phanerozoic rocks and sediments of primarily Devonian to Quaternary age (McCleary, 1997). The lowermost units directly overlying the basement are the Granite Wash and Red Beds, which vary up to 50 m in thickness (McCleary, 1997). The lowest sedimentary section in the area comprises Devonian marine sedimentary rocks, including evaporite and carbonate units of the Elk Point and Beaverhill Lake groups, overlain by a thick succession of shale and argillaceous carbonate. Included in the Devonian sequence are the Keg River carbonate and the Slave Point limestone, both prime hydrocarbon exploration targets. A major unconformity separates the Devonian sequence from the overlying Cretaceous marine shale of the Loon River and Shaftesbury formations. A thin layer of Quaternary to Recent sediments, of glacial and post-glacial origin, overlies the shale.

1.3.3 Mineralization

The potential of the Steen River area to host precious and/or base metal mineralization is not well known. However, lead-zinc mineralization has been noted along the GSLSZ–MacDonald Fault strike extension, and in shallow drillholes along faults about 5 km southeast and 20 km east of the SRS, respectively (McCleary, 1997).

1.4 Previous Work

The Steen River area is bordered to the west and south by large oil and gas fields, the Zama and Dizzy fields, and is underlain by carbonate rocks of the hydrocarbon-rich Keg River and Slave Point formations. As a result, much of the exploration conducted in the region since the early 1960s comprised drilling and geophysical surveying, with a focus on oil and gas reservoirs (Figure 1). The presence of unusual features, textures, volcanic rocks and minerals within the core promoted additional studies, by government, academic and private organizations, into the origin of the SRS (Carrigy and Short, 1968; Winzer, 1972; Mossop and Shetsen, 1994; McCleary, 1997). Detailed exploration programs, comprising airborne and ground geophysical surveying, geochemical surveying and drilling, were conducted within and around the SRS to determine its geometry and its potential to host precious and base metals (Germundson and Fischer, 1978; Brown, 1995), and more recently, diamonds (Brown, 1995; Bird Geophysical, 1999).

In the 1960s, Imperial Oil Enterprises (IOE) Limited drilled into the geophysical anomaly, now called the SRS. Geologists, expecting 1200 to 1500 m of flat-lying sedimentary rocks, encountered 184 m of undisturbed sedimentary rocks overlying 333 m of shattered pyroclastic and plutonic rocks in one of the drillholes (Steen 12-9). In addition, well IOE Steen 16-9-21-22, drilled west of Steen 12-9, intersected upper Devonian strata, dipping up to 45°, below undisturbed Cretaceous and Quaternary sediments (Carrigy and Short, 1968). Carrigy and Short (1968) investigated several of the wells in the area, including the IOE Steen wells. Samples of plutonic rock collected from IOE Steen 12-9 contained abundant pyroclastic and injection features, such as macrofractures infilled by rock dust, solid state vitrification, strain lamellae in feldspars and pyroclastic textures. Pseudotachylite and various forms of high quartz were also found in the core samples. Radiometric K-Ar dating on some of the pyroclastic and partially melted basement samples from IOE Steen 12-19 yielded an age of 95 ± 7 Ma (Carrigy and Short, 1968). Carrigy and Short (1968), uncertain whether the origin of the SRS was by meteor impact or an intracrustal volcanic explosion, noted its resemblance to other, better documented craters. However, based on stratigraphic evidence of continued tectonic activity throughout the Devonian and the presence of pyroclastic horizons in IOE Steen 12-9 and adjacent wells, they also suggested that portions of the

SRS could have formed as a result of volcanic activity subsequent to tectonic adjustment of the basement in the area.

The geometry of the SRS was later refined by Winzer (1972) using available borehole and geophysical data. Structural contours of the basement defined the SRS as an elliptical feature approximately 24 by 19.5 km in extent. The outer boundary of the structure was defined by a gentle rise of crystalline basement from outside to the annular rim syncline; inside the syncline, the rocks dropped off sharply by 180 m in the southeast and 520 m in the northwest. The rim is cut by numerous faults, infilled by sedimentary rocks of uncertain age, and overlain by undisturbed Cretaceous strata (Ibid.). The central portion of the SRS was uplifted, on average, 1280 m above the base of the rim syncline and lay 762 m above the normal basement elevation in this area. Winzer (1972) also examined cores from two of the boreholes in the area, including IOE Steen 12-9. Petrographic analysis of the samples identified several features and textures indicative of extreme shock pressures and temperatures, including suevite breccia and melt phases; planar deformation and varying degrees of asterism of quartz grains; diaplectic quartz glass; flowed glass and maskelynite; lattice disorientations; and vitrification. Analysis of isolated quartz crystals by X-ray diffraction (XRD) yielded possible a-quartz, b-quartz and coesite diffraction patterns. However, none of these could be positively identified.

In 1977, Gulf Minerals Canada Ltd. conducted drilling for base metals in the SRS's vicinity (Germundson and Fischer, 1978). Five diamond-drill holes were put down to test the Devonian Wabamun Formation and the Winterburn and Fort Simpson groups for base metals. Samples of Cretaceous shale were also analyzed for comparison. Anomalous concentrations of Zn, Pb, Cu and Ni were reported in both the Devonian carbonate and in the Cretaceous black shale. However, the geochemical results were not considered significant enough to warrant further exploration.

By the 1990s, many of the exploration programs and research conducted on the SRS were suggesting a meteor-impact origin (Mossop and Shetsen, 1994; McCleary, 1997). Simplified seismic sections across the SRS portrayed a pattern of small-scale normal faults forming horsts and grabens in the disturbed zone and cutting the raised rim. Within the rim syncline, the structure is extremely complex, with overthrusting disturbing and inverting the normal stratigraphic succession. It was suggested that the SRS could have been modified by post-impact movement on the subsurface extension of the GSLSZ and the faulted boundary between the Hottah Terrane and the Great Bear Magmatic Arc. Movement on these features may have been triggered by the impact, resulting in hydrocarbon-rich structural traps, both within and along the GSLSZ. It is more likely that impact triggered movement on the McDonald Fault, which is a late brittle feature associated with the GSLSZ (McCleary, 1997).

In the latter part of the 1990s, Troymin Resources Ltd. conducted several exploration programs, including geochemical and airborne geophysical (high-resolution aeromagnetic (HRAM) and gravity) surveys, in the region to assess the base-metal and diamond potential of the SRS (Brown, 1995; Bird Geophysical, 1999). Brown (1995) studied two key wells in the SRS, IOE Steen 12-19-121-21 and Dome et al. Steen 3-12-121-22, from which volcanic rocks and chrome mica (fuchsite?) were reported. Brown (1995) suggested that these rocks and minerals were possible evidence of Early Cretaceous diatreme-like ultramafic intrusions into the SRS complex, and compared them to known kimberlite fields in Alberta, the Northwest Territories and Saskatchewan. Brown (1995) believed that there was evidence of significant volcanism in the area, which may or may not have been triggered by the meteorite impact. He also suggested that the GSLSZ may have been a conduit for mineralized hydrothermal fluids that were the source of the base and precious metals found in the region. The results of the HRAM survey show the SRS as a distinct, elliptical, magnetic anomaly measuring approximately 17 km along its northwesterly trending long axis. Six small, roughly circular magnetic anomalies, up to 2 km wide, surround the main magnetic anomaly. A stream-sediment sampling program, conducted in 1995, yielded no diamond-indicator minerals, suggesting that kimberlite bodies, if present in the region, were either not exposed, or were eroded by glacial and or fluvial activity.

Although, the SRS was originally the focus of hydrocarbon exploration, little hydrocarbon exploration or research was reported until the late 1990s (Robertson, 1997; Mazur et al., 1999). Robertson (1997) presented an update of the latest exploration phase undertaken on the Steen River megastructure. Relying on information to date, he described the SRS as one of the only remaining lightly explored, but highly prospective areas with hydrocarbon potential in the Western Canada Sedimentary Basin that may yield significant reserves of Middle Devonian oil and gas. Mazur et al. (1999) highlighted enigmatic features that occur in seismic records, made within the Western Canadian Sedimentary Basin, in the quest for hydrocarbons. Within the framework of the current Consortium for Research in Elastic Wave Exploration Seismology (CREWES) Project, Mazur et al. (1999) have suggested that the geometry of the SRS is similar to other impact structures with associated economic resources of minerals and hydrocarbons. As a result, they believe that the SRS has potential to have associated hydrocarbon and mineral resources, but that this potential has not been fully evaluated, mainly due to its relative lack of infrastructure.

Several proposals for scientific drilling of the SRS were submitted between 1989 and 1993 (Wilson et al., 1989). These proposals, designed to study the impact of the SRS on the climate, its hydrocarbon potential and its origin, were apparently never implemented.

2 Methodology

Early in 2000, New Claymore Resources Ltd. gave permission to the AGS to log, sample and study the core from three holes drilled into the SRS (ST001, ST002 and ST003). Selected portions of the core were displayed, systematically logged in detail and sampled by AGS personnel. Various petrographic, mineralogical, geochemical and geophysical methods were used to study and analyze the cores from the New Claymore diamond-drill holes (Figures 1 and 2). Selected portions of the core from the three drillholes studied for this report included ST001 from 9.1 to 389.3 m (30 to 1277 feet), ST002 from 15.2 to 252 m (50 to 827 feet) and ST003 from 18.3 to 377.4 m (60 to 1238 feet). In total, 976.1 m of core were systematically logged in detail for lithology, macrostructures and textures, unit contacts, precious- and/or base-metal mineralization, and possible diamond-indicator minerals (Appendix 1). Initially logged by B. Molak, the core was also reviewed at a later date by R.A. Olson (EUB/AGS), S.A. Balzer (Caithness Consultants Ltd.), F. Hein (EUB/AGS, Calgary), and A. Hildebrand (University of Calgary), a recognized expert in the study of impact structures and their associated features.

Magnetic susceptibility and radiometric measurements were taken at predetermined intervals on the cores during the detailed logging. The SRS is defined by a magnetic anomaly (Figure 2), and it was thought that a systematic study of the units within the core might help to better define the source of the magnetism. Magnetic measurements, using an Exploranium susceptibility meter, were taken at regular intervals (typically about every 6 m) at the top of each core box compartment. The radiometric survey was conducted on the cores in an attempt to identify units that may be representative of a lamproitic body, which is a potential diamond host. Radioactivity of the cores from the upper parts of drillholes was also measured using a McPhar Geophysics scintillometer.

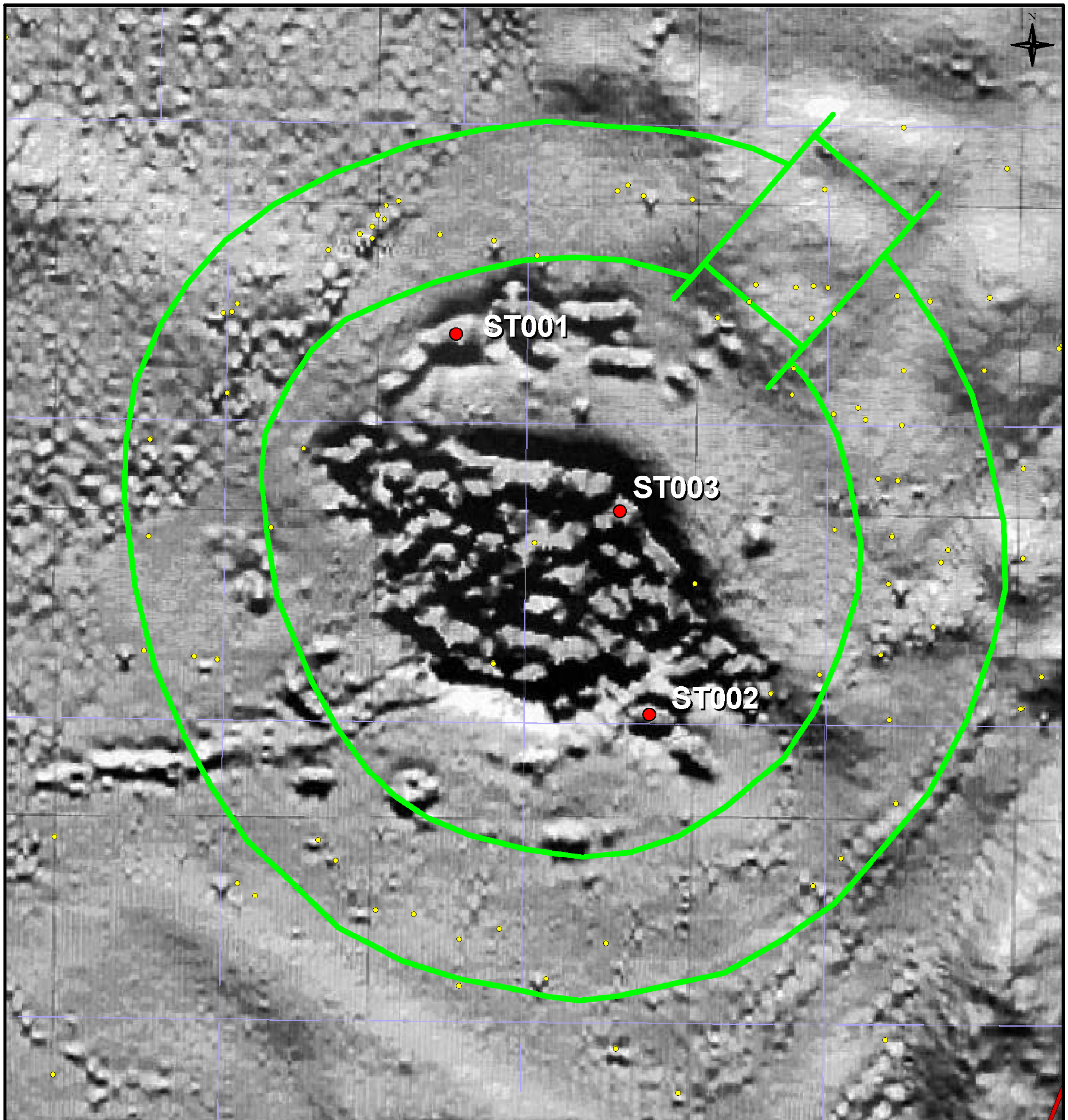


Figure 2

Airborne magnetic anomaly over the Steen River Structure, showing locations of wells and diamond-drill holes

October, 2001

A total of 150 samples were collected from selected sedimentary and breccia units within the three cores (Appendix 1). Of these, 66 samples were sent to various laboratories for petrographic, mineralogical and geochemical analysis. The intent of the analysis was to identify the nature of the minerals and rocks within the core and to classify them based on possible origin and time of formation. Attention was also paid to platinum-group elements (PGEs) and to elements indicating kimberlitic or lamproitic minerals or rocks.

3 Results

The results of the core logging, petrographic, mineralogical, geochemical and geophysical analyses are described below.

3.1 Core Logging

The drillcores contain three main lithological groups: shale with intercalated sandstone, breccia, and granite-gneiss. Detailed logs of the cores are presented in Appendix 1. Shale and sandstone comprise the upper portions of all three cores. These sedimentary units overlie a thick, brecciated unit of variable colour and composition. One of the drillholes, ST002, was abandoned in the upper part of the breccia unit before reaching the planned target depth, due to drilling problems. A granite-gneiss unit, lying stratigraphically below the breccia in ST003, likely represents the basement rock.

3.1.1 Drillhole ST001

3.1.1.1 Shale-Sandstone Unit

The upper portion of drillhole ST001, between 9.1 and 275.5 m, comprises a thick sequence of finely bedded, marine, black to grey, silty shale with numerous intercalations of grey to green sandstone and occasional ironstone. The shale and sandstone are cut by thin veinlets of fibrous anhydrite (selenite) and/or calcite. Sulphide and sulphate minerals, represented by pyrite, marcasite and, in a few places, barite and possibly chalcopyrite, occur as crystals or in disseminated nest, veinlet clusters or stratified forms, in both the shale and the sandstone.

The shale is primarily noncalcareous, although several intercalations of calcareous shale are present. The shale colour and composition variances are represented by thick laminae to semimassive beds. Locally fossiliferous and bioturbated, the shale contains abundant brachiopod fragments, fish scales and worm burrows. The fish scales appear to be restricted to a bioturbated zone in the core between 43.3 and 75 m (Appendix 1). Shells and other fossil fragments are also common between 244.8 and 246.6 m. An ironstone intercalation, possibly composed of fine-grained siderite, was found at 228 m. There are also several intercalations of a grey, locally biotitic rock, similar in texture to a tuff, below 137 m. Disseminations and stratified clusters of sulphide minerals (pyrite and marcasite) occur locally within the shale and in bands associated with a pink crystalline mineral below 264 m. A green clay-like mineral (glauconite) and a clear glassy mineral appear in the shale below 230 m, becoming more abundant within the shale and the intercalated sandstone with increasing depth.

Sandstone, intercalated with the shale, varies from grey, calcareous to noncalcareous units with ripples and cross-bedding, to greenish grey, glauconitic units with calcite veining. The frequency and thickness of the sandstone units appear to increase with depth. Unit thickness varies from intercalations only 20 cm thick in the upper portions of the core, to 3 m thick units within conglomeratic bands overlying the breccia. Ripple marks, cross-bedding and fining-upward sequences with silty and conglomerate horizons typify the lowermost greyish sandstone unit. In the green glauconitic sandstone, the glauconite appears to represent up to three-quarters of the rock volume.

3.1.1.2 Breccia

The upper contact of the breccia unit, at approximately 275.6 m, is disturbed, weathered and appears almost gradational with the overlying shale and sandstone unit. Desiccation cracks are prevalent in the core along the contact area down to 281.4 m. Clasts of breccia are found a few centimetres above in the overlying shale. Compact and grey to olive or khaki green in colour, the upper portions of the breccia contain a very fine grained matrix and support large subangular to angular limestone clasts and granite lithoclasts. This section of the core is locally very calcareous.

The breccia begins to develop a reddish tinge at about 291.8 m, and contains increased amounts of dark red to black fragments and rinds of melted glass. By approximately 308 m, much of the reddish tinge is gone, but the breccia groundmass is still quite green. At this depth, the breccia contains large crystals, abundant vugs and glass melt (Figure 3). The breccia matrix has a feather-like appearance. Disseminated sulphide minerals appear locally. At depths over 309 m, the number of large (up to 30 cm in diameter) clasts of subrounded, altered granite lithoclasts rimmed by black pitchstone increases. Several of the granite lithoclasts are fractured, containing displaced segments (Figure 4). Larger subrounded fragments of white limestone and veins of fibrous anhydrite become prevalent below 370 m and continue to the end of the drillhole at 389.3 m.

3.1.2 Drillhole ST002

3.1.2.1 Shale-Sandstone Unit

The upper portion of drillhole ST002, between 15.2 and 224 m, comprises the same thick sequence of finely bedded, marine, black to grey, silty shale with intercalations of grey to green sandstone that was described in drillhole ST001. Like ST001, the shale and sandstone are cut by thin veinlets of anhydrite, or selenite, with fibres oriented subperpendicular to the strike of the vein. Striated anhydrite lenses were also noted at 77.4 m. Sulphide minerals, represented by pyrite, marcasite and possibly chalcopyrite, are more prevalent than in ST001, and occur primarily in disseminated, nest, veinlet cluster or stratified forms in the shale.

The shale in ST002 is similar to that in ST001, and varies from thick laminae to semimassive in structure. However, much of the shale appears to be more calcareous than in ST001, and the sandstone intercalations are less frequent and more calcareous. Locally fossiliferous and bioturbated, the shale hosts a fish scales unit between 50 and 80 m (Appendix 1). Several of the sandstone units contain petrified organic material. Traces of solidified bitumen were found in slightly glauconitic sandstone at 196 m. As in ST001, the shale-sandstone unit contains intercalations of a grey rock speckled with a white mineral (albite?).

3.1.2.2 Breccia

The upper contact of the breccia, at a depth of 224.1 m, is conformable with the overlying shale unit. Some disturbance at the contact is evident, with small clasts of breccia found a few centimetres up into the shale and pyritic shale fragments occurring within the upper few centimetres of the breccia. The breccia is very similar in appearance to that described in ST001. Grey to green in colour, the breccia is polymictic and lithoclastic in texture. The upper portion is weathered, loose and much greyer in colour.

Figure 3. Cavity filled by calcite in suevite breccia, 320.1 m in drillhole ST001. Scale marked in centimetres.

Figure 4. Suevite breccia composed of grey to olive green, clayey matrix with shocked angular quartz and feldspar grains, granite lithoclasts and Fladen, 369.5 m in drillhole ST001. Note the fracture and displacement in the granite lithoclast encased in pitchstone (arrow). Pink K-feldspars in the granite are zeolitized. Scale marked in centimetres.

It becomes more compact and greener below 227 m, containing abundant white calcite veinlets and subrounded lithoclasts of altered granite and limestone. Many of the lithoclasts are rimmed by a green clay mineral (montmorillonite). Black, glassy particles and lenses are not as abundant as in ST001. Also unlike ST001, the breccia in ST002 does not contain glassy vugs infilled with large crystals. The breccia changes little in appearance or apparent composition until about 245 m. From 245 m to the end of the core at 252.1 m, the breccia contains less altered granite lithoclasts, several of which are rimmed or bordered by violet devitrified glass.

3.1.3 Drillhole ST003

3.1.3.1 Shale-Sandstone Unit

The upper portion of ST003, between 18.3 and 205.6 m, contains the same thick, dark grey, fossiliferous, silty shale, with intercalated sandstone units and possible volcanic material, as described in ST001 and ST002. The fish scales unit was encountered between 45.7 and 70.1 m depth. Calcite and anhydrite veinlets are common. Sparse sulphide minerals, including pyrite, marcasite and possibly pyrrhotite, are present in crystalline and disseminated forms throughout the unit. Like ST001, several of the calcareous sandstone units display cross-bedding between 203 and 205.4 m. Some of the calcareous sandstone intercalations contain sulphide-rich bands (Figure 5). Intercalations of microbreccia start to appear immediately above the contact with the underlying breccia, at 205.3 m.

3.1.3.2 Breccia

The upper contact between the shale unit and the breccia, between 205.3 and 206 m, is disturbed and intercalated. Two shale olistoliths, one 5 cm and the other 25 cm thick, mark the contact. The upper portion of the breccia is similar in appearance to that described in ST001. Loose, friable and weathered, the breccia is pale greyish green, and contains chloritized biotite and altered granite lithoclasts. Calcareous sections within the core are common. The breccia develops a distinctive reddish tinge around 223 m that increases in intensity with depth to various shades of pink and violet. The core loses the reddish tinge at 239.9 m, and becomes magnetic. Granite lithoclasts are commonly zeolitized to various degrees (Figures 6 and 7) and contain numerous vugs and veins infilled by possible stilbite (Figure 8). Fractures in the lithoclasts are infilled by black melt in the same manner as in ST001 (Figure 9). Disseminated crystals of pyrite and possible pyrrhotite are sparse, but found throughout the breccia unit. Toward the bottom of the core, the breccia is progressively replaced by pitchstone, which comprises dark to black melt rock with blocks of more or less vitrified granite-gneiss lithoclasts (Figures 7, 10 and 11). The pitchstone is dark grey, brown or black in colour, aphanitic in texture and magnetic. It contains small, white, angular, shocked and vitrified quartz and feldspar fragments, and amygdules lined with clay, vermiculite (?), chlorite (?), calcite and zeolites. Amygdule centers are commonly hollow. Magnetite occurs as very small black grains or irregular clusters, frequently attached to or rimming large grains, or forming disseminations in the melt. Lath-shaped feldspar microlites (trichytes) are aligned in flow bands around larger inclusions.

3.1.3.3 Granitic Basement Unit

The lowermost unit, which was intersected in the ST003 core, comprises a coarse-grained biotitic granite rich in potassium feldspar that changes downhole into possibly granodiorite or orthogneiss. Fragments of this unit were intersected in the lower half of the overlying breccia, but the unit did not dominate core composition until approximately 362.7 m. Fine-grained granite exists intercalated with pitchstone near the upper half of the unit. Deformation and vitrification features also are present. The

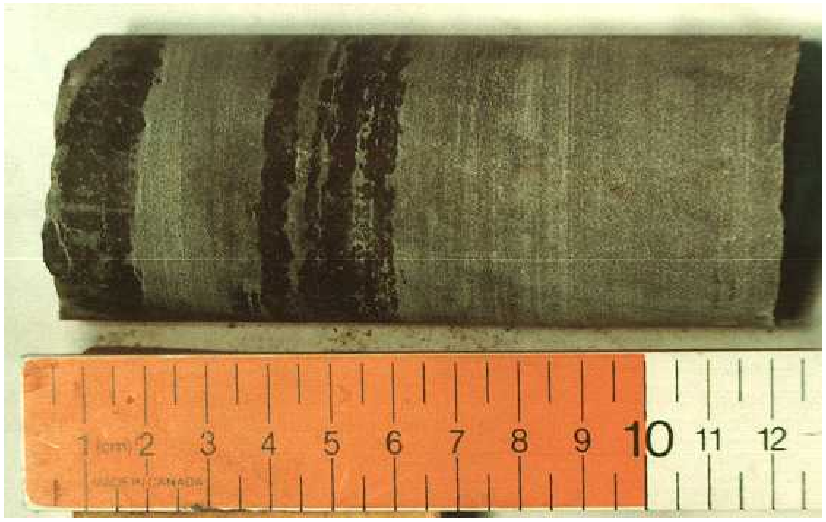


Figure 5. Dark bands rich in pyrite and barite in calcareous sandstone, 200.7 m in drillhole ST003. Scale marked in centimetres.

Figure 6. Strongly shocked magnetic granite lithoclast, with biotite replaced by magnetite, and feldspar (pink) replaced by zeolites, 343.9 m in drillhole ST003. Note the suevite breccia with Fladen (black lenses) on the right. Scale marked in centimetres.

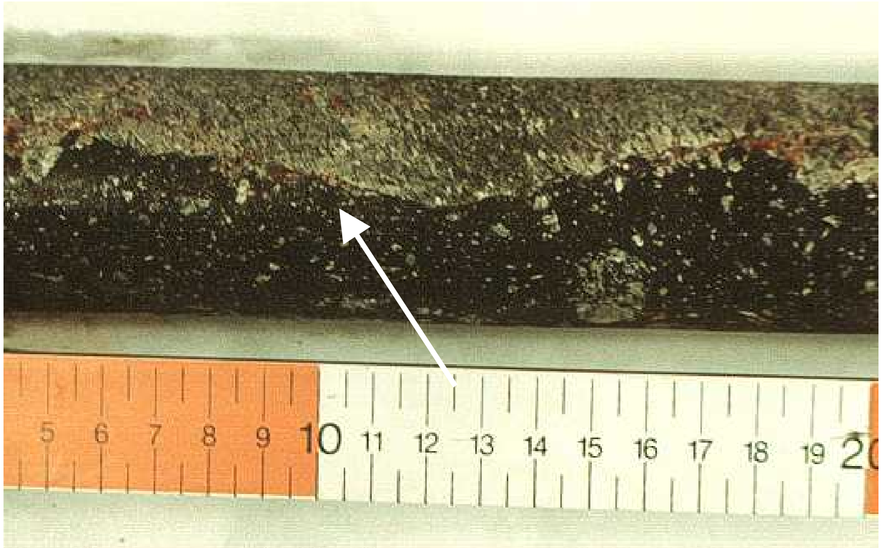


Figure 7. Chilled contact between granite and black pitchstone with minute diaplectic quartz and feldspar grains, 345.7 m in drillhole ST003. Note the pink zeolite occurring locally along the contact (arrow). Scale marked in centimetres.

Figure 8. Vug and vein of pink to orange stilbite in granite with zeolitized K-feldspars, 272.1 m in drillhole ST003. Biotite is oxidized and transformed into magnetite. Prismatic Na-K-Ca stilbite fills the vug, and radial, needle-like Na-Ca stilbite fills the vein. Scale marked in centimetres.

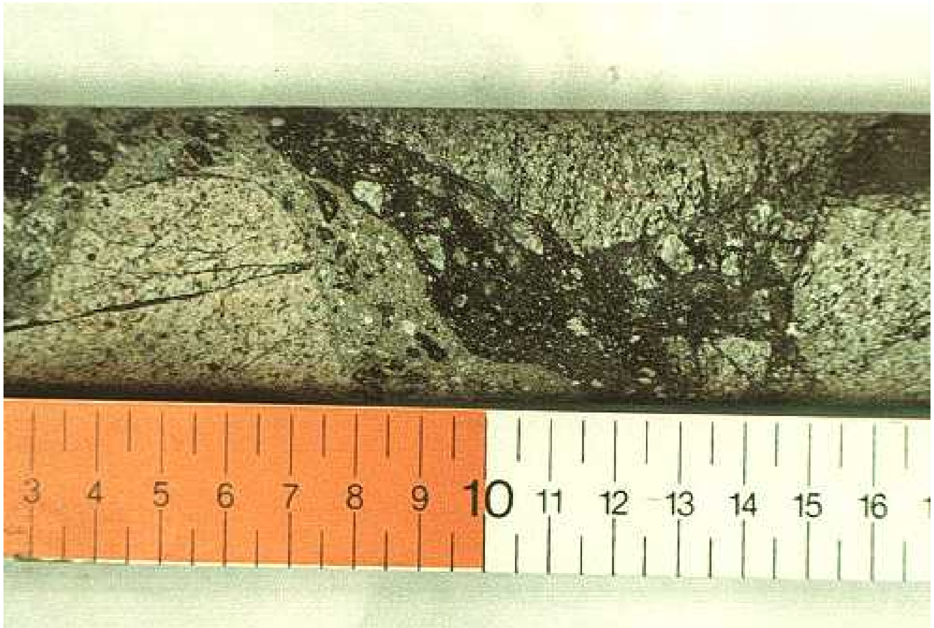


Figure 9. Shocked granite lithoclasts in suevite breccia and pitchstone, 283.9 m in drillhole ST003. Fractures in granite are injected by black melt; biotite and amphibole were oxidized to form magnetite. Scale marked in centimetres.

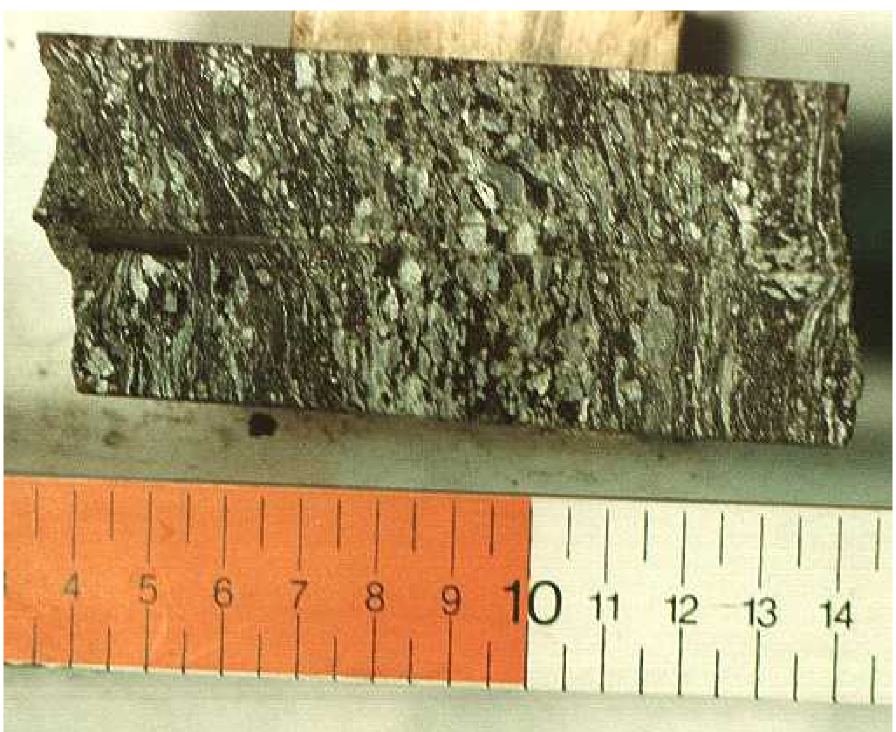


Figure 10. Vitrified (sintered) granite with flow textures, 335.8 m in drillhole ST003. Scale marked in centimetres.

Figure 11. Granite lithoclasts separated by pitchstone, 344.4-350.0 m in drillhole ST003. Note the strong flow texture in the vitrified granite lithoclast on right. Biotite in the granite is replaced by magnetite and the feldspar is zeolitized. Scale marked in centimetres.

Figure 12. Basement granite-gneiss with a fracture infilled by rock dust (arrow), 375.6 m in drillhole ST003. Scale marked in centimetres.

majority of these features, however, are overprinted by argillization, chloritization and zeolitization. Comminuted material (rock dust) was observed infilling fractures in the upper parts of the unit (Figure 12).

3.2 Magnetic Susceptibility Survey

Magnetic susceptibility measurements were taken on the three cores, between 223 and 387.8 m in ST001, between 203.8 and 252.1 m in ST002, and between 200.5 and 374.1 m in ST003. Although most of the readings were collected from the breccia unit (Appendix 2), readings were also taken from the lowermost portions of the shale and sandstone, and from the underlying granite unit, for comparison.

In general, the uppermost portion of the three cores, including the shale, sandstone and grey to green breccia units, shows negligible to very little magnetic susceptibility (Appendix 2; Figures 13, 14 and 15). In constrast, the green breccia in drillholes ST001 and ST003 show an increase in magnetic susceptibility with increasing depth (Figures 13 and 15). The magnetic signature does not increase significantly, however, until the breccia loses its deep reddish tinge and becomes much greener. Increased magnetism is restricted primarily to several intervals within ST001 and ST003. In ST001, higher but extremely variable magnetic measurements occur between 294 m and 311 m, 323 m and 340 m, and 363 m and 379 m (Figure 13). Extremely high magnetic values were associated with a granite lithoclast sample at approximately 352 m, and a pitchstone sample at 363 m. Between these aforementioned intervals the magnetic measurements are highly variable, but with no consistent trends. In ST003, elevated magnetic susceptibility values start at approximately 240 m and continue to the end of the hole (Figure 15). As in ST001, the highest values are associated with increased amounts of granitic lithoclasts and pitchstone in the core.

3.3 Scintillometer Survey

Radiometric measurements taken on the three cores did not show significant variations in radiation values within the major lithological groups. Most of the readings were at or slightly above background levels. Appendix 3 summarizes the general range of values for various lithological groups in the cores. A small increase in radioactivity was noticed with increased depth and granitic rock content in the core.

3.4 Petrography

A total of 61 samples, 51 (plus three duplicates) by the AGS and seven by New Claymore Resources (NCR), were collected from selected units within the three holes and sent for petrographic analysis. Most of the samples were collected from the breccia unit found within all three cores. A few representative samples from the shale-sandstone and granite-gneiss units were also collected for comparison.

Sixteen of the AGS samples, mainly from the breccia units, were submitted for thin-section preparation (17 in total) to Calgary Petrographics Ltd. These 17 thin sections, (P5, P9, P10A, P12, P15, P19, P28, P30, P36, P39, P40, P42A, P42B, P43, P44, P46 and P47) were studied under the polarizing microscope at the AGS. The seven NCR samples (1521007, 1631225, 243826, 346917, 3541068, 3591154, 3611195), which initially were sent to Lakefield Research for petrographic analysis by New Claymore, were also assessed. The results of both petrographic studies are described in Appendix 4.

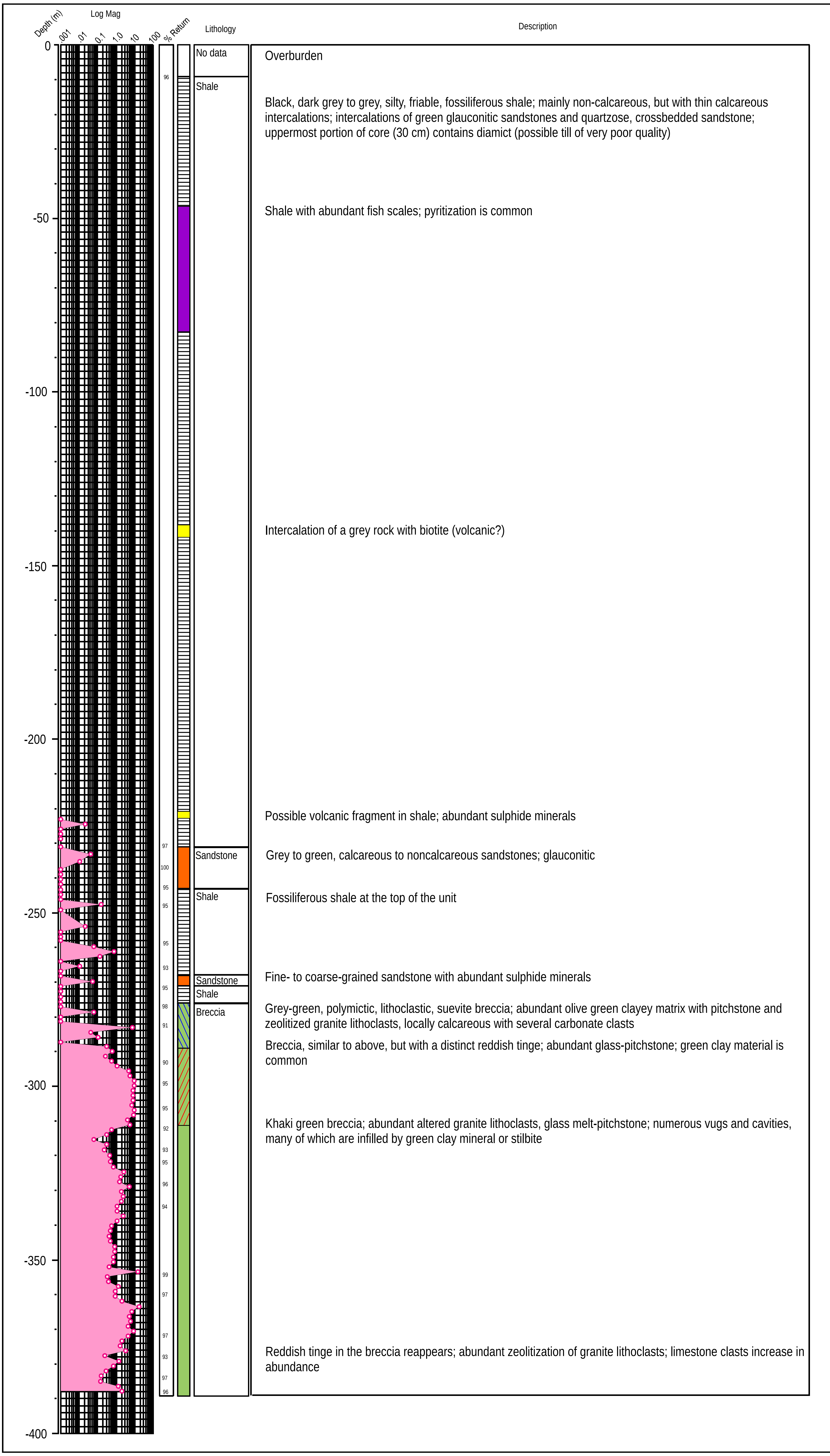


Figure 13. Magnetic susceptibility log and generalized lithological description of drillhole ST001.

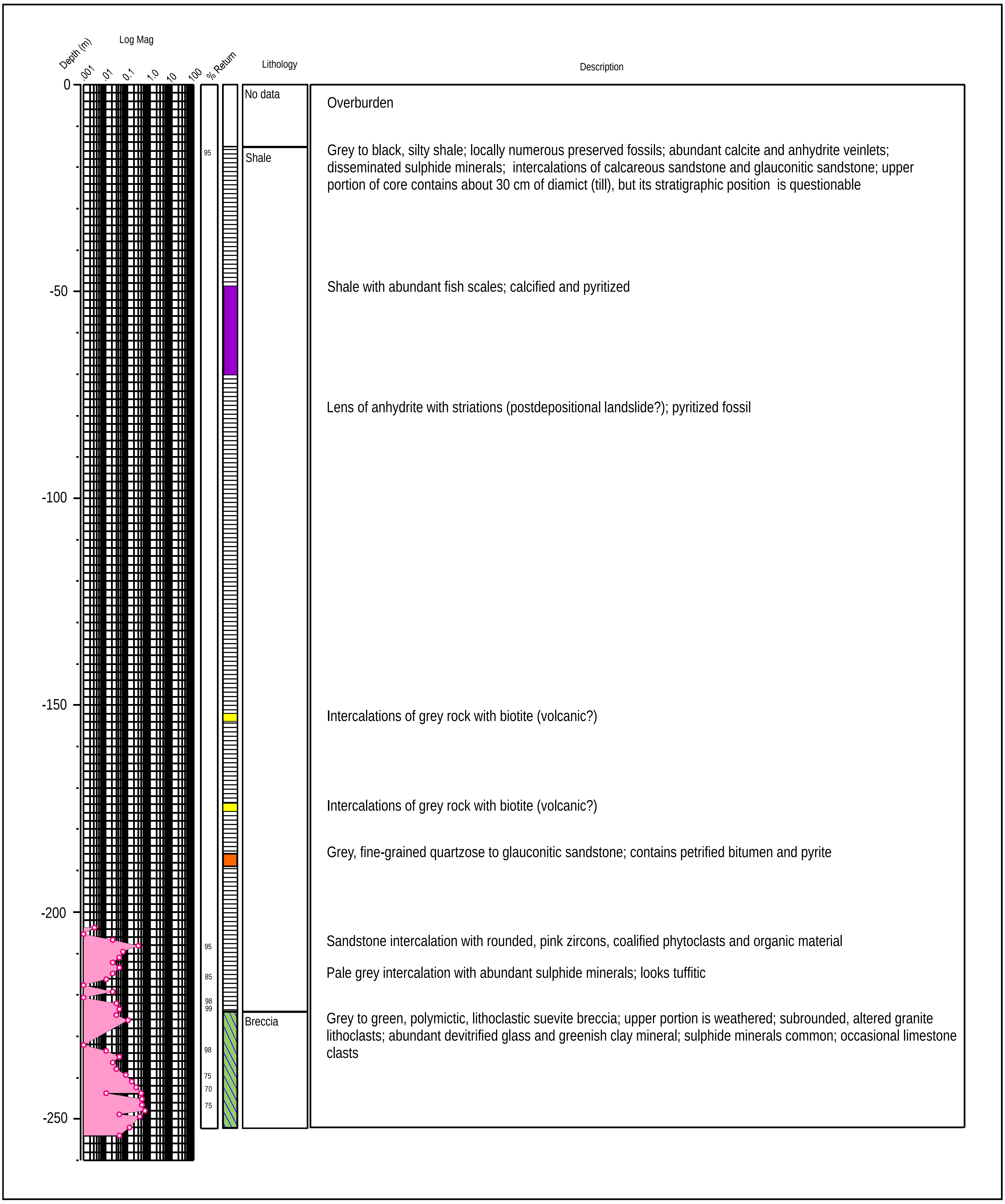


Figure 14. Magnetic susceptibility log and generalized lithological description of drillhole ST002.

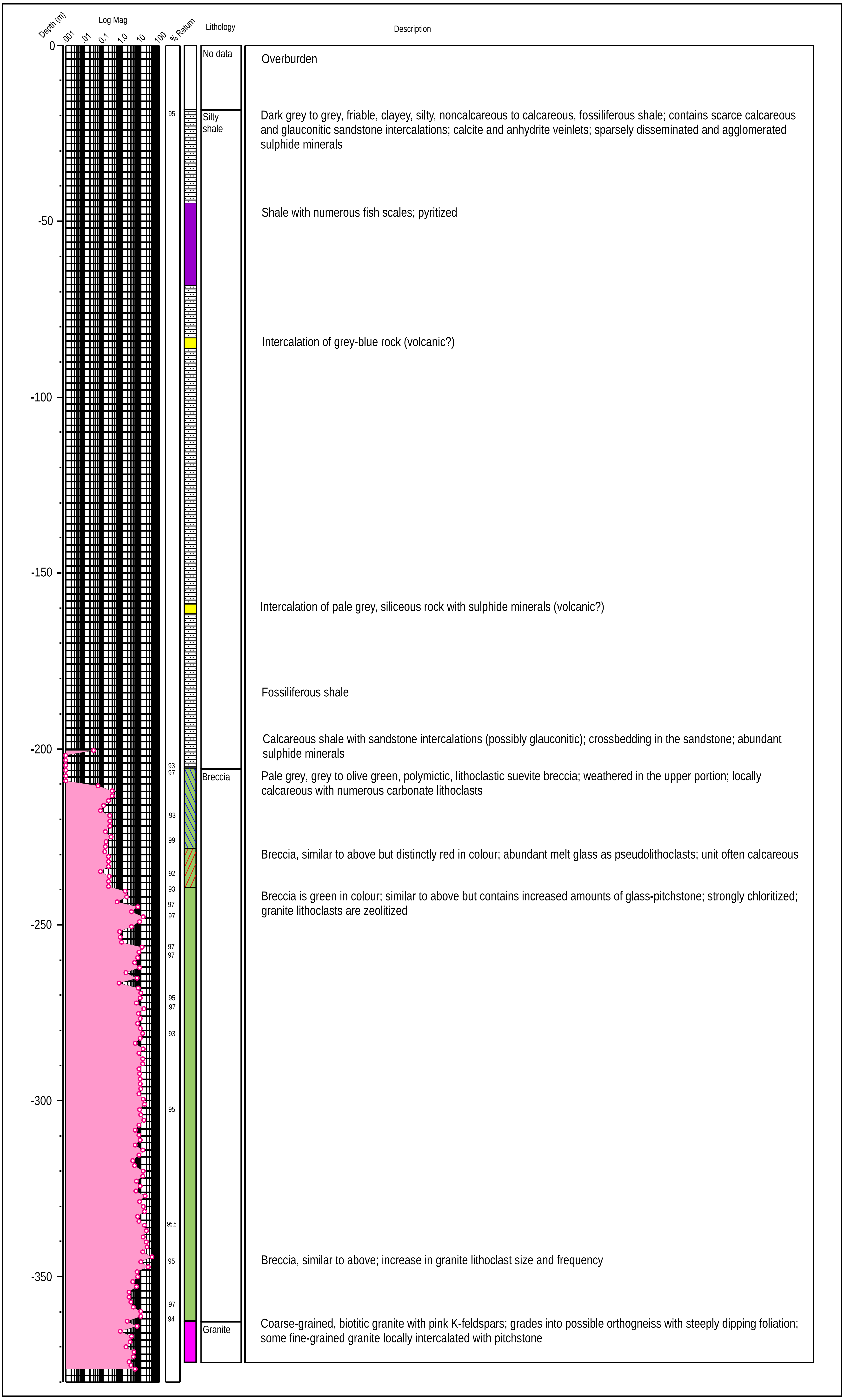


Figure 15. Magnetic susceptibility log and generalized lithological description of drillhole ST003.

Six of the NCR samples (1521007, 1631225, 243826, 346917, 3541068, 3591154) and seven of the AGS samples (P05, P09, P10A, P19, P30, P36, P39), all from the breccia unit, were identified as suevite breccia on the basis of dark brown lumps of amygdaloidal glass, Fladen and/or granite and carbonate lithoclasts (Figure 16). Quartz within the suevite breccia and in granitic lithoclasts shows cataclasis, planar deformation features (PDFs) and vitrification features, including 1) extreme undulatory extinction and decoration caused by bubbles or mineral inclusions, 2) plastic deformation, 3) diaplectic glass, and 4) development of glass, locally composed of globular clusters (ballen textures) enclosed in devitrification products (chlorite?). Some diaplectic quartz recrystallized to form fine mosaics. Feldspars are strongly cataclastic, contain PDFs and decorations, and have cloudy extinction grading to opacity and brown colour that may be due to alteration to clay and iron oxides. The albite twinning in many grains has an alternative, shock-generated oblique twinning, and diaplectic glass (maskelynite) occurs in the grains. Feldspar microlites developed in the melt phases. Amphibole shows mechanical twinning; loss of birefringence and pleochroism; and, locally, opaque decomposition, oxidation and replacement by magnetite. Biotite, when present, is kinked and may be partially oxidized. Vesicles within the breccia unit are outlined with clay, zeolite and possibly chlorite (Figure 17). Argillization of glass, progressive zeolitization, and possible chloritization of biotite are also seen in the thin sections. Carbonate lithoclasts are strongly shocked, often decorated, and either have reduced birefringence or are opaque. Several of the lithoclasts are associated with pyrite (P05, P36).

Samples NC 3611195 and P46 were identified as vesicular pitchstone with heat-shocked granodiorite (NC 3611195). The pitchstone contains irregularly shaped glass with partly melted quartz and feldspar inclusions. Flow structures are evident. Feldspar and quartz locally show signs of devitrification (chloritization?) and zeolitization. Seven of the remaining nine samples (P28, P40, P42A, P42B, P43, P44, P47) were identified as granite, granodiorite and orthogneiss, some of which have undergone partial or extensive vitrification and show various PDFs. Quartz and feldspar grains are strongly undulose, isotropic or recrystallized, and often deformed and elongated with or without melt rock (pitchstone). Glassy material is locally replaced by zeolite minerals (Figure 18). Small black grains or irregular clusters of magnetite locally replace biotite and amphibole (Figure 19). Sample P47, which is from the ‘basement’ granitic unit in ST003, was identified as a shocked biotite-amphibole granodiorite. The sample shows signs of extreme deformation and brecciation and rock dust occurs within the sample matrix. In addition, the sample shows signs of argillization, chloritization and zeolitization.

The remaining two samples, P12 and P15, were collected from the upper shale unit of ST001. Sample P15 was identified as glauconitic sandstone, with high proportions of glauconite (glauconite:quartz ratio of 4:1). The remaining sample, P12, was identified as an ironstone accumulation.

3.5 Mineralogy

The mineralogical study was based on X-ray diffraction (XRD) on minerals selected during the core logging of drillholes ST001, ST002 and ST003 (Appendix 1). Minerals were identified by their diffraction patterns. The study was extended to clay minerals and an attempt was made to isolate coesite and stishovite from granite inclusions in the breccia. Stishovite and coesite are high-pressure polymorphs that do not occur naturally under near-surface conditions.

In total, 29 laboratory samples from 24 core samples were prepared using the powder and/or clay method, as described in Appendix 5. These 29 samples were analyzed by D. Goulet using a Siemens D5000 diffractometer at the Alberta Research Council. The XRD method was used to identify and confirm selected minerals present in the core from the Steen River drillholes. Powder diffraction data cards were used to interpret the resulting patterns (Appendix 5).

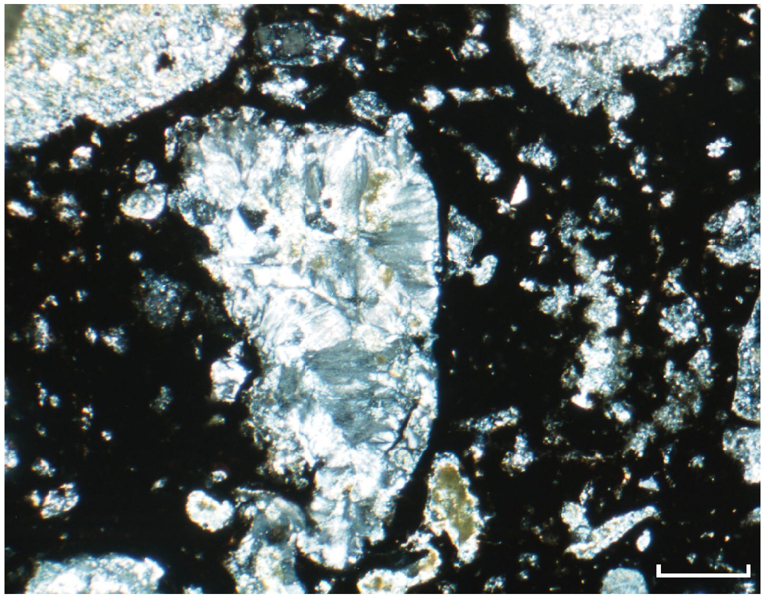


Figure 16. Photomicrograph of black impact melt rock (Fladen) with amygdules filled by sheaf-like zeolite(stilbite?) aggregates and small angular quartz fragments in suevite breccia, sample 3541068 from 325.5 m in drillhole ST003. Cross-polarized light; magnification 120X. Scale bar equals 0.1 mm.

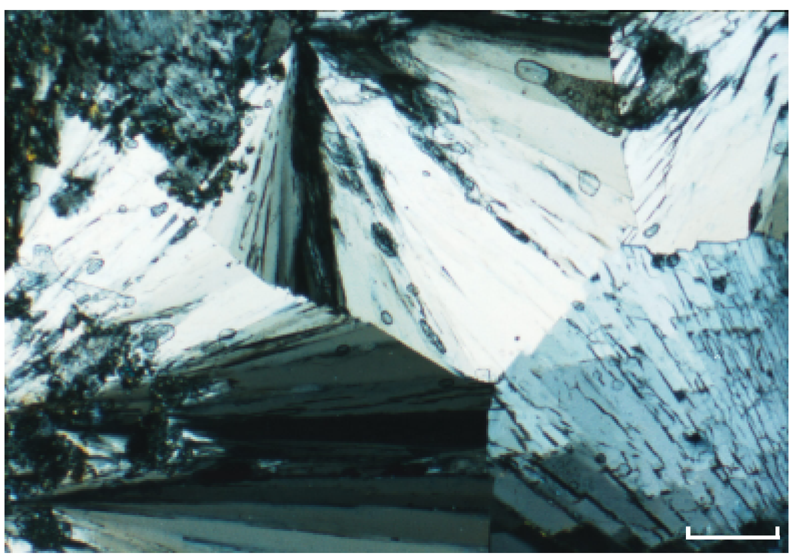


Figure 17. Photomicrograph of zeolite (stilbite?) aggregates filling an amygdule in suevite breccia, sample 3541068 from 325.5 m in drillhole ST003. Cross-polarized light; magnification120X. Scale bar equals 0.1 mm.

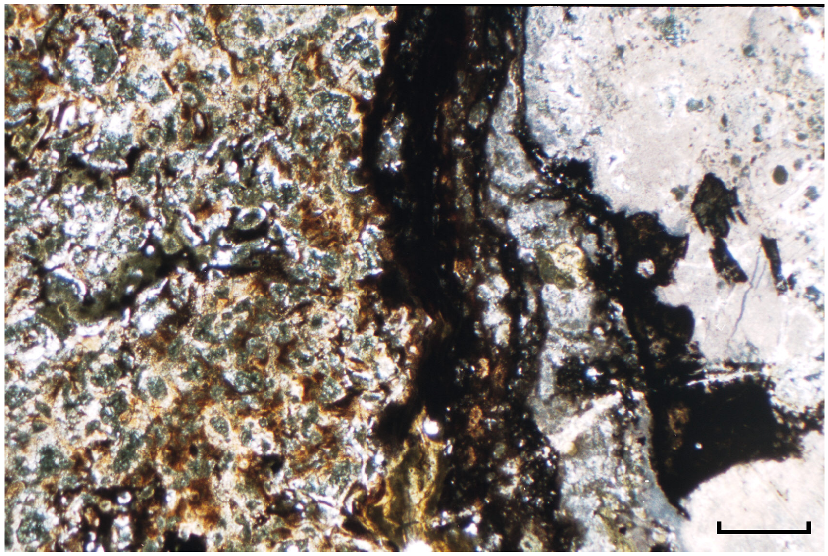


Figure 18. Photomicrograph of melt phase (brown and black on left) with argillic and zeolitic amygdules (green, yellow and white), sample P28 from 332.2 m in drillhole ST001. Basement granite (on the right) is composed of oxidized biotite (black) with magnetite and feldspar (white and yellowish grey); feldspar is largely isotropized and glassy parts are stained by clay and iron oxides(?). Contact contains black glass with schlieren and inclusions. Plane polarized light; magnification 120X. Scale bar equals 0.1 mm.

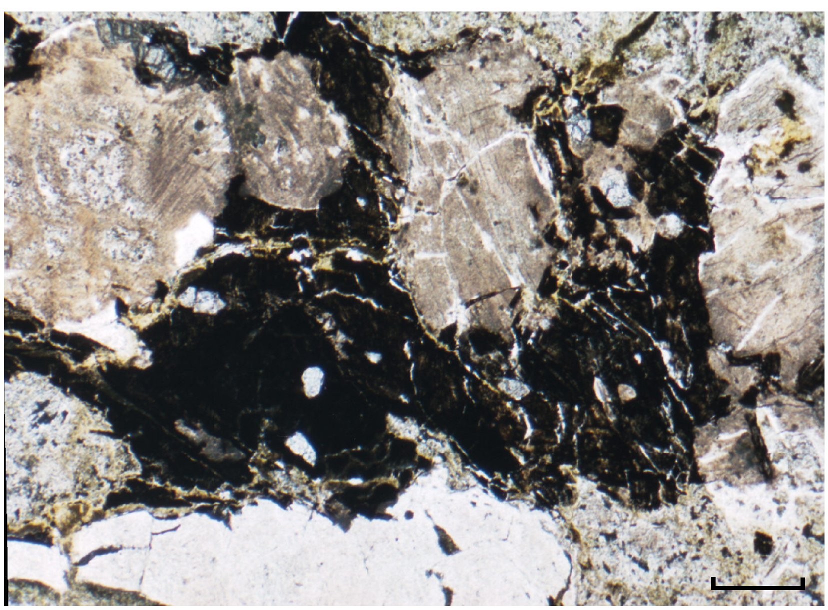


Figure 19. Photomicrograph of biotite and amphibole (black) in basement granodiorite, sample P28 from 332.2 m in drillhole ST001. Both biotite and amphibole were oxidized during the impact and largely transformed into magnetite (and maghemite?). Pale brown and white grains are diaplectic feldspars. Plane polarized light; magnification 120X. Scale bar equals 0.1 mm.

3.5.1 Iron Sulphide Minerals

Sulphide-bearing samples were collected from the shale units in ST001 (M07), ST002 (M03) and ST003 (M22), and from the breccia unit in ST003 (M34). Pyrite was confirmed by XRD, and occurs in disseminated form, as small grains accumulated in bands within pale grey, silty, noncalcareous or calcareous, locally laminated shale; or as small irregular bodies or nests, 2 to 3 cm across, composed of cubic crystals. In the breccia, the pyrite is finely disseminated in glass, locally forms cubic crystals, or is concentrated in the rims of devitrified glassy grains. Marcasite, also confirmed by XRD, is associated with pyrite in disseminated and agglomerate form, controlled by bedding in calcareous, locally laminated shale and in black noncalcareous shale.

3.5.2 Barite

Samples from the shale (M22) and breccia unit (M27) in ST003 confirmed the presence of barite in the core. The barite tends to associate with both pyrite and marcasite in black noncalcareous and pale grey calcareous shale, and with calcite in grey calcareous suevite breccia containing calcareous fragments or matrix.

3.5.3 Calcite

The presence of calcite in the shale and breccia units was confirmed in drillholes ST001 (sample M09, M18) and ST003 (samples M27, M30, M31, M32). In the shale, calcite may form in extensional veins (M09); in the breccia, it occurs as veinlets or crystals in vugs (M18), or as one of the minerals replacing the impact glass (?), including clay minerals, chlorite and quartz (M27, M30, M31, M32).

3.5.4 Magnetite and Hematite

The presence of magnetite and hematite was confirmed in sample M35, which was collected from the breccia in drillhole ST003. Magnetite occurs in the form of small irregular grains, clusters of tiny grains that are locally globular or elongated, or skeleton-shaped grains in shocked granite and melt rocks. It was extracted from an altered granite lithoclast, about 15 cm across, in which strong magnetization was indicated in what appeared to be biotite- and amphibole-rich domains. The X-ray pattern also shows a subordinate amount of hematite.

3.5.5 Zeolite Minerals

Samples M17, M18A, M18B, M36, M36A, M37 and M38 were analyzed to determine the type of zeolite minerals present. Four zeolite types were identified: analcime, stilbite, laumontite and leonardite. Analcime was found to occur in two polytypes: $(Na,K)Ca_2Al_5Si_{13}O_{36}$•14 H_2O and $(Na,K)Ca_{1.5}NaO$•$32(SiAl)_9O_{18}$•8.5 H_2O. Laumontite typically occurs in veins and cavities of igneous rocks and as an alteration product of plagioclase and glass. It easily looses about an eighth of its water to become leonhardite, a chalky and friable variety of zeolite.

3.5.6 Gypsum

Sample M19A confirmed the presence of gypsum in the core. Gypsum was noted in all three holes, mainly in the form of veinlets that cut across the shale and breccia. Typically, its texture is fibrous and oriented approximately perpendicular to the strike of the veinlet. Most veinlets are clear and resemble selenite.

3.5.7 Clay Minerals

Samples M5A, M11, M14A and M34A were analyzed to identify or verify the clay minerals found in the cores. Three types of clay minerals were identified by their diffraction peaks:

- illite-kaolinite (9:1 ratio), probably derived from glauconite (as its dull green colour, diffraction peaks at 0.2592 and 0.4537 nm and mode of occurrence suggest) and forming cement in a glauconitic quartzose sandstone bed that can be identified in all three holes;
- montmorillonite, which occurs in two devitrification product forms, the first affecting the fine glass matrix in suevite microbreccia and the second the glassy lenses that probably developed from calcareous materials; and
- a mixed-layer clay mineral composed of vermiculite–swelling chlorite (V-Cg) or chlorite-montmorillonite (C-M), another devitrification product of the melt phases.

3.5.8 Isolation of Coesite and Stishovite

These two high-pressure SiO_2 polymorphs, considered to be meteorite-impact indicator minerals, had not yet been unequivocally identified in the Steen River Structure impactite rocks. In an attempt to isolate them, the acid-digestion method proposed by Stöffler (1971) was used on three of the less shocked samples (one from each borehole) to remove the host quartz glass and other silicate phases. After two steps of isolation, the X-ray diffraction did not confirm the presence of coesite in the residues. A third step, the isolation of stishovite by dilution of quartz, aluminosilicates and glass phases was considered, but never completed.

3.6 Geochemistry

A total of 13 samples, including three suevite breccias (G22, G32, G11), three pitchstones (G38, G39, G40), two granitic rocks (G33, G41) and five sedimentary units (G02, G13, G16, G18, G35) from the overlying formations, were analyzed for oxides using the whole-rock analysis X-ray fluorescence (WRA-XRF) method and for 48 trace elements using the inductively coupled plasma (ICP) method. The results are given in Appendix 6. Three duplicate samples (G52, G69, G70) were submitted to check the precision of the analytical methods used (see Appendix 6). The intent of the geochemical analyses was to compare the chemical composition of SRS samples with the compositions of diatreme rocks, to use petrological diagrams in interpretations and to assess the amounts of precious metals in the shale. This information was vital in the development of genetic reconstructions.

Increased contents of Fe, Mg and Ca were found in some of the breccia (G11), shale (G35), sandstone (G13) and pitchstone (G38) samples. The elevated LOI values suggest that the increases in the aforementioned samples may be representative of carbonate rocks. The shale and sandstone samples also show increased amounts of As, Ba, Bi, Cr, Mn, Mo, Ni and Zn. Elevated Cr is associated with the glauconitic sandstone (sample G16). Barium is anomalous in samples G02 and G18, both of which are shale with sulphide and barite mineralization. Sample G13 contained tiny opaque mineral grains within the sandstone. The WRA-XRF analysis yielded values of 43.6% FeO and 30.4 % LOI, suggesting that the mineral may be siderite.

The pitchstone sample (G38) is anomalous, containing elevated concentrations in Mn, Sr, Y and the rare-earth elements Ce, Eu, La, Lu, Nd, Sm, Tb and Yb. The geochemistry of the breccia samples is relatively homogeneous, with very few elevated or anomalous results. The most notable exception is sample G11, a suevite breccia, which yielded the highest concentration of Sr (2810 ppm).

4 Interpretation

4.1 Core Logging

The stratigraphic sequence portrayed within the three drillholes is comparable and can be summarized in a generalized stratigraphic column (Figure 20). All of the cores intersect a relatively thick sequence of shale with intercalated sandstone beds and a distinctive fish-scale horizon. The contact with the underlying breccia is conformable but disturbed, and occurs at depths between 206 and 276 m. The breccia unit changes with depth, from a grey-green colour to a reddish zone with increased alteration. Below the reddish zone, the breccia regains its greenish tinge, becomes magnetic, and the amounts of granite-granodiorite lithoclasts, melt bodies and pitchstone in it increase. The lower contact of the breccia unit is gradational into the underlying granitic basement, and is identified primarily by the prevalence of granitic material in the core. The three major stratigraphic units are described in more detail below.

4.1.1 Shale and Sandstone Unit

The upper parts of the three drillholes are represented by marine shale with psammitic (±psephitic) and volcanic (?) intercalations of the Loon River and Shaftesbury formations of Early to early Late Cretaceous age. The contacts are disturbed, with clasts of breccia found a few centimetres up in the overlying shale and with olistoliths (5 to 25 cm thick) occurring as much as 40 cm away from the main contact, suggesting postdiagenetic submarine slides. It is believed that the psammitic and calcareous facies of the Loon River and Shaftesbury formations were deposited in the subtidal to pelitic and aleuritic facies of a basinal paleoenvironment. The basinal black shale was deposited under anoxic conditions. Abundant brachiopod fauna and fish scales in some of the shale units indicate periods of prolific marine life after the SRS event. The sandstone contains ripple marks and cross-bedding of probable marine origin and fining-upward sequences with silty and conglomeratic horizons. In glauconitic sandstone, the glauconite (confirmed by XRD) accounts for as much as three-quarters of the rock volume. Traces of solidified bitumen were found in slightly glauconitic sandstone at a depth of 196 m in drillhole ST002. This sandstone may be part of the Bluesky Formation in the lower part of the Loon River sequence. The calcareous cement in sandstone is probably marine in origin. Sulphide minerals, represented by pyrite, marcasite and, in a few places, chalcopyrite(?) and barite, occur in disseminated, nest, cluster or stratified forms. All but chalcopyrite were confirmed by XRD (Appendix 5).

Thin intercalations (mostly less than 10 cm thick) of a problematic, locally biotite-bearing or altered rock have been observed in the core between 137 and 217 m. Occurrences of volcanic rocks related to post-impact volcanic activity were reported by Carrigy and Short (1968) and Brown (1995). If these intercalations prove to be of a volcanic origin, then the paleoenviron-mental setting included intermittent volcanic activity. The source of that activity is still uncertain.

4.1.2 Breccia Unit

Breccia underlying the Loon River and Shaftesbury formations is the most prominent and problematic rock type present in the cores. This breccia was considered to be the result of a meteorite impact, a volcanic diatreme or a combination of both. The three New Claymore holes were drilled into the centers of positive magnetic anomalies previously delineated by an HRAM survey (Figure 2), presumed to represent volcanic rocks and possible diatremes.

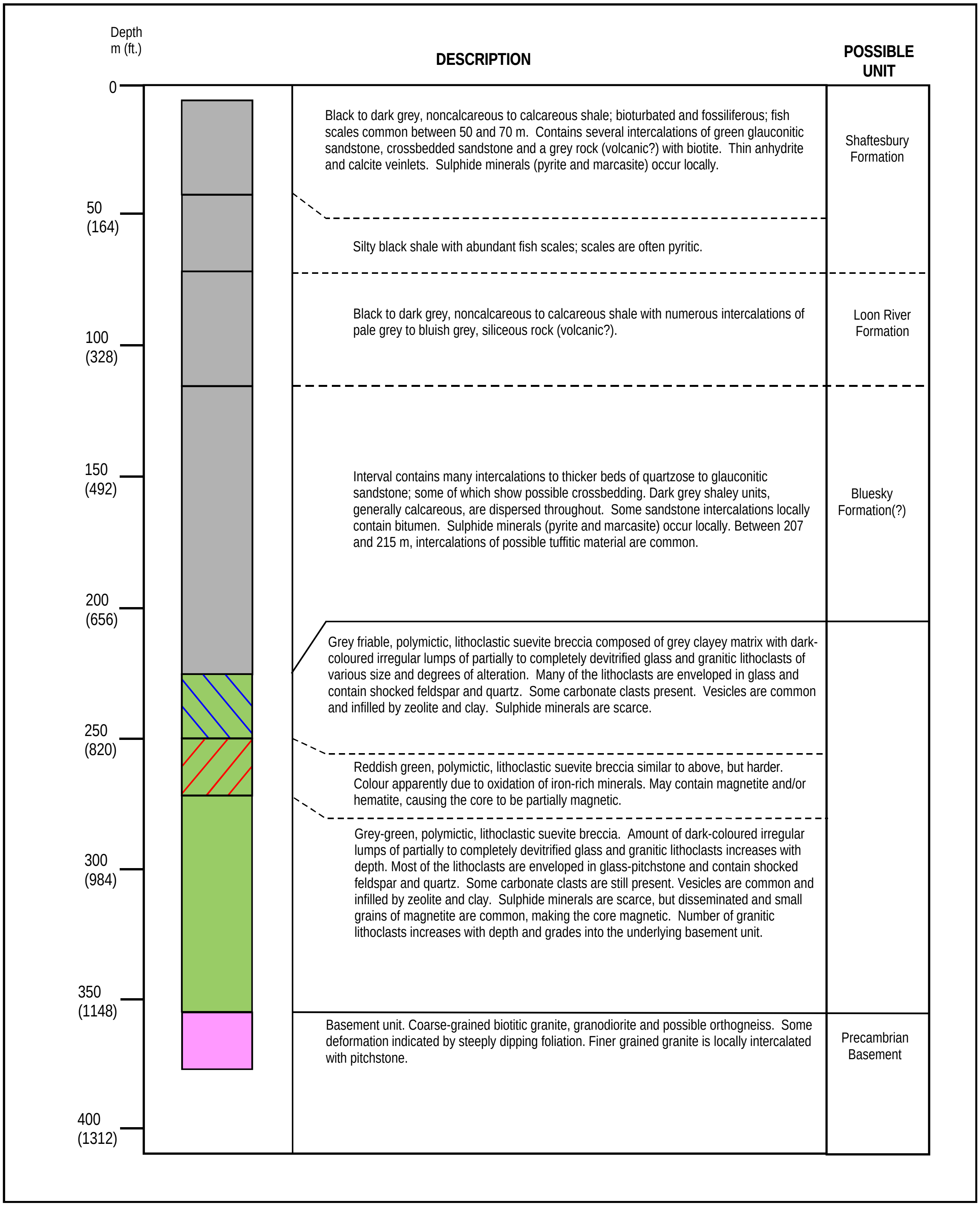


Figure 20. Composite stratigraphic column for drillholes ST001,ST002 and ST003. Dashed lines represent subintervals within the major lithological units.

The calcareous sections in the upper portions of the breccia contain abundant limestone clasts. This calcareous component may be the remnants of the Paleozoic carbonate rocks that originally infilled the space now occupied by the SRS. A meteoric impact would have fractured and pulverized the underlying substrata, ejecting some of it into the atmosphere. This ejected material would eventually settle out of the atmosphere, blanketing and infilling portions of the crater and its rim.

Both macroscopic and microscopic studies have shown that the breccia units in drillholes ST001, ST002 and ST003 can be classified as suevite breccia, known and described from several terrestrial meteorite craters. A suevite breccia is composed of discrete fragments of rocks and minerals, along with bodies of melt, in a clastic matrix of similar but finer grained material (French, 1998). This suevite breccia is the vesicular pyroclastic rock described by Carrigy and Short (1968). There are no features in the breccia that can be attributed with certainty solely to volcanic activity. No evidence of volcanic diatreme activity was encountered in the cores.

4.1.3 Granitic Basement Unit

Although the lithoclasts were initially interpreted as granite and orthogneiss, petrographic analysis indicates that many of them appear to be granodiorite. Biotite-amphibole granodiorite and various biotitic granitoids and gneisses were intensely brecciated, despite having been overlain by at least 1250 m of Paleozoic sedimentary rocks at the time of impact. The impact excavated, deformed, disintegrated, comminuted, vitrified or melted both the Devonian sedimentary rocks and the upper portions of the basement. The intensity of shock effects in the rocks depended on the distance from the impact center and the propagation of rarefaction waves. All four stages of shock metamorphism described by Stöffler (1971) can be observed in SRS rocks. Deformation and vitrification features can be observed macroscopically, although they may be somewhat obliterated by superimposed argillization, chloritization and zeolitization. The fracturing of the basement probably continued down to a depth of a few kilometres and, at shallower levels, many fractures were invaded by the rock dust.

Quartz in the basement rocks shows cataclasis, PDFs and vitrification features similar to those seen in the lower portions of the breccia, including extreme undulatory extinction and decoration caused by bubbles or mineral inclusions, plastic deformation, diaplectic glass and development of pure silica glass–lechatelierite rimmed by devitrification products (chlorite?). Some diaplectic quartz recrystallized to form fine mosaics. Feldspars are strongly cataclastic, contain PDFs and decorations, and have cloudy extinction grading to opacity and brown coloration, which may be due to alteration to clay and iron oxides. The albite twinning in many grains has an alternative, shock-generated oblique twinning and diaplectic glass (maskelynite) occurs in the grains; lathy feldspar microlites developed in the melt phases. In biotite, kink bands indicate lower stages of shock deformation, whereas oxidation and replacement by magnetite suggest temperatures in excess of 1400°C and pressures above 50Gpa (500 kbar), which do not occur in natural volcanic processes (French, 1998). Lower stage, shock-affected amphibole shows mechanical twinning, loss of birefringence and pleochroism; higher stage shock-affected grains show opaque decomposition, oxidation and replacement by magnetite.

Closer to the center of impact, the basement rocks have likely been partly or wholly vitrified, the grains have lost their habits, granitic textures have been replaced, and the remaining crystalline grains in the melt phases have been digested to various degrees. Microbreccia likely formed at some rock-melt boundaries.

4.2 Magnetic Susceptibility Survey

The SRS is defined by its strong aeromagnetic signature. Mineral analysis by XRD has confirmed the presence of magnetite and hematite in the core (Appendix 5). The lack of cleavage in biotite and amphibole minerals in thin section suggests that they became amorphous and oxidized due to impact heat and the FeO in them was converted to magnetite±hematite (or maghemite?). Thus, magnetite appears to be the main replacement product and the source of magnetic susceptibility throughout the SRS. The magnetite may form in zones of stages III and IV shock metamorphism, especially near the center of impact (Stöffler, 1971). Due to the rebound process, the rocks hosting newly formed magnetite were uplifted and now cause the magnetic anomaly. Magnetic susceptibility decreases with distance from the impact center, where the heat was too low to oxidize biotite and amphibole but still high enough to vitrify low-temperature minerals and produce hematite in schlieren in the melt phases. The average magnetic values for pitchstone exceed those for granite, supporting the presumption that, during total vitrification of the basement rocks, all biotite and amphibole was available to form magnetite.

Pitchstone and breccia are vesicular rocks characterized by relatively low gravity. This characteristic may explain the juxtaposition, observed by Excel Geophysics Inc. (1996) and Bird Geophysical (1999), of magnetic highs with gravity lows in the SRS.

4.3 Scintillometry Survey

The results of the scintillometry survey did not define any significantly anomalous lithological units within the core. The readings, grouped in ranges of values for specific rock types, yielded four orders of magnitude, the highest being found in pitchstone, followed by those in basement granite and green suevite breccia, with the lowest being obtained from Cretaceous sedimentary rocks (Appendix 3). The slightly higher radiation values in the pitchstone and basement granite are not unexpected. Granitic units in northeastern Alberta and northwestern Saskatchewan have been the focus of uranium exploration for many years, and the increased levels of radioactivity in the core are likely linked to increased content of granitic rocks.

4.4 Petrography

Petrologically, the Steen River breccia units vary in 1) colour of the matrix and melt inclusions (called Fladen, glass lumps or bombs) and their consistency, depending on the zone of shock metamorphism (relative to the center of the impact); 2) content of the calcareous phases; 3) postdepositional redox changes (and related contents of trivalent or divalent iron); and 4) type of superimposed alteration of the melt phases. Alteration overprinted on the breccia includes vitrification, devitrification, chloritization, argillization and zeolitization (Appendix 4). The top parts of the breccia immediately underlying the undisturbed Cretaceous sedimentary rocks are grey, calcareous and friable, and the Fladen are grey. The surface of the core is friable and peels off, probably due to desiccation of montmorillonite, a product of devitrification. Farther down in the core, the breccia is composed mainly of calcareous and siliceous phases and contains less montmorillonite. Its colour is grey and it becomes firm and hard.

At greater depths, the colour of the breccia grades to grey-green and calcareous phases disappear, except for scarce limestone clasts, most of which are up to a few centimetres across. Lentiform lumps of more-or-less devitrified and argillized glass were probably calcareous fragments, because their number is greater in the upper, more calcareous parts of the breccia. The decrease in the calcareous component of the breccia may reflect a transition from predominantly ejecta to melt within the core. The glass lenses are commonly rimmed by tiny disseminated sulphide minerals, indicating contents of iron in the original carbonate. Most of the glass lenses are enveloped by green montmorillonite and/or their insides are partly or completely transformed into montmorillonite. The colour of Fladen in this type of breccia ranges from grey through various shades of violet and red, to dark grey and black, depending mostly on the degree of weathering and the content of bi- or trivalent iron, respectively. Most Fladen contain, or originally contained, magnetite and/or hematite (or maghemite?), but magnetite was converted into hematite in those exposed to subsequent oxidation, and the rock thus lost its magnetic susceptibility. Other constituents of Fladen are small quartz and feldspar clasts, which may be more-or-less vitrified. Similar clasts occur in the matrix; however, the matrix also contains larger clasts of quartz and feldspar, which obviously originated from the basement. These clasts show cataclastic, planar deformation features (PDFs) and vitrification indicative of shock metamorphism. Fracturing, kink bands in biotite, mechanical twinning in amphibole, plastic deformation, diaplectic glass, normal glass of quartz and feldspar, flow textures in lithoclasts are all indicative of the presence of shock-metamorphic effects in the breccia.

Fladen represent the melt bodies ejected from the melt sheet during the excavation stage (French, 1998). They, together with vitrified dust, shocked and/or vitrified clasts and lithoclasts, formed the ejecta blanket and/or the breccia lens. Their shapes are aerodynamic and elongated, and the degree of ablation indicates very high flight velocities. Most Fladen contain schlieren, which are laminar flow structures with discrete bands and streaks controlled by Fladen shape. The Fladen are mostly vesicular and the quantity of vesicles and/or amygdules may be as numerous as in volcanic pumice (e.g., in hole ST001 at 332 m). The vesicles are either empty or lined with clay, zeolite and/or calcite, and their size ranges from tenths of millimetres up to 2 cm. Some Fladen contain shocked or sintered granite-gneiss lithoclasts and the number of basement rock fragments that are completely encased in Fladen-like melt envelopes increases with depth.

Closer to the basement, the breccia is progressively replaced by pitchstone, which comprises dark to black melt rock containing blocks of more-or-less vitrified granite-gneiss. It is a part of the original melt sheet, almost continuous in the lower parts of hole ST003 near the contact with the basement rocks. The pitchstone is a dark grey, brown or black aphanitic rock that contains small, white, angular, shocked and vitrified quartz and feldspar fragments, and amygdules lined with clay, vermiculite (?), chlorite (?), calcite and zeolite. The zeolite centers are commonly hollow. Magnetite occurs in the form of very small black grains or irregular clusters, frequently attached to or rimming the large grains, or forming disseminations in the melt. During the early devitrification phases, lathy feldspar microlites (trichites) developed and became aligned in flow bands around larger inclusions.

Superimposed on the core are several retrograde processes: devitrification, argillization and zeolitization. These three processes affect the glassy melt phases. Devitrification initially occurred in the impact melts when there was time enough for laths of new feldspar and/or hair-like pyroxene phenocrysts (trichites) to crystallize. Montmorillonite and/or mixed-layer clay minerals are secondary devitrification products replacing the fine glassy matrix in suevite, pitchstone and Fladen. Zeolite minerals likely formed from impact glasses shortly after or during the post-impact marine sedimentation. Deformed, vitrified feldspars in shocked granite-gneiss were largely replaced by zeolite. Zeolite minerals, together with clay minerals and carbonate, line up the vesicles and amygdules in the impact melts.

4.5 Mineralogy

The XRD analysis confirmed the identification of many of the minerals suspected in the core during logging, including pyrite, magnetite, hematite, barite, glauconite, montmorillonite, calcite and gypsum (Appendix 5). Several new minerals were also identified in the core, including marcasite, four types of zeolite minerals (analcime, stilbite, laumontite and leonhardite), and two clay mixtures (vermiculite-swelling chlorite and chlorite-montmorillonite). Coesite and stishovite, indicator minerals for meteoric impact structures, were not isolated or identified in the samples.

Magnetite and hematite, confirmed in sample M35, are common throughout the breccia units. In shocked granite and melt rocks, the magnetite appears globular or elongated, indicating extreme temperatures and pressures. Crystallization of new magnetite during the melting process requires local temperatures of at least 1400°C, and cooling past the Curie point (580°C) must have taken place shortly after the suevite was deposited (Dennis, 1971). Transformation of iron-rich schlieren in glass phases into magnetite and hematite at 1180 °C has been reported by Hörz (1965), and Shoemaker and Chao (1961).

There appears to be two generations of hematite, a progressive 'by-product' of magnetite formation (it may include maghemite) and a product of superimposed oxidation of magnetite and iron sulphide minerals. Hematite, as a formational 'by-product' of magnetite, could have formed during the impact event. The replacement of magnetite by hematite is reflected in the breccia by the change in the colour of the matrix from green to red. This change coincides with a weak magnetic susceptibility reading (Figures 13 and 15). The weak magnetic susceptibility of hematite is regarded as ferromagnetic or paramagnetic.

Zeolite minerals are common within the breccia unit. Figures 21 and 22 show two separate clusters of samples that differ in their proportions of Na and K. Chemical substitution within minerals lining the zeolites is possible at high temperatures. Up to 25% of Na may be replaced by K in analcime formed at high temperatures, but little atomic substitution takes place at low temperatures. This suggests that crystallization or solid state transition of the analyzed analcime likely occurred during an impact event. No other high-temperature event has been documented that could have brought about the substitution of Na by K. Hay (1966), however, reported that volcanic glass can react to form zeolite minerals in saline (lacustrine and marine) and freshwater deposits. The transformation of glass to zeolite can be idealized as a hydration reaction, but the actual chemical change is commonly more complex than this. Montmorillonite commonly accompanies zeolite minerals in marine and freshwater siliceous tuffs.

Calcite in shale and turbidite units (conglomerate and sandstone) occurs in the form of calcareous cement, suggesting initial shallow, subtidal marine sedimentation and later basinal sedimentation of black shale under anoxic conditions. In the upper parts of the suevite breccia, the limestone clasts are shocked and some have been converted to glass, which occurs as lenses 0.5 to 7 cm across. Calcite clasts within the breccia may have originated from the Devonian Wabamun Formation, part of which would have been shattered by the impact event.

Gypsum appears to be one of the youngest minerals in the core. Its origin may be partly linked to gypsum-rich horizons within Devonian strata disrupted by the impact, or to postdepositional changes after the impact.

4.6 Geochemistry

Samples collected from the cores do not show any significant anomalous concentrations of elements used in exploration (Appendix 6). However, several geochemical associations are evident. The shale unit contains elevated but not anomalous concentrations of base metals, such as Mn, Mo, Ni and Zn. Previous drilling during base metal exploration in the 1970s yielded similar results (Germundson and Fischer, 1978). The ability of the SRS to host base-metal deposits is still uncertain.

A comparison of the samples by rock type was conducted for several elements using ternary diagrams. Figure 21 is a ternary diagram showing Ca:Na:K relationships in SRS and Boltysh meteorite crater melt rocks. A pitchstone sample result from Carrigy and Short (1968) was included for comparison. Two of the pitchstone samples (G39 and G40) from drillhole ST003 fall within, or are close to, the cluster

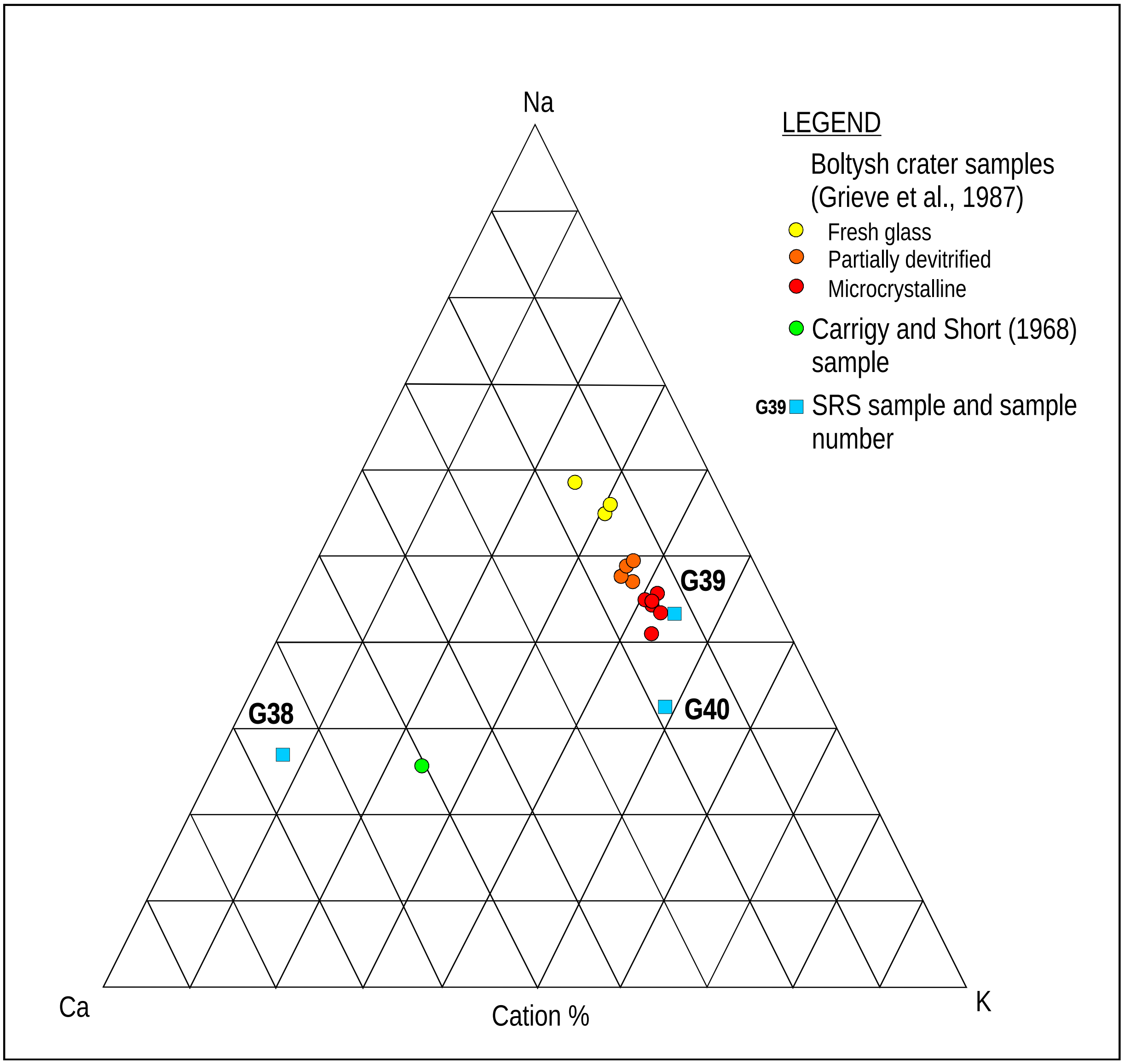
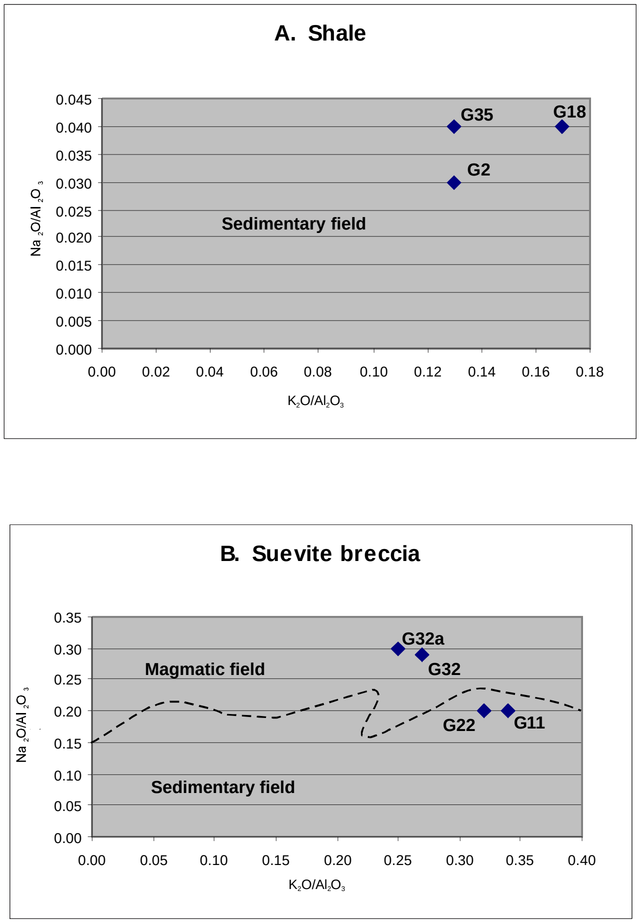


Figure 21. Bulk composition of melt rocks (in cation percent Na:Ca:K) for SRS samples G38, G39 and G40. Carrigy and Short (1968) and Grieve *et al.* (1987) samples plotted for comparison.



	K_2O/Al_2O_3	Na_2O/Al_2O_3
Shale		
G2	0.13	0.03
G18	0.17	0.04
G35	0.13	0.04
Suevite breccia		
G11	0.34	0.20
G22	0.32	0.20
G32	0.27	0.29
G32a	0.25	0.30
Glaucontic sandstone		
G16	0.49	0.06
Pitchstone		
G38	0.07	0.16
G39	0.30	0.31
G40	0.30	0.26
Carrigy	0.14	0.13

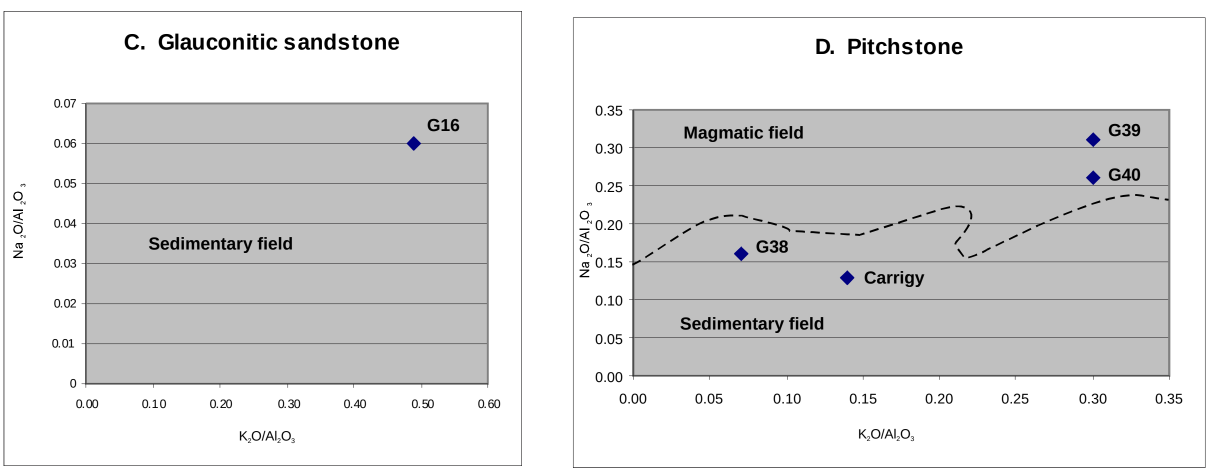


Figure 22. Geochemical composition plots of K_2O/Al_2O_3 versus Na_2O/Al_2O_3 for selected rock types: A) shale, B) breccia, C) glauconitic sandstone and D) pitchstone. Carrigy and Short (1968) pitchstone sample included for comparison. Dashed line indicates approximate boundary between rocks of magmatic and sedimentary origin (after Garrels and Mackenzie, 1971).

occupied by microcrystalline Boltysh melts, whereas Carrigy's sample and the sample containing excessive Ca and Fe, are separated from the others. A carbonate progenitor or a heterogeneous source for the sample (e.g., the Devonian Wabamun Formation) could explain this feature. The presence of Ca zeolite within these core samples may have also been a factor.

Plots of Al_2O_3/Na_2O versus Al_2O_3/K_2O for the shale, suevite breccia, pitchstone and sandstone are shown in Figure 22. Sedimentary rocks (samples G2, G16, G18 and G35) are closely grouped with the field of sediments as defined by Garrels and Mackenzie (1971). The suevite breccia and pitchstone, however, are both split into two distinct clusters, one within the sedimentary and another within the magmatic field (Garrels and Mackenzie, 1971). This split in composition suggests that both the pitchstone and the breccia had magmatic (i.e., basement rock) and sedimentary (i.e., Devonian rock) sources. Sample G38, which plots in the sedimentary field in Figure 22d, is also the sample with elevated concentrations of several elements, including the rare earths. Samples G39 and G40 were collected from stratigraphically below sample G38 and plot in the magmatic field.

5 Discussion

The SRS has been postulated to be the result of a meteorite impact. Numerous forms of evidence, including spatially associated horst- and graben-like structures, evidence of 'shock metamorphism' and impact melting in core from oil wells and exploration drillholes, and aeromagnetic data, support such an origin (Carrigy and Short, 1968; Winzer, 1972; Mossop and Shetsen, 1994; Bird Geophysical, 1999).

Carrigy and Short (1968) classified the shock-metamorphic features in the SRS impact rocks as facies I of Stöffler (1971). Winzer (1972) described deformations suggestive of Stöffler's (1971) middle or upper stage II. In the current study, all four shock-metamorphic stages were observed in the SRS impact rocks. They include 1) fracturing, plastic deformations and diaplectic glass (stage I); 2) phase transitions and diaplectic glass (stage II); 3) selective melting, normal quartz and feldspar glasses, and partial oxidation of biotite and amphibole (stage III); and 4) complete melting of target rocks (stage IV). The dynamic pressures and temperatures in the central impact zone were so great that the rocks of Precambrian basement and Paleozoic sedimentary provenance melted and produced the melt sheet and/or ejecta represented by Fladen in the suevite breccia. The rock-forming minerals can be ordered, according to packing densities, as follows: cordierite, orthoclase, albite, sillimanite, quartz, amphibole, biotite and zircon. In the facies IV zone, the minerals cordierite, orthoclase, albite, sillimanite and quartz would likely have been changed into glass (Stöffler, 1971).

The results of this study support an impact origin for the SRS and for the four shock-metamorphic stages described above. Core logging, petrographic and geochemical results support the identification of suevite breccia, in holes ST001, ST002 and ST003, that is similar to other known and described breccias from several terrestrial meteorite craters.

Studies of the available geophysical and stratigraphic data for wells drilled within and around the SRS have produced a number of cross-section reconstructions over the past 30 years (Carrigy and Short, 1968; Winzer, 1972; McCleary, 1997; Mossop and Shetsen, 1994). All these reconstructions have taken a simplified approach to the structure of the SRS, primarily due to the lack of data. Figure 23 shows the SRS prior to erosion and sedimentation. The central portion of the structure is displayed as a large uplift offset to the east of the actual center of the feature. Uplift was stronger on the eastern side of the central uplift (CU) suggesting the meteorite arrived from the east and the maximum impact energy was released in that portion of the structure (A. Hildebrand, pers. comm., 2000). The CU is rimmed (inner and outer

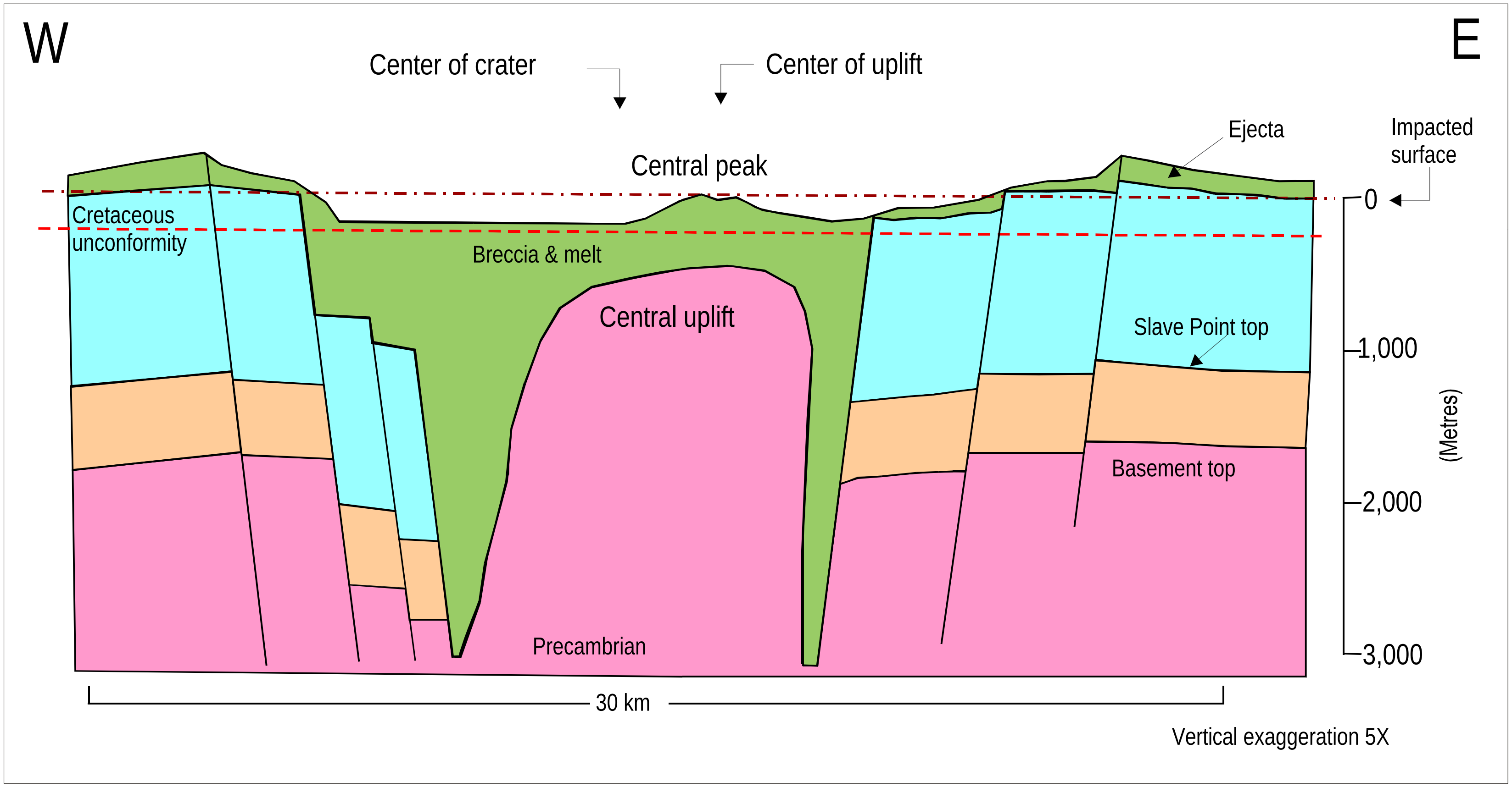


Figure 23. Schematic cross-section through the Steen River Structure after impact but prior to post-impact erosion and deposition of overlying Cretaceous strata (*from* Hildebrand, 2000).

rims) by a number of steeply dipping faults or fractures with variable amounts of displacement. Ejecta from the impact is distributed over the CU and its inner and outer rims. Deep valleys infilled by breccia and melt surround and overlie the CU.

A post-erosional and infilled SRS was chosen as the basis for the cross-sections because the magnetic contours of the SRS correlate well with the distribution of anomalous suevite breccia and melts on the uplifted basement rocks. These contours were used in the crater reconstruction cross-sections shown in Figure 24. Extrapolation of the crater geometry and facies between drillholes was based primarily on the magnetic data. A steeply dipping source model was adopted because the magnetic anomalies are sensitive to the depth and location of the tops of the causative magnetic bodies. Also, the symmetry of potential-field anomalies and close spatial relationships between the gravity and magnetic anomalies (Excel Geophysics, 1996) support such a model. In Figure 24, the CU is composed of several basement blocks topped by the impactite and uplifted along steeply dipping fractures. Escarpments separate unevenly uplifted parts of the CU. This pattern is applicable to the peripheral subanomalies intersected by drillholes ST001 and ST002. The post-impact erosion was followed by transgression and deposition of Cretaceous shale and turbidite, effectively sealing and preserving the crater from further erosion.

The SRS is an inhomogeneous magnetic body composed of at least thirteen oval subanomalies. The majority of these subanomalies are aligned in a crescent-shaped cluster southeast of the central subanomaly. The rest are located to the north and southeast of the main cluster. Excel Geophysics (1996) compared the gravity and magnetic data over these magnetic subanomalies, finding a strong correlation between gravity lows and magnetic highs. They suggested that the low-gravity rocks were similar to porous lithological rock types such as volcanic rocks. Drilling into three of these subanomalies by New Claymore has indicated that the geophysical signatures are representative of the vesicular and porous, magnetite-bearing melt phases and suevite breccia, and not volcanic rocks. It is likely that the subanomalies may represent 1) impacts of segments from disintegrated meteorite; 2) erosional and escarpment-bound topographic features of the basement rocks topped by magnetic vesicular rocks; or 3) sites unaffected by oxidation processes but rimmed by oxidation zones in which magnetite was transformed into nonmagnetic hematite or limonite.

Geochemical analyses of samples from the magnetic melt phases indicate two possible sources: Paleozoic sedimentary and Precambrian igneous rocks. The iron for the formation of magnetite in igneous rocks was available in the mafic minerals, mainly biotite and amphibole. However, the source of iron in the Paleozoic sedimentary rocks is problematic. It may have been iron in a carbonate form. Alternatively, the melt could have been homogenized, but the plots of Na_2O/Al_2O_3 versus $K2O/Al_2O_3$ split the melts into sedimentary and magmatic fields (Figure 22), suggesting that homogenization did not occur. Dence (1972) reported distinct magnetic anomalies over suevite and melt-rock concentrations in the Ries crater. Magnetic fields in most impact craters, however, are variable (Stöffler, 1966; Dressler et al., 1994; Dressler and Sharpton, 2000), commonly subdued and merge with the regional field magnetic signatures (e.g., Clearwater Lake craters, Deep Bay and Brent).

Several intercalations of possible volcanic material, which locally contains biotite, were described in the shale unit of drillholes ST001 to ST003. The origin of this material, however, has not been verified as volcanic and there are no features in the core that can be attributed with certainty to volcanic activity. The fish scales interval within the Cretaceous black shale contains increased carbonaceous matter, a feature that may indicate a massive marine-extinction event. In addition, the bottom-hole temperature of 55°C, measured in the IOE Steen 12-19 well at a depth of 570 m, is nearly double the average reading for this depth in Western Canada (Carrigy and Short, 1968). It is possible that this elevated temperature

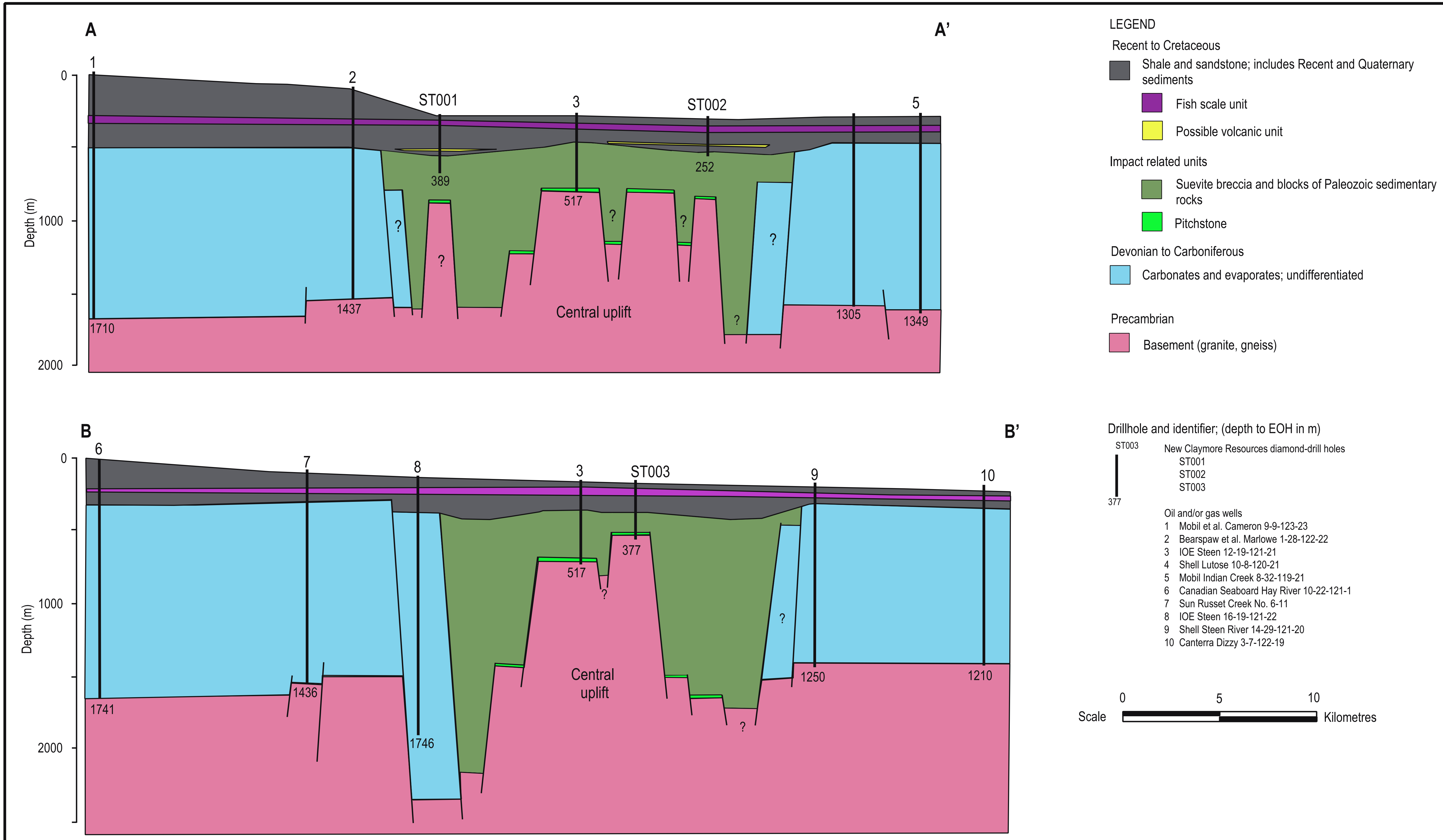


Figure 24. Schematic cross-sections A-A' and B-B' through the Steen River Structure (*see* Figure 1 for locations).

may indicate a nearby volcanic center or ‘hot spot’. Alternatively, it may represent possible crustal thinning as a result of the impact.

Extensive bentonite and pyroclastic horizons have been identified in adjacent drillholes through the rim syncline (Carrigy and Short, 1968; Winzer, 1972). In well IOE 12-19, Carrigy and Short (1968) reported the presence of vesicular volcanic agglomerate and “five feet of dark green glassy rock (pitchstone), in the bottom of the hole….[that has] a more basic chemical composition than the plutonic or vesicular rocks above.” They were likely describing a unit correlative with the suevite breccia described in the New Claymore cores. The age of the SRS, however, correlates with that of kimberlite intrusions and volcanism in other parts of Alberta and Saskatchewan. Radiometric K-Ar dating of pyroclastic material in well IOE 12-19 indicates an age of about 95 Ma (Carrigy and Short, 1968), which is approximately the same age as 1) the kimberlites near Fort à la Corne, Saskatchewan; 2) the Crowsnest volcanic rocks in southwestern Alberta; 3) the Fish Scale Horizon, which is purported to be the result of a condensed section formed in an anoxic basin; and 4) bentonite associated with the Fish Scale Horizon (Dufresne et al., 1996). It is possible that, upon closer examination of the intercalations in the upper portions of the Steen cores, evidence of volcanism may be found.

6 Economic Potential

Part of the focus of this study was to determine the potential of the SRS to host economic deposits of diamonds, base or precious metals and/or hydrocarbons. The limited results obtained on the structure to date are insufficient to properly assess its economic potential, particularly in terms of diamonds and base or precious metals.

6.1 Diamonds

The three drillholes studied in this report were initially drilled in the search for kimberlitic units. Logging and petrographic investigations show that no kimberlite or lamproite, the most common hosts for diamonds, were intersected by holes ST001, ST002 and ST003. The sources of the magnetic anomalies are mainly impact melt rocks and suevite breccia. The magnetic anomalies frequently correlate with negative gravity anomalies, because the magnetic rocks are vesicular and porous. In short, there is no evidence within the SRS of magnetic anomalies caused by sources other than those that are impact related.

Although the discovery of diamonds genetically related to impact processes has been reported from some craters (e.g., Popigai in Russia), their occurrence is of academic rather than of industrial interest (Hough et al., 1995; Koeberl et al., 1995; Miyamoto, 1995; Masaitis, 1998). These types of diamonds are generally industrial grade at best, and are rarely economic as a diamond deposit. In addition, the original sedimentary units in the Russian example contained coal and/or graphite. In the Steen River Structure, the rocks were Mississippian calcareous shale; Devonian carbonate, shale and evaporite formations; and Precambrian basement. As a result, the formation of diamonds could only be constrained by the availability of carbon in the shale. Little is known about how meteorite impacts influence the formation of kimberlite diatremes (e.g., whether the fracturing due to impact reaches the lithosphere and enables diamondiferous ultramafic diatremes to make their way to the surface).

The mineralogical and geochemical results, combined with the apparent lack of volcanic rocks encountered in the drilling program and the lack of diamond-indicator minerals (DIMs) in the sediment sampling program, suggest that the potential of the SRS and surrounding region to host diamondiferous kimberlite or lamproite bodies is not high. However, diamond exploration in the region has been limited and because of the presence of kimberlite fields north and southeast of the SRS, undiscovered kimberlitic diatremes may exist in the region. In addition, the elevated temperature detected in the base of one of the oil wells warrants further study to determine its connection (if any) to possible volcanic activity in the region. The lack of DIMs in the overlying sediment may indicate that if kimberlite diatremes exist in the area, they have not been eroded and may therefore be preserved in their entirety.

6.2 Base Metals

Occurrences of base metals have been documented along major structural features in the Steen River area. Geochemical analyses conducted on drillcore from Cretaceous shale and Devonian carbonate in the SRS in the 1970s yielded elevated base-metal concentrations (Germundson and Fischer, 1978). Similar analysis of shale samples in the New Claymore drillholes also yielded elevated base-metal concentrations. Unfortunately, as was the case with the 1970s samples, the results were not sufficiently anomalous to warrant follow-up exploration.

The lack of detailed structural information on the SRS is problematic. Data that have been collected to date on base-metal occurrences in the region have been restricted to structural lineaments, such as faults and shear zones. It is possible that the SRS may contain base-metal deposits along such fault systems within the outer and inner rims of the crater. Alternatively, the CU, which is composed of porous and vesicular breccia, could allow hydrothermal fluids to reach the overlying Cretaceous shale and form a sedimentary stratiform ore or Mississippi Valley–type base-metal deposit. Unfortunately, there are insufficient data to propose any metallogenic scenario with even a small degree of certainty. The likelihood of a base-metal deposit being associated with the SRS cannot, therefore, be properly assessed.

6.3 Hydrocarbons

Grieve (1997) stated that hydrocarbon deposits in impact structures are epigenetic and occur generally in the central uplifted area of complex impact structures and in the rim area of both simple and complex structures. In some cases, the impact structure not only hosts the reservoir rocks, but also provides the central topographic basin in which the organic-rich post-impact sediments that would become the source rocks were deposited. There are numerous hydrocarbon-producing impact structures throughout North America, including Red Wing Creek, Newport, Ames, Avak, Calvin, Marquez, Sierra Madera and Campeche Bank (Grieve et al., 1998). Several new impact structures with evidence of shock metamorphism are discovered each year.

In the Steen River Structure, the primary target rocks for oil and gas exploration consist of approximately 1400 m of Devonian carbonate, evaporite and shale. In the center of the SRS, 185 m of Loon River shale is underlain by approximately 120 m of suevite breccia that exhibits a range of shock-metamorphic features. In the reconstructions presented in Figure 24, the ‘valleys’, limited by fault-bounded escarpments that separate the uplifted areas (magnetic subanomalies), are two or more kilometres wide. Thus, overturned sedimentary strata within these ‘valleys’ could provide suitable traps for hydrocarbon accumulation. Glauconitic sandstone was found in all three of the drillcores and included, in one sample, a fragment of solidified bitumen. It is possible that these glauconitic sandstone units are representative of the tarry oil-bearing Bluesky Formation (Glass, 1990).

To date, more than 50 oil and gas exploration wells have been drilled into the raised rim of the SRS (Figure 2). An additional 14 wells were drilled into the rim syncline and two into the central uplift (CU). Oil is currently produced from two wells in fractured dolomite of the Keg River Formation on the northern rim, at a rate of approximately 600 barrels per day. The cumulative production of these wells is approximately 300,000 barrels (Grieve et al., 1998). The structure is relatively isolated and operations are currently limited to winter months, when the ground is frozen (Toth and Stewart, 1994). Gulf Canada has recently drilled 12 wells in the region, of which nine are gas discoveries with absolute open flow rates of 37 to 95 million cubic feet per day (Grieve et al., 1998). Current recoverable reserve estimates, based on existing wells, are 50 to 70 billion cubic feet of gas.

The potential of the CU and the rim syncline has not attracted much attention in the past. The five holes (including the three New Claymore holes) drilled within these structures are widely spaced, with distances generally exceeding 5 km. Information concerning the geometry and structure of the SRS between these few drillholes is inferred, with interpolations based on known subsurface stratigraphy and surface magnetic and gravity signatures.

The geometry of the SRS is complex and information between wells is limited. Based on data obtained to date, however, the favourable relationship between impact structures and hydrocarbon elsewhere in North America, plus the presence of producing wells in the area, indicate that the SRS could host additional oil and gas reserves.

7 Conclusions

The Steen River Structure (SRS) is an unusual geophysical anomaly with an equivocal origin. Deeply buried and overlain by Cretaceous marine sedimentary rocks and Quaternary glacial sediments, the feature has no apparent surface expression. The aeromagnetic signature of the SRS clearly indicates an elliptical, unevenly uplifted basement high that lies near several major structural features.

The three cores studied in this report show features supportive of the four shock-metamorphic stages described by Stöffler (1971) for impact structures. Core logging, petrographic and geochemical results support the identification of suevite breccia in drillholes ST001, ST002 and ST003 that is similar to those described from several terrestrial meteorite craters. Although, the age of the SRS is comparable to known kimberlite intrusions and volcanism in Alberta and Saskatchewan, no conclusive evidence of such activity was documented in the cores.

The presence of magnetite in the suevite breccia and pitchstone portions of the core causes the magnetic anomaly over the SRS. The low gravity signature is not representative of mafic or ultramafic rock types, as previously thought, but to the porous nature of the breccia and glass melt in the crater. The strength of the coincident magnetic highs is attributed to the abundance of magnetite in the breccia and the depth at which it occurs.

The economic potential of the SRS is inadequately evaluated. Exploration to date, which includes sediment-sampling programs, geophysical surveys and drilling, has yielded only limited information about the SRS, its origin and its potential to host economic deposits of precious and base metals, diamonds, and oil and gas. Exploration in the region has not yielded significant concentrations of base or precious metals, but the amount of data is very limited. No concrete evidence of volcanism has been found in the recent drillcores, and no kimberlitic units have been intersected in drilling programs. In addition, surface-sampling programs have yielded no diamond-indicator minerals, but to date the amount and extent of such DIM sampling is quite small. However, the proximity of the SRS to other known kimberlite fields and the possibility of a 'hot spot' in the area suggest that volcanism, and possibly diatreme activity, may exist in the region. On a positive note, the potential for the SRS to host additional hydrocarbon reserves is high, based on the geometry of the structure and the two wells along the rim that are currently in production.

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Appendix 1 - Drill Logs

Drill Log Summary

Drillhole: ST001
Date drilled: February 20, 2000
Location: NAD 27, Zone 11 UTM (462500E, 6605425N)
11-122-22W5
KB elevation: Not recorded

Core Interval m (ft.) From	To	Description
9.1 (30.0)	275.6 (904.0)	Black, dark grey to grey, silty more or less friable fossiliferous shale; mainly noncalcareous, but thin calcareous intercalations occur; also intercalated are green glauconitic sandstone, crossbedded sandstone with rare ripple marks and fining-upward sequences, and grey (volcanic?) rock containing biotite; thin anhydrite and/or celestite and calcite veinlets and sulphide minerals (pyrite and marcasite) occur locally. Fish scales, pyritized, appear at 43.3 m. Between 268 m and 271 m, the unit contains mainly fine-grained sandstone grading into medium- to coarse-grained sandstone with local thin bands of conglomerate and numerous small sulphide grains and locally larger nests of sulphides and oval clasts. Washed diamict (possible till) at top of core from 9.1 to 9.4 m.
275.6 (904.0)	275.6 (904.0)	Shale-breccia boundary: a 1-2 cm thick recrystallized zone with agglomerate pyrite crystals.
275.6 (904.0)	389.3 (1277.0)	Grey-green, polymictic, lithoclastic 'suevite' breccia composed of olive green clayey matrix, white, grey, red, violet or dark to black, irregularly shaped lumps (bombs?) of more-or-less devitrified glass (called pumice, pumicite, impactite or pitchstone) and granite-gneiss lithoclasts of various sizes and degrees of alteration; many of them are partly or wholly rimmed or enveloped by pumiceous rock with small white clasts of shocked feldspar and quartz up to 2 mm across, or in pitchstone with vesicules, which are either empty or lined with clay, zeolites or calcite; impact glass in original matrix, lumps (bombs) and rims are mostly devitrified and argillized to form clay of typical olive-green colour; the coloration of breccia in oxidation zone grades to red due to presence of trivalent iron oxide; clasts of limestone occur locally.
389.3 (1277.0)		End of hole.

Appendix 1 - Drill Logs

Drillhole ST001

Metreage (Footage)				Description	Sample		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
9.1 (30.0)	224.6 (737.0)	9.1 (30.0)	224.6 (737.0)	Black shale, noncalcareous with worm burrows; sandstone intercalation at 37.2-37.5 m (122-123'); fish scales appear at 43.3 m (142'); appearance of scarce 1 mm thick anhydrite veinlets at 107.9 m (354'); a 5 cm thick bed of grey tuff(?) with biotite at 137 m (449.5'); thin calcareous and green glauconitic sandstone intercalations; crossbedded sandstone with rare ripple marks and fining-upward sequences, and grey (volcanic?) rock containing biotite; thin anhydrite and/or celestite and calcite veinlets and sulphides (pyrite and marcasite) occur locally.	223.2 223.3 226.5 228.0	223.5 223.6 226.5 228.1	sulphides; biotite black shale anhydrite(?) hard rock; calcite	M07; A02 CM01, G12 M08 G13, P12; M09
		208.5 (684.0)	217.0 (712.0)	Several thin, pale grey, altered volcanic(?) rock intercalations containing montmorillonite (expandable).				
		223.1 (732.0)	223.6 (733.5)	Fossil imprint; thin intercalation of igneous rock, 1-3 cm thick, very biotite rich; oval fragment resembling volcanic rock in a sedimentary shale; black shale contains irregular lenses of fine-grained pyrite and grey rock with disseminated pyrite.				
224.6 (737.0)	231.0 (758.0)	224.6 (737.0)	228.8 (750.5)	Very fine grained clayey (silty?) black shale; friable, breaks along bedding planes and diagonally along random planes; rich in organic matter (OM); local nests or irregular lenses of disseminated sulphides (chalcopyrite? + pyrite); scarce, thin veinlets of gypsum (anhydrite?) up to 0.1 mm; brown objects (possibly fossils or mineral); shale is noncalcareous; lens of anhydrite in a strongly disturbed shale at 226.5 m (743') showing randomly oriented slip planes with abundant striation marks; 4 cm thick section of shale with several partial anhydrite veins with fibrous texture oriented perpendicular to strike of vein, some calcite (effervesces with HCl).				
		228.0 (748.0)	228.1 (748.5)	Very hard and compact rock (granite or skarn?) with two lentiform veins of yellow mineral; heavy.				
		228.8 (750.5)	231.0 (758.0)	Dark grey to grey, clayey (silty?) shale resembling that in the upper part of well ST002; uneven breaks, mostly along bedding planes; curvilinear lines resembling worm burrows; shale is quite friable; sandy bed with fine calcite veinlets at 228.8 m (750.5'), veinlets about 1 mm thick and perpendicular to bedding; dark green mineral seems to form a cement to another equigranular crystal of glassy transparent colourless mineral <0.1 mm in diameter, closely associated in a mass that appears to have replaced the grey shale; local grains of calcite and brown (organic?) matter (peat?); numerous black minerals.				
		230.5 (756.0)	231.1 (758.0)	Grey-green intercalation of a rock composed of glauconitic sandstone; in the glauconite cement is equigranular, glassy, finely-crystalline quartz less than 0.1 mm across; calcite grains and brown substance resembling peat occur locally.	230.8	230.9	grey-green rock	M10; G14, P13
231.0 (758.0)	237.4 (779.0)	231.0 (758.0)	231.3 (759.0)	Grey, fine sandy shale or sandstone with darker irregular streaks of shaly intercalations; contact with green hydrothermal replacement(?); rock is gypsum vein and diagonal sporadic calcite veinlets.				
		231.3 (759.0)	236.5 (776.0)	Sandstone is calcareous.	236.1	236.3	sandstone	G15, P14
		236.5 (776.0)	236.8 (777.0)	Sandstone becomes noncalcareous.				
		236.8 (777.0)	237.4 (779.0)	Clayey grey shale, slightly sandy; scarce inclusions of rock with green mineral.				

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
237.4 (779.0)	243.2 (798.0)	237.4 (779.0)	241.4 (792.0)	Grey, fine-grained sandstone with tiny disseminated grains ofgreen mineral; locally mottled with darker grey shale, which forms streaks parallel to bedding; diesel smell likely due to contamination during drilling; intercalations and streaks of black shale (small olistoliths) increase with depth.				
		241.4 (792.0)	243.2 (798.0)	Content of shale increases; rock becomes darker and by 242.9 m (797'), the rock is predominately shale; both the shale and sandstone are noncalcareous.				
243.2 (798.0)	249.0 (817.0)	243.2 (798.0)	244.8 (803.0)	Dark grey shale, breaks along bedding planes; tiny conglomerates of green mineral, especially at 243.7-244.1 m (799.5-801'), turns the core dark grey-green; watery, colourless minerals are scarce in this interval.	243.9	244.1	glauconitic sandstone	M11, P15; G16
		244.8 (803.0)	246.6 (809.0)	Visible, calcified fossil fragments and shells in the shale.				
		246.6 (809.0)	249.0 (817.0)	Clayey shale of dark grey colour; disintegration starts; very fine grained; scarce sulphides (pyrite +/- chalcopyrite); anhydrite veinlets cut across bedding at 248.4 m (815'); local striation marks.				
249.0 (817.0)	253.9 (833.0)	249.0 (817.0)	253.9 (833.0)	No core description.				
253.9 (833)	260.0 (852.0)	253.9 (833)	260.0 (852.0)	Dark grey, clayey silty shale; friable, breaks along bedding planes and at random; colour is darker at 254.1-254.5 m (833.5-835') and contains fracture planes with black staining (OM?), darker portion is more compact and less friable; local, but sparsely disseminated, very small pyrite crystals (some chalcopyrite?).	259.5	259.6	shale	G17
260.0 (852.0)	265.3 (870.5)	260.0 (852.0)	264.0 (866.0)	Dark grey, silty clayey shale; friable, breaks along bedding planes and at random; scarce thin anhydrite veinlets; noncalcareous; some sulphides.	261.6	261.6	sulphide	M12
		264.0 (866.0)	264.6 (868.0)	Lighter grey, silty or very fine sandy calcareous and firmer shale; some sulphides and a pink mineral.	264.5	264.6	shale	G18, P16
		264.6 (868.0)	265.3 (870.5)	Darker shale with abundant sulphides (pyrite, chalcopyrite?) and a pinkish brown mineral; sulphides up to 3 mm in size and may form nodules up to 1 cm in diameter; rock is very compact and hard (possible hydrothermal alteration?).	264.6	264.8	sulphide + pink mineral	M13
265.3 (870.5)	271.1 (889.5)	265.3 (870.5)	267.9 (879.0)	Fine-grained clayey silty, pale grey shale; calcareous; locally darker bands.				
		267.9 (879.0)	271.0 (889.0)	Fine-grained sandstone grading downcore into medium- and coarse-grained sandstone; some ripple marks at 267.9 m (879'); local thin bands of conglomerate; very hard and recrystallized; contains numerous small sulphide grains and locally larger nests of sulphide minerals and oval clasts; local thin bands of clayey shale accompanied by increased amounts of sulphides and larger white to beige minerals.	268.1 268.3 270.4	268.3 268.3 270.4	sandstone sandstone sandstone	G19 P17 P18
		271.0 (889.0)	271.1 (889.5)	Grey to dark grey, clayey silty calcareous shale.				
271.1 (889.5)	277.1 (909.0)	271.1 (889.5)	275.5 (904.0)	Grey, fine, clayey silty shale; very fine sulphides, disseminated; local darker bands rich in OM, calcareous; sharp lower contact; round agglomerates of a sulphide mineral (pyrite).				
		275.5 (904.0)	277.1 (909.0)	Weathered grey breccia; contact represented by 1-2 cm thick recrystallized zone; surface of core is peeling off (possibly due to desiccation of anhydrite?); clast of calcite, quartz, glassy mineral, pyrite, and anhydrite in the matrix; desiccation cracks and big black mineral (ore or tourmaline?).	275.6 275.6	275.6 275.9	lithological contact suevite breccia	P19 G20

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
277.1 (909.0)	283.0 (928.5)	277.1 (909.0)	281.3 (923.0)	Grey breccia with desiccated surface.				
		281.3 (923.0)	283.0 (928.5)	Grey breccia with white subangular to subrounded fragments of limestone as much as 3.5 cm across; lithoclasts of granite, slightly altered, although biotite looks fresh, with a greenish tint (chloritization?); granite has some preferred orientation; groundmass of breccia seems to be glass, locally forms veinlets with fibrous texture oriented perpendicular to the strike of the vein; tiny pyrite crystals are sparsely disseminated; black mineral that resembles tourmaline; breccia has desiccation cracks.				
283.0 (928.5)	288.5 (946.5)	283.0 (928.5)	288.5 (946.5)	Grey medium-grained breccia becomes reddish grey and reddish green with depth; contains clasts of green expandable clay minerals, lithoclasts composed of pink glass(?) and green clay mineral and limestone +/- pyrite; matrix is another generation of grey whitish glass; most clasts are 1-5 mm across, but larger ones may measure 1 cm, granite lithoclasts are 3-4 cm across.				
288.5 (946.5)	294.0 (964.5)	288.5 (946.5)	293.5 (963.0)	Reddish grey and grey-red breccia composed of pink glass and green clay mineral lithoclasts; clasts (or replacement?) subangular clasts of green soft expandable clay mineral (desiccation cracks are around and inside it); granite lithoclasts up to 2 cm in diameter are strongly affected by alteration, biotite is red and altered and plagioclase is also pinkish; small quartz +/- limestone, +/- pyrite clasts and grains are cemented by colourless glass; breccia is nonmagnetic; unit is tectonically disturbed at 291.7-292.2 m (957-958.5').				
		293.5 (963.0)	294.0 (964.5)	Appears to be the same as above, but is magnetic.				
294.0 (964.5)	299.8 (983.5)	294.0 (964.5)	299.8 (983.5)	Colourful, variegated breccia with lithoclasts and clasts, mostly subangular or subrounded; local lithoclasts of granitoid, strongly altered by anhydritization(?); brown violet-red colour is due to lithoclasts, subangular, up to 2 cm across, composed of pink, violet and brown-red glass; green clay mineral may also form clasts on its own up to 3 cm in diameter; white or pale grey clasts up to 2 cm appear to be carbonate; calcite in minute scarce veinlets; a subrounded granitoid lithoclast at 296.9 m (974') with biotite deeply red-brown coloured and affected by alteration; local occurrences of pyrite; very weak effervescence with HCl.	286.9 287.2 297.7 297.9	287.2 287.2 297.7 297.7	suevite breccia suevite breccia suevite breccia suevite breccia	G21 P20 G22 P21
299.8 (983.5)	305.4 (1002.0)	299.8 (983.5)	305.4 (1002.0)	Dark red-grey to greyish red breccia combined with pale green lithoclastic breccia; lithoclasts are dark grey-red +/- violet +/- brown glass with inclusions of green clayey mineral and white glass clasts up to 5 mm across; scarce limestone clasts; effervescence with HCl is due to minute calcite veinlets; matrix is greenish grey and composed mainly of clayey green mineral that may have been replaced the glass(?) and the rock acquires greenish tint, but red still dominates.	302.6 302.7	302.7 302.7	suevite breccia suevite breccia	G23 P22
305.4 (1002.0)	311.0 (1020.5)	305.4 (1002.0)	311.0 (1020.5)	Lithoclastic breccia with glass(?) lithoclasts, subrounded to subangular 5 mm to 5 cm across, colour turns blackish with deep red tint; matrix is more green (increase of green clay mineral); almost no calcite; 10 cm subrounded lithoclast of granite at 309.4 m (1015') is anhydritized.	307.0 309.5 310.8	307.1 309.5 311.0	breccia, pitchstone granite lithoclast granite lithoclast	NC 1521007 G24, P23 G25, P24
311.0 (1020.5)	316.7 (1039.0)	311.0 (1020.5)	316.7 (1039.0)	Khaki green-grey lithoclastic breccia with increasing number of granite lithoclasts from a few cm up to 15 cm across; granite is strongly affected by anhydritization(?) and structure is locally the only indication that it was once granite; porous; anhydritic lithoclasts are leached and replaced by green clayey mineral matrix; no calcite; white subangular clasts up to 3 mm across are also glass(?); no quartz.	311.1 311.1	311.1 311.2	altered granite altered granite	P25 G26

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
316.7 (1039.0)	323.1 (1060.0)	316.7 (1039.0)	323.1 (1060.0)	Lithoclastic breccia with altered granite lithoclasts up to 30 cm across; matrix is green clayey mineral; locally black and porous rock with white subangular and subrounded soft glass clasts with some pyrite, more compact than green rock; vugs with yellow to brownish calcite crystals (aragonite); several clay-filled cavities.				
323.1 (1060.0)	328.9 (1079.0)	323.1 (1060.0)	328.9 (1079.0)	Evaporitic(?) glass breccia with suboval fragments of basement(?) granite; khaki pea green colour; granite fragments enveloped by a reddish black glass, porous; white, small (1-2 mm across), subrounded to subangular clasts of composition similar to those in glass lithoclasts and in green mineral(?) clay matrix; some limestone lithoclasts and glassy, colourless, clear mineral; apparent association with green mineral and the violet glass(?) matrix (oxidation of Fe_2O_3 and FeO?); some sulphides (pyrite); vugs filled with yellow to brown crystals of aragonite(?), locally up to 3 cm across and frequently at contacts with granite fragments; high mobility of evaporate formed cavities and voids (locally infilled by carbonates).	324.5 324.5 324.5 324.5 328.7	324.5 324.5 324.5 324.5 328.7	calcite or aragonite clay breccia green mineral devitrified glass (?)	M14 M14A P26 M15 M16
328.9 (1079.0)	334.5 (1097.5)	328.9 (1079.0)	334.5 (1097.5)	Lithoclastic (evaporitic) breccia; matrix is green clayey mineral; lithoclasts of dark red-black with white subangular minerals 1-2 mm across; cavities infilled by green clay mineral or clear glassy quartz(?); some granite lithoclasts show chloritization of the biotite; possibly pumicite at 332 m (1089').	329.0 332.0 332.2	329.1 332.0 332.3	altered granite zeolite crystal granite lithoclast	G28, P27 M17 G29, P28
334.5 (1097.5)	340.2 (1116.0)	334.5 (1097.5)	340.2 (1116.0)	Lithoclastic (evaporitic?) polymictic breccia; green clay mineral as matrix; white subangular clasts, up to 5 mm across and large granite lithoclasts up to 20 cm across; granite generally altered, biotite is chloritized(?), and lithoclasts are enveloped by dark grey to black porous glass(?) with white clasts of corroded first generation glass(?); small grains and nests of sulphides up to 2 mm across; locally small cavities filled with green clay mineral; at 335.1-335.3 m (1099.5-1100') some granite lithoclasts are strongly affected by argillization(?) whereas others are less altered.	335.2	335.4	altered granite	G30, P29
340.2 (1116.0)	346.1 (1135.5)	340.2 (1116.0)	346.1 (1135.5)	Lithoclastic (bedrock) breccia composed of green clayey mineral matrix with subangular white fragments 1-5 mm across and lithoclasts of porous glass(?); large lithoclasts of affected granite, locally up to 90 cm in length, enveloped by black porous glass(?); large 'clast' of green clay mineral 4 cm across at 342.1 m (1122.5').				
346.1 (1135.5)	352.0 (1155.0)	346.1 (1135.5)	352.0 (1155.0)	Lithoclastic, polymictic breccia; light greenish grey in colour; composed of two lithoclasts: strongly altered basement(?) granite and dark to black glass(?) containing white subangular porous clasts with sulphides; granite lithoclasts up to 50 cm across.	349.8	349.8	granite+pitchstone	P30
352.0 (1155.0)	357.5 (1173.0)	352.0 (1155.0)	357.5 (1173.0)	Lithoclastic, polymictic (evaporitic?) breccia composed of green clay mineral matrix and small white subangular clasts, fragments of altered granite up to 20 cm across, and dark to black porous glass(?) rims with small white subangular clasts similar to those in the green-clay bound breccia (which also occurs as subrounded lithoclasts); some sulphate minerals; light brown transparent aragonite(?) crystals in vugs, some associated with crystal quartz; voids are locally infilled with green clay mineral +/- aragonite(?) and quartz crystals.	352.9	352.9	zeolite, calcite, quartz	M18
357.5 (1173.0)	363.3 (1192.0)	357.5 (1173.0)	363.3 (1192.0)	Greenish grey lithoclastic polymictic breccia; greenish grey clay mineral matrix with white small subangular clasts 1-5 mm across and reddish dark grey to black lithoclasts up to 5 cm across of porous glass(?) with similar white clasts as above and subrounded, altered granite lithoclasts up to 12 cm across; granite lithoclasts have irregular rims of black, porous glass(?).	358.7	358.7	breccia	G31, P31

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
363.3 (1192.0)	369.1 (1211.0)	363.3 (1192.0)	369.1 (1211.0)	Grey-green polymictic, lithoclastic breccia; groundmass of green clayey mineral with white subangular clasts, mostly 1-5 mm across (feldspar, quartz or corroded glass?) and lithoclasts; two types of lithoclasts: red, dark grey to black, porous with similar white clasts as in the green matrix and with some tiny sparse sulphides, material may envelop the altered granite lithoclasts (up to 20 cm across); local occurrence of quartz crystals, generally associated with the green clay mineral.	365.5 367.1	365.5 367.2	quartz(?) glass(?) breccia	M19 P32, G32
369.1 (1211.0)	374.8 (1229.5)	369.1 (1211.0)	374.8 (1229.5)	Green-grey, lithoclastic, polymictic breccia; green clay mineral matrix with white subangular and subrounded clasts of feldspar(?), quartz(?) and glass(?) 1-5 mm across; reddish, dark grey to black porous glass(?) lithoclasts with identical white clasts as in green clayey matrix; granite lithoclasts with pink K-feldspar, up to 15 cm across, some are altered (chloritized biotite); green clay mineral locally forms clasts up to 2 cm long; possibly white limestone fragments up to 3 cm.	373.5	373.6	breccia + pitchstone	NC 1631225
374.8 (1229.5)	379.0 (1243.5)	374.8 (1229.5)	379.0 (1243.5)	Greenish grey, polymictic, lithoclastic breccia; green clayey mineral matrix with white subangular 1-5 mm clasts of feldspar(?), quartz(?) and porous dark to almost black glass(?); lithoclasts of two types: dark, subangular with subangular white clasts 1-5 mm in diameter, similar to those in green matrix and subrounded granite lithoclasts, some of which are enveloped by dark porous microbreccia of same composition as the dark lithoclasts; altered granite lithoclasts up to 40 cm across.	376.8 378.2 378.5	377.1 378.4 378.5	anhydrite(?) altered granite altered granite	M19A G33 P33
379.0 (1243.5)	383.4 (1258.0)	379 (1243.5)	383.4 (1258.0)	Greenish grey, oligomictic lithoclastic breccia; groundmass is green clayey mineral in which white subangular clasts of feldspar(?), quartz(?) 1-3 mm across occur; whitish clasts of porous rock (glass?) filled with grey, pink or dark minerals oriented in streaks or by soft green clay mineral (may be corroded); porous clasts are possibly devitrified glass(?) and inclusions are chloritized or argillized glass(?); granite, sometimes altered, lithoclasts, subrounded, up to 15 cm across, some partly enveloped by dark rock/mineral.	382.5	382.6	breccia	G34, P34
383.4 (1258.0)	387.7 (1272.0)	383.4 (1258.0)	387.2 (1270.5)	Green-grey, polymictic, lithoclastic breccia, similar to that above; most of the greenish chlorite(?) clayey(?) matrix with white subangular clasts 1-3 mm across of feldspar(?), quartz(?) and pink K-feldspar(?).				
		387.2 (1270.5)	387.7 (1272.0)	Breccia colour turns reddish grey-green; glass(?) veinlets up to 3 mm thick cut diagonally across the core; scarce limestone clasts up to 2 cm across.				
387.7 (1272.0)	389.2 (1277.0)	387.7 (1272.0)	389.2 (1277.0)	Variegated polymictic lithoclastic breccia matrix; combination of orange-red to brick red K-feldspar(?) and green clay mineral that effervesces in HCl; green soft clay mineral forms elongated grains (pseudoclasts) up to 1 cm in length with possible devitrified glass(?) cores of pinkish colour; granite lithoclasts up to 3 cm across, altered with brick red feldspars within them; young fibrous glass veinlets cut matrix and clasts at various angles; lithoclasts of grey-green colour with green clay minerals and small subangular whitish clasts up to 1 mm as inclusions; subrounded limestone clasts more abundant with depth; clast of devitrified glass(?) 3 cm across occurs at 389.2 m.	389.2	389.2	limestone, pitchstone	M20, M21
389.2 (1277.0)		389.2 (1277.0)		End of hole.				

Appendix 1 - Drill Logs

Drill Log Summary

Drillhole: ST002
Date drilled: February 29, 2000
Location: NAD 27, Zone 11 UTM (468772E, 6593075N)
04-121-21W5
KB elevation: Not recorded

Core Interval m (ft.)		Description
From	To	
15.2 (50.0)	224.0 (735.0)	Grey, grey-green, dark grey to black silty shale; locally numerous preserved calcified fossils; calcified and pyritized fish scales; anhydrite (fibrous) and calcite veinlets; disseminated sulphides; mostly friable, or firmer with conchoidal fracture; intercalations of more or less calcareous and glauconitic sandstone; intercalations of volcanic (?) rock with biotite. Displaced (?) or misplaced (?) diamict (possible till) between 16.7 and 17.1 m (55 and 56').
224.0 (735.0)	224.0 (735.0)	Conformable contact with breccia; small rock/mineral clasts about 1 cm across occur immediately above in the shale.
224.0 (735.0)	252.0 (827.0)	Grey, greenish grey polymictic, lithoclastic suevite breccia; at the contact it contains shale clasts 1-1.5 cm across with pyrite; in upper part it is weathered and loose; below the breccia is composed of lithic, mineral and devitrified glassy particles, more-or-less altered subrounded granite lithoclasts as much as 4 cm across, subangular to subrounded whitish carbonate rock mostly around 1 cm, but may be as much as 5 cm across, greenish subangular rock fragments and grey slightly calcareous cement; in grey-green matrix white subangular clasts of feldspar, quartz, calcite and devitrified glass, and soft clayey olive green mineral that may be identical with that in the matrix, but also occurs in the form of lense-shaped 'clasts' as much as 4 cm across, and frequently with whitish cores of devitrified glass; tiny sulphide (pyrite?) disseminations frequently associate with green mineral and scarce limestone clasts up to 5 cm across occur.
252.0 (827.0)		Hole lost at this depth.

Appendix 1 - Drill Logs

Drillhole ST002

Metreage (Footage)				Description	Sample Interval		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
15.2 (50.0)	186.5 (612.0)	15.2 (50.0)	186.5 (612.0)	Grey, grey-green, dark grey to black silty shale; locally numerous preserved calcified fossils; calcified and pyritized fish scales; anhydrite (fibrous) and calcite veinlets; disseminated sulphides; mostly friable, or firmer with conchoidal fracture; intercalations of more-or-less calcareous and glauconitic sandstone; intercalations of volcanic(?) rock with biotite at 154.5 m (507') and 173.4 m (569'); rare pyrite and marcasite agglomerates (up to 2 mm in diameter); fish scales appear at 50 m (164'); calcareous intercalation 3 cm thick at 71.9 m (236'); lens of anhydrite with striations at 77.4 m (254'); anhydrite bed 3 cm thick at 93.9 m (308'); appearance of thin calcite veinlets at 96.9-102.4 m (318'-336').				
186.5 (612.0)	203.75 (668.5)	186.5 (612.0)	203.75 (668.5)	Grey fine-grained quartzose sandstone, locally calcareous, intercalated with a dark grey, fossiliferous shale; sandstone intercalations are glauconitic between 191.1and 198.1 m (627 and 650') and contain petrified bitumen and pyrite.				
203.75 (668.5)	217.8 (714.5)	203.75 (668.5)	217.8 (714.5)	Dark grey, fossiliferous, calcareous shale; clayey to silty; bedding perpendicular to axis of the drillhole; colour banding up to several mm thick; thin bands rich in organic-carbonaceous matter. Numerous well-preserved shells up to 2.5 cm across in upper portions; some fossils are encased in thin, brown, calcareous crust. Shales breaks easily but unevenly along faint bedding planes. Sulphides (pyrite) and possibly montmorillinite. Long, lustrous fragments (phytoclasts?) up to 1 mm; three tectonically affected zones at 211.8-212.1 m (695-696'), 213.7-214 m (701-702') and 214.3-214.9 m (703-705'); a sandstone intercalation with rounded pinkish zircons as much as 0.5 mm in diameter, coalified phytoclasts and organic matter occur at 207.1 m (679.5').	206.7 206.9 207.1 207.1	206.7 206.9 207.2 207.3	shale carbonate/sulphide zircon(?) shale	G01 M02 A01 G02
		203.8 (668.5)	206.0 (676.0)	Shale is not as dark as overlying shale; contains fossil shells; two gypsum(?) veinlets up to 4 mm thick; pink-brown, with a fibrous crystalline structure; sporadic black elongated lustrous fragments resembling phytoclasts.	205.1 205.6	205.1 205.6	shale anhydrite(?)	P01 M01
		206.0 (676.0)	207.3 (680.0)	Fossils are scarce, shale seems less carbonaceous; still has black phytoclasts; two striated clast fragments (larger is pyritic carbonate, the smaller a shale) in the shale up to 2 cm in length; scattered pyrite concretions in the shale.				
		207.3 (680.0)	208.2 (683.0)	Shale does not contain OM or the dark and thin laminae; now pale brownish grey and grey, clay-silty, very well sorted and possibly tuffitic downwards; more fractured and friable, mica flakes (mostly white) about 0.1 mm in diameter; contains black laths up to 1 cm long (organic?), possible presence of tourmaline.	207.3	207.3	shale	P02
		208.2 (683.0)	208.8 (685.0)	Rock is hard, pale khaki grey colour, looks tuffitic; silty with tiny, glittering pyrite(?) disseminated and forming scarce nests or accumulations of minute grains; tiny, white mica flakes.	208.7	208.8	shale	G03
		208.8 (685.0)	209.6 (687.6)	Darker colour and less compact, upper contact is conformable but sharp; some gypsum(?) forms veinlets with a fibrous structure oriented perpendicular to strike of vein.	208.8	208.8	shale	P03 (A,B)
		209.6 (687.6)	214.7 (704.5)	Grey, clayey silty shale; breaks easily in a conchoidal fashion, locally intercalated with darker grey, more OM in bands (noncalcareous); more tectonically affected, breaking diagonally in various directions versus the bedding; very homogenous, with an isolated mica flake and nodule of pale grey silt with possible OM.				

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample Interval		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
217.8 (714.5)	224.1 (735.0)	217.8 (714.5)	224.1 (735.0)	Grey calcareous shale with intercalated sandstone; pale grey, fine, clayey silty calcareous shale, finely laminated locally; compact; locally contains disseminations, lenses, bands and nests of sulphides (pyrite); calcareous lithoclasts between 223.4 and 223.6 m (733 and 733.5').	221.1 221.3	221.1 221.4	sulphide shale	M03 P04,G04
224.1 (735.0)	226.2 (742.0)	224.1 (735.0)	226.2 (742.0)	Grey-weathered breccia; conformable but sharp upper contact; small fragments of breccia in the lower 1 cm of the shale; breccia contains fragments of black shale with pyrite (1-1.5 cm in diameter), basement granitoids up to 4 cm in diameter, suboval fragments of calcareous whitish grey rocks, greenish subangular fragments, subangular to suboval white limestone fragments up to 5 cm.				
226.2 (742.0)	232.1 (761.5)	226.2 (742.0)	232.1 (761.5)	Grey breccia with subangular and suboval fragments, mostly greyish white limestone; most fragments are 0.5 cm in diameter, but some are up to 3 cm across; calcite(?) veinlets and lenses up to 4 mm thick occur sporadically, larger lithoclasts up to 7 cm also occur; 3 granite suboval fragments occur between 227.2 and 227.5 m (745.5 and 746.5'); core is not disrupted or swollen below 228.3 m (749') and becomes noncalcareous; sulphide (pyrite) blobs; pink mineral associated with the limestone fragments; at 229.5 m (753') appearance of green fragments of soft mineral with some sulphides (pyrite), frequency and size increases with depth; non calcareous, but may contain small veinlets of carbonate that efferverse in HCl.	229.1 229.4	229.3 229.4	breccia breccia	G05 P05
		229.8 (754.0)	231.0 (758.0)	White calcite veinlets up to 4 mm thick occur; subangular fragments of grey khaki shale with some calcareous content (minute veinlets or groundmass?) also occur in breccia. Breccia immediately underlying the calcareous shale has a strongly weathered surface (swelled on reaction with water), becomes harder and more compact downcore, changing to a pale grey to grey colour.	232.0	232.2	breccia	G06, P06
232.1 (761.5)	236.4 (775.5)	232.1 (761.5)	236.4 (775.5)	Greenish grey breccia with scarce fragments of limestone(?) of light grey to white colour up to 5 cm in diameter; numerous fragments of green soft mineral (chlorite?) with frequently occurring calcite 'cores'; green mineral causes the green colour of the rock, suboval fragments resemble shale.	233.5 233.8	233.8 233.8	breccia anhydrite(?); montmorillonite(?)	G07, P07 M04, M05
236.4 (775.5)	240.8 (790.0)	236.4 (775.5)	240.8 (790.0)	Grey-green to greenish grey breccia with green minerals and very fine grained matrix with green subangular clasts of green mineral (chlorite? freolite?) that may contain gypsum +/- calcite cores; clasts up to 4 cm across; white calcite(?) fragments up to 1.5 cm across are common, but less frequent than above; sulphide (pyrite) forms disseminations or nests locally associated with the green mineral; granite fragments up to 10 cm in diameter become more prevalent between 240.2 and 240.8 m (788 and 790') ; clast of brownish grey limestone rimmed by a soft green mineral with ubiquous striations (dragged?) at 242.9 m (797').	239.8 239.5	239.9 239.6	breccia clay	G08, P08 M05A
240.8 (790.0)	245.1 (804.0)	240.8 (790.0)	245.1 (804.0)	Grey-green or khaki breccia with clasts or fragments of green mineral, which is also part of the groundmass; sparse, subangular clasts of limestone, greyish white and up to 2 cm in diameter; gypsum(?) with some calcite (veinlets, grains) locally forms cores of clasts enveloped in green soft mineral (montmorillonite? glauconite?); khaki brown colour increases with depth; desiccation cracks in core at 244 m (800.5') and from 244.4 to 244.8 m (802 to 803') within the green mineral; brown staining may be due to oxidation of disseminated sulphides; breccia contains hollows/voids; a limestone(?) clast at 243 m (797') enwrapped in green clay mineral bears striation marks; oil stains are present (contamination?).	243.0 243.6	243.0 243.7	limestone(?) breccia	M06 G09, P09

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample Interval		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
245.1 (804.0)	249.5 (818.5)	245.1 (804.0)	249.5 (818.5)	Grey-khaki breccia with green clasts of subangular shapes, mostly elongated, some with whitish gypsum(?) cores, granite fragments up to 5 cm across, with relatively unaltered, fresh looking biotite; amphibolite(?) and plagioclase are altered; matrix in breccia appears as a combination of green mineral, gypsum of violet colour and fine-grained rock; from 245.5 m (805') downward, there are fragments of basement granite up to 10 cm across; at 249.3 m (818') scarce black glass(?), magnetic(?).	246.3 249.4	246.3 249.4	breccia devitrified glass(?), clay mineral	G10, P10 P10A, M06A,B
249.5 (818.5)	252.1 (827.0)	249.5 (818.5)	252.1 (827.0)	Greenish grey breccia composed of subangular, mostly elongated grey-green soft mineral up to 4.5 cm in length, white to greyish white, scarce, subangular fragments and suboval larger fragments of basement(?) granite with fresh biotite, white and pale brown plagioclase (+/- amphibole?) up to 10 cm; green mineral and violet (gypsum?) matrix; green mineral swells in water (glauconite?).	250.8 252.0	250.9 252.0	breccia breccia	G11, P15 NC 243826
				Fragment of basement(?) granite at 251.9 m (826.5') separated from the breccia by a band of violet pitchstone; matrix is green but does not resemble the green clasts (does not swell); abundant violet devitrified glass(?) forming streaks, irregular bands in the matrix; green clasts (zeolites) may be rimmed by colourless gypsum with fibrous structure oriented perpendicular to the strike of the veinlets; green staining of the breccia and the granitic clasts.				
				Between 245.5 and 252 m (805 and 827'), subrounded lithoclasts of relatively less altered granite as much as 10 cm across; some are enwrapped or partly bordered by violet devitrified glass(?), others by anhydrite, scarce fibrous anhydrite(?) veinlets, disseminated sulphide and chlorite(?) as a devitrification product.				
252.1 (827.0)		252.1 (827.0)		Hole lost at this depth.				

Appendix 1 - Drill Logs

Drill Log Summary

Drillhole: ST003
Date drilled: March 3, 2000
Location: NAD 27, Zone 11 UTM (467825E, 6599675N)
29-121-21W5
KB elevation: Not recorded

Core Interval m (ft.)		Description
From	To	
18.3 (60.0)	205.6 (674.5)	Dark grey to grey, friable, clayey silty, noncalcareous fossiliferous shale containing scarce calcareous and glauconitic(?) sandstone and volcanic(?) rock intercalations; calcite and anhydrite veinlets and sparsely disseminated or agglomerated sulphides.
205.6 (674.5)	362.7 (1190.0)	Pale grey, grey olive-green, reddish grey polymictic lithoclastic suevite breccia made up of comminuted crystalline rocks and grey, greenish, reddish, dark violet to black streaky vesicular pumicite, impactite or pitchstone that was devitrified and contains subangular clasts of shocked quartz and feldspar; in the upper part it is grey and loose, and looks like a volcanic agglomerate, but instead of tuff there is shocked granite rock 'flour' with black mica, into which clasts and/or lithoclasts were thrown as indicated by their heavily striated clay coatings; calcareous clayey cement, limestone clasts and sulphides in disseminated or agglomerated form occur locally; calcareous cement in upper part of breccia is probably of marine origin (as in shale and sandstone, and may indicate impact into a marine environment); scarcity of green clay as a devitrification product determines grey colour of this rock.
362.7 (1190.0)	377.4 (1238.0)	Almost continuous mass of coarse-grained biotitic granite with pink K-feldspars grading into possible orthogneiss with steeply dipping foliation; some fine-grained granite locally intercalated with pitchstone.
377.4 (1238.0)		End of hole.

Appendix 1 - Drill Logs

Drillhole ST003

Metreage (Footage)				Description	Sample Interval		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
18.3 (60.0)	84.4 (277.0)	18.3 (60.0)	45.7 (150.0)	Silty black shale, breaks along bedding planes, bioturbated; anhydrite crystals appear at 44.8 m (147') along bedding planes; possible desiccation of the core locally; shale is dark grey to black and becomes less friable with depth; anhydrite crystals and small blebs appear at 68.6 m (225').				
		45.7 (150.0)	70.1 (230.0)	Pyritized fish scales.				
84.4 (277.0)	104.5 (343.0)	84.4 (277.0)	87.5 (287.0)	Black, calcareous shale; intercalation 2-3 cm thick with grey bluish strange rock (volcanic?) at 84.4 m (277').				
		87.5 (287.0)	104.5 (343.0)	Black shale with a lens of brownish transparent crystalline calcite; rare calcite intercalations millimetres thick.				
104.5 (343.0)	159.7 (524.0)	104.5 (343.0)	111.3 (365.0)	Homogenous black shale, silty, breaks along bedding planes.				
		111.3 (365.0)	159.7 (524.0)	Dark grey shale, still homogenous and noncalcareous; numerous calcareous intercalations begin at 129.8 m (426'); anhydrite (crystalline) intercalations appear at 151.5 m (497'); pale grey limestone intercalations.				
159.7 (524.0)	184.4 (605.0)	159.7 (524.0)	160.0 (525.0)	Pale grey siliceous rock with tiny white grains of feldspar(?) and pyrite, aggregations of grains and biotite; transitional contact with black shale.			volcanic(?) rock (biotite)	A3
		160.0 (525.0)	184.4 (605.0)	Black shale continues; pyrite-marcasite agglomerates appear between 165.2 and 166.7 m (542 and 547').				
184.4 (605.0)	190.8 (626.0)	184.4 (605.0)	190.8 (626.0)	Fossiliferous shale as in ST002.				
190.8 (626.0)	200.4 (657.5)	190.8 (626.0)	200.4 (657.5)	Dark grey shale, homogenous.				
200.4 (657.5)	206.0 (676.0)	200.4 (657.5)	201.9 (662.5)	Dark grey shale; no fossils; friable, noncalcareous; sulphide agglomerate 1 cm across at 200.7 m (658.5)'.	200.7	200.7	sulphide	M22
		201.9 (662.5)	205.6 (674.5)	Calcareous shale with sections of sandier shale and noncalcareous shale; at 203.3 m (667') shale is recrystallized with two bands of sulphides (pyrrhotite or pyrite?), possibly magnetic; sandier portions contain possible crossbedding between 203 and 205.4 m (666 and 674'); intercalation of suevite breccia at 205.2-205.3 m (673-674').	203.2 203.4	203.4 203.4	calcareous shale shale + sulphides	G35 P35, M23
		205.6 (674.5)	206.0 (676.0)	Pale grey breccia; weathered, loose; sharp upper contact; 5 cm thick intercalation of black calcareous shale in microbreccia at 206 m (676').				
206.0 (676.0)	211.8 (695.0)	206.0 (676.0)	210.5 (690.5)	Grey microbreccia with weathered, loose core surface (possible desiccation cracks); composed of rock flour(?), a mixture of rock (granite) fragments and minerals, biotite and soft grey fragments resembling chalcedony that may be devitrified glass(?); 8 grains of sulphide (pyrite, pyrrhotite?) on one section of core are oxidized with yellow-brown limonite portions around them; calcareous (possible calcite veinlets?)				

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample Interval		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
		210.5 (690.5)	211.8 (695.0)	First appearance of strongly altered granite lithoclasts, 7 to 8 cm in diameter, biotite is chloritized, some sulphides, occurs in grey microbreccia with white subangular clasts up to 1 cm across; breccia is grey; smaller, homogenous fragments of devitrified glass(?) with less devitrified and harder cores.	211.1	211.1	devitrified glass(?)	M24, M25
211.8 (695.0)	217.5 (713.5)	211.8 (695.0)	217.5 (713.5)	Grey microbreccia containing lithoclasts of altered granite up to 7 cm in diameter; increasing number of devitrified glass fragments(?) with remnants or inclusions(?) of glassy quartz (coesite?); devitrified lithoclasts(?) are limited by irregular slip planes with striation marks, surrounding is rock flour(?) matrix; disseminated sulphide (pyrrhotite?) grains; sulphides are locally disseminated, often in contact with granite lithoclasts; at 237.9 m (780.5') there are devitrifed glass(?) with vesicles and quartz (coesite?) or glass inclusions; breccia is an orderless mess; devitrifed streaky glass(?) fragments enwrapped in rock flour protrude from the matrix; a mixture of rock dust with some biotite, subangular quartz, feldspar and limestone; pieces of glass were altered into a soft clay mineral of grey colour, some contain micrograins of sulphide; sulphide microcrystals form wrathes around orange K-feldspars locally; anhydrite veinlets cut through locally.	213.3 213.3 214.6 216.0	213.3 213.3 214.6 216.0	devitrified glass(?) quartz, zeolite(?) quartz, zeolite(?) devitrified glass(?)	P36 M26 M27 P37
217.5 (713.5)	223.4 (733.0)	217.5 (713.5)	223.4 (733.0)	Green-grey breccia, polymictic; contains streaky whitish grey structures with darker inclusions and clasts of white orange mineral (K-feldspar?) and glass; alteration of clasts into a greenish clay mineral, some with the core less devitrified; one clast observed with a fresh glass or glassy looking mineral at 728.5'; green-grey soft cracked grains of what may have formerly been glass, now clayey matter, locally black and harder; remainder of core is green-grey clayey matrix and subangular shale clasts of granite, feldspar, limestone; sulphides are disseminated in some argillized(?) glass clasts.	217.7 217.7 217.7 217.7	217.7 217.8 218.3 218.3	limestone(?) orange mineral devitrified glass(?) calcite/clay mineral	M28 M29 M30 M31
223.4 (733.0)	229.1 (751.5)	223.4 (733.0)	229.1 (751.5)	Greenish-grey polymictic breccia with pseudoclasts of whitish grey to pink calcareous rocks with dark, black, inclusions of devitrified glass or glass(?), elongated, angular or lens-shaped, quite soft clayey(?) mineral (totally altered glass?); mostly around 5 mm, but one 2 cm across; altered granite lithoclasts, subangular to subrounded, 1 to 6 cm across in the upper part of the core box, some wrapped in grey, in the lower part of the core box in brown-red devitrified glass(?) or rock dust with devitrified glass inclusions; pink to orange K-feldspars clasts occur locally; change of colour from grey-green to grey-reddish green (redox condition change?); one streaky psuedoclast contained preserved glass(?), other inclusions were turned into green clayey mineral, or had vesicles; greenish grey clayey matrix contains small (millimetre) subangular clasts of quartz, feldspar and limestone.				
229.1 (751.5)	234.8 (770.5)	229.1 (751.5)	234.1 (768.0)	Green-reddish grey, polymictic, lithoclastic breccia, composed of strongly altered suboval granite lithoclasts as much as 15 cm in diameter, some are so strongly altered that only the remnant texture indicates it was granite; pseudolithoclasts of streaky red-pink rock with inclusions of tiny, subangular, dark to white devitrified glass(?) and vesicles; subangular elongated grey-green clasts of devitrified glass(?) clay or chlorite(?); matrix is greenish grey, clayey(?) and contains tiny white minerals: quartz, feldspar and some limestone; calcite veinlets at 229.5 m (753').	233.7	233.7	calcite (+ clay?)	M32
		234.1 (768.0)	234.8 (770.5)	Strongly calcareous with clasts of heavily striated limestone and white calcite veins, lenses and nests; locally numerous sulphide minerals (pyrite crystals).				

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample Interval		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
234.8 (770.5)	240.5 (789.0)	234.8 (770.5)	239.1 (784.5)	Reddish grey, polymictic lithoclastic breccia, prevalence of red, pink or violet psuedoclasts of streaky rock with inclusions of devitrified glass(?), chloritized or argillized(?) and altered granite with red biotite and pink feldspar; matrix is green-grey and contains mostly white, small (up to 2 mm) subangular clasts of quartz, feldspar and sparse calcite; grey-green specks of soft clay(?) chlorite that developed after glass? occur; red breccia contains little calcareous material, calcite or limestone.				
		239.1 (784.5)	239.9 (787.0)	Red pseudoclasts progressively decrease with depth ; core is still nonmagnetic, with the exception of a single black pseudoclast.				
		239.9 (787.0)	240.5 (789.0)	Pseudoclasts are predominantly green-grey; granite and black lithoclasts increase in number; core is magnetic; at 240.3 m (788.5'), an altered granite lithoclast is in contact with a pink-brown calcite vug with crystals and veinlets.				
240.5 (789.0)	246.3 (808.0)	240.5 (789.0)	246.3 (808.0)	Grey-green, lithoclastic, polymictic breccia; matrix appears as a microbreccia, composed of green clay mineral with white subangular clasts up to 2 mm in diameter; lithoclasts of altered granite and dark violet-grey, irregular, subangular lithoclasts with inclusions of whitish or pinkish minerals that may be devitrified(?), argillized(?) or chloritized(?) glass vesicles or voids (some coated inside by green clay or chlorite and/or calcite or anhydrite; matrix envelopes some granite lithoclasts totally or partly, appears to be the magnetic source.	240.5 240.5 245.1	240.5 240.5 245.1	magnetic mineral pyrite suevite breccia?	M33 M34 P38
246.3 (808.0)	251.9 (826.5)	246.3 (808.0)	251.9 (826.5)	Green-grey, lithoclastic, polymictic breccia with altered, subrounded granite lithoclasts up to 4 cm across, some enveloped by almost black rock containing small subangular quartz, feldspar(?); subangular pseudolithoclasts in a green-grey matrix measure up to 7 cm across; some contain vesicles or voids that are partly filled around their walls by an unknown mineral (not calcite or anhydrite); black pseudolithoclasts are abundant; core is magnetic.	247.9 248.1	248.1 248.1	breccia/devit.glass breccia/devit.glass	G36 P39
251.9 (826.5)	257.7 (845.5)	251.9 (826.5)	257.7 (845.5)	Green-grey, lithoclastic, polymictic mesobreccia; lithoclasts of granite, black biotite (chloritized?), magnetic, some are associated with or enveloped by black porous rock with mostly white subangular quartz, feldspar and granite fragments; contact with granite contains glittering fine-grained magnetite(?); black rock is locally chloritized appearing olive green with 1 mm clasts and local fissures of chloritized(?) green mineral; at 255.1 m (837') there is a black microbreccia, little magnetism except for a granite clast with black biotite; fine-grained granite lithoclast with orange-red K-feldspars(?) is friable, desiccated (zeolitization?) and strongly magnetic.	256.6 256.6 256.9	256.6 256.7 256.9	impactite+mag.min clay impactite+mag.min	P40 M34A G37
257.7 (845.5)	263.5 (864.5)	257.7 (845.5)	263.5 (864.5)	Grey-olive green lithoclastic mesobreccia; grey-green matrix contains small (0.5-2 mm) subangular clasts of quartz, feldspar and small granite lithoclasts and large biotitic grey to yellowish grey granite up to 15 cm in diameter with pink K-feldspars locally altered, orange and disintegrating; black pseudolithoclasts up to 7 cm across, usually elongated, subangular, irregular and at contacts with granite form envelopes of various thickness and enter cracks in the granite, are porous and magnetic; locally chloritized; scarce subangular fragments of limestone occur in grey-green matrix, but are never enveloped by black glass(?); rare calcite veinlets.	257.8 259.3	257.8 259.3	zeolitized(?) granite magnetite?	P40A M35
263.5 (864.5)	269.3 (883.5)	263.5 (864.5)	269.3 (883.5)	Similar to above; grey olive green lithoclastic polymictic breccia with subrounded granite lithoclasts 1 to 10 cm in diameter, pink feldspars, some enveloped by black devitrified glass(?); black pseudolithoclasts of devitrified glass are porous, contain small white subangular clasts of quartz, feldspar, up to 7 cm in diameter or envelop the granite; magnetic.				

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample Interval		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
269.3 (883.5)	275.1 (902.5)	269.3 (883.5)	275.1 (902.5)	Grey-olive green to khaki green polymictic lithoclastic breccia; granite lithoclasts 3-25 cm across, some are crushed with cracks infilled by black glass(?) and displacements along cracks; green chlorite(?) matrix and green clasts of chlorite or clay(?) mineral; at 272.3 m (893.5') a vug infilled by pink-orange crystals and a vein that cuts across granite with similar pink-orange altered K-feldspars(?); two granite types in contact at 273.1 m (896'), a coarse biotitic without pink K-feldspar, the other finer grained with abundant pink K-feldspar; limestone clasts, subangular at 273.9 m (898.5').	272.1	272.1	stilbite	M36
275.1 (902.5)	280.7 (921.0)	275.1 (902.5)	280.7 (921.0)	Similar to above; frequency of granite lithoclasts is reduced and the clasts are smaller (up to 7 cm); two limestone clasts, subangular (<2 cm across); grey-green breccia with black lithoclasts of suevite filled with white small clasts; suevite is irregular, hard and vuggy; vesicles may be filled by chlorite, zeolite; pitchstone.	279.4 279.6	279.4 279.6	zeolites breccia	M36A NC 346917
280.7 (921.0)	286.5 (940.0)	280.7 (921.0)	286.5 (940.0)	Grey-olive green polymictic lithoclastic breccia with black suevite up to 5 cm or around granite lithoclasts up to 20 cm in diameter; cracks in the granite may be infilled by black glass(?) displaced blocks; granite contains pink to orange, altered K-feldspars and voids after an unknown mineral; other type of granite has no pink feldspar.				
286.5 (940.0)	292.3 (959.0)	286.5 (940.0)	292.3 (959.0)	Similar lithology; two types of granite, one strongly biotitic with no pink K-feldspar, the other less biotitic with pink feldspar; between two granite blocks is black suevite with thin calcite veinlets; black suevite envelopes most granite lithoclasts, but also occurs as independent irregular lithoclasts in grey-green microbreccia.				
292.3 (959.0)	297.9 (977.5)	292.3 (959.0)	297.9 (977.5)	Grey-olive green chlorite(?) matrix with tiny subangular white 0.5-2 mm clasts and pitchstone; areas with granite lithoclasts up to 10 cm in diameter contain thicker porous pitchstone with quartz, feldspar fragments; glass at 292.9 m (961'); locally chloritized and porous; some granites are porous.	293.0	293.0	pitchstone	G38, P41
297.9 (977.5)	303.9 (997.0)	297.9 (977.5)	303.9 (997.0)	Grey-olive green chloritic microbreccia pitchstone lithoclasts up to 5 cm in diameter containing white subangular quartz and feldspar forms envelopes around granite; small granite lithoclasts up to 18 cm across, one is cracked with fissures filled with black pitchstone; limestone lithoclasts 2 cm in diameter within pitchstone envelope.	301.2	301.2	zeolite, quartz, clay	M37
303.9 (997.0)	309.7 (1016.0)	303.9 (997.0)	309.7 (1016.0)	A similar rock, but more granite lithoclasts as large as 30 cm in diameter; at 303.9 m (997') a leucocratic pink K-feldspar granite contains cracks infilled with black pitchstone; biotite granite with preferred orientation of biotite.				
309.7 (1016.0)	315.5 (1035.0)	309.7 (1016.0)	315.5 (1035.0)	Grey-olive green matrix with pitchstone and grey lithoclasts; altered granite fragments in uppermost part of breccia (streaky white ones); relatively few granite fragments in this section of the core; microbreccia with grey-green matrix and pitchstone fragments (from millimetres to 5 cm) envelopes small granite clasts.				
315.5 (1035.0)	321.4 (1054.5)	315.5 (1035.0)	321.4 (1054.5)	Very similar to above; few granite lithoclasts; grey-olive green microbreccia with pitchstone fragments; granite lithoclasts are surrounded by porous pitchstone; at the boundary between different granites, lbiotite was locally rearranged by the pressure to form a thin envelope; two limestone subangular fragments, both are partly thinly enveloped by pitchstone; orange crystals in vugs (zeolite?).				
321.4 (1054.5)	327.1 (1073.0)	321.4 (1054.5)	327.1 (1073.0)	Similar lithology as above; microbreccia and pitchstone; one large boulder of nonaltered granite 70 cm in diameter.	325.6	325.7	breccia, pitchstone	NC 3541068

Appendix 1 - Drill Logs

Metreage (Footage)				Description	Sample Interval		Samples	
Core Interval		Units			m (ft.)		Description	Identifier
From	To	From	To		From	To	Rock/Mineral	Number
327.1 (1073.0)	332.8 (1092.0)	327.1 (1073.0)	332.8 (1092.0)	Bulk is grey-olive green microbreccia with small white subangular clasts (quartz, feldspar) and irregular pitchstone lithoclasts from millimetres to 10 cm across, mostly elongated, irregular shapes and envelopes larger clasts up to 30 cm across; pitchstone is again porous and contains small subangular quartz, feldspar, voids and zeolite(?).				
332.8 (1092.0)	338.6 (1111.0)	332.8 (1092.0)	338.6 (1111.0)	Suevite breccia; olive green matrix with white clasts and black pumice with irregular shapes; elongated granite lithoclasts 1-1.2 m; at 335.8 m (1101.7') a granite lithoclast was partly vitrified with flow textures around relic features; local zeolitization(?) of granite.	335.8	335.8	granite, flow texture	P42A,B
338.6 (1111.0)	344.3 (1129.5)	338.6 (1111.0)	344.3 (1129.5)	Similar lithology; suevite breccia; olive green matrix with white clasts and pumice breccia with black pumice rims around granite clasts; some granite clasts are cracked with cracks infilled by pumice; granite locally has orange zeolitization(?); granite lithoclasts 1-30 cm in diameter; a granite fragment about 10 cm in diameter is zeolitized and cracked with rock dust infills the cracks along with the pumice.				
344.3 (1129.5)	349.9 (1148.0)	344.3 (1129.5)	349.9 (1148.0)	Similar to above; mostly suevite breccia with cracked zeolitized granite (gneiss) up to 30 cm in diameter, cracks are infilled with black glass or pumice; medium-grained granite with streaks of black biotite and magnetite along with pink K-feldspars and zeolitization is strongly magnetic.	344.4 348.9	344.4 348.9	magnetite+zeolite glassy pitchstone	P43 P44, G39
349.9 (1148.0)	355.7 (1167.0)	349.9 (1148.0)	355.7 (1167.0)	Similar suevite breccia; olive green chloritic matrix; granite lithoclasts up to 30 cm in diameter, locally zeolitized.	351.8	351.9	breccia, pitchstone	NC 3591154
355.7 (1167.0)	361.2 (1185.0)	355.7 (1167.0)	358.7 (1177.0)	Similar lithology as above; olive green matrix with orange zeolitisation of amygdules; granite clasts have chloritized biotite; local zeolitization of K-feldspar; pumice is grey-violet; glass is changed in chlorite, one site has asterized quartz(?) in a chloritized clast(?).	356.6	356.6	zeolite	M38
		358.7 (1177.0)	361.2 (1185.0)	Black or dark grey pumice prevails over the green chloritic(?) rock as granite becomes ubiquitous.				
361.2 (1185.0)	365.5 (1199.0)	361.2 (1185.0)	365.5 (1199.0)	Basement granite with some pitchstone, white-olive green chloritic rock is scarce; at 364.1 m (1194.5') the pitchstone is very hard, containing amygdules, either void or lined with chlorite or zeolite; granite is vitrified.	364.2 364.3	364.2 364.4	pitchstone granite, pitchstone	P46, G40 NC 3611195
365.5 (1199.0)	369.9 (1213.5)	365.5 (1199.0)	369.9 (1213.5)	Basement granite, biotitic, foliated, grades into orthogneiss; pitchstone between 368.5 and 369.9 m (1209' and 1213.5'); core is mainly coarse-grained biotitic granite grading to orthogneiss, with a few locally finer grained sections.				P46?
369.9 (1213.5)	374.0 (1227.0)	369.9 (1213.5)	374.0 (1227.0)	Coarse-grained biotite granite grading to orthogneiss; foliation is oriented steeply towards the hole axis; pink feldspars; pitchstone present only between 369.9 and 370.2 m (1213.5' and 1214.5').	372.9	372.9	granite/orthogneiss	G41, P47
374.0 (1227.0)	377.0 (1237.0)	374.0 (1227.0)	377.0 (1237.0)	Granite gneiss, a crack 0.5 cm wide infilled by rock dust, grey; no green clay, but chloritized zeolites, zeolitized feldspars and feldspars extremely deformed and fibrous; massive cracked locks uplifted and dust invaded them.				
377.0 (1237.0)		377.0 (1237.0)		End of hole.				

Appendix 2 - Legend

BS	black shale
GS	grey shale
DGS	dark grey shale
ST	sandstone
GST	grey sandstone
DGST	dark grey sandstone
BR	suevite breccia
GRAN	granite-gneiss
PIT	pitchstone
FLT	flow textures
calc	calcareous
gy	grey (no green clay)
gn	grey-green (Fe^{2+})
fri	friable
red	reddish tint (Fe^{3+})

Appendix 2 - Magnetic Susceptibility Measurements: Review and Average Values

Gran	Pit	Bs	Gs	Gs/calc	St	Br/fri/calc	Br/gy/calc	Br/gy	Br/gy/red	Br/gn					
1.62	9.98	0.03	0.00	0.00	-0.03	-0.01	0.19	0.19	0.14	0.07	9.02	12.10	2.92	8.11	3.07
4.20	1.82	0.00	0.04	0.02	-0.02	0.00	0.10	0.10	0.13	0.22	5.77	8.06	4.07	6.65	0.24
4.00	12.90	0.00	0.00	0.00	0.00	-0.01	0.29	0.04	0.12	0.21	7.18	3.57	9.84	8.87	1.35
2.40	12.90	0.02	0.00	0.03	0.00	0.05		0.01	0.18	0.22	9.29	4.58	0.77	8.27	0.66
2.86	16.70	0.29	0.00	0.01	-0.02	-0.03	**0.145**	0.34	0.19	0.13	6.56	12.00	3.25	3.96	0.28
4.81	54.30	0.06	0.00	0.00	-0.07	-0.04			0.18	0.25	9.00	5.98	2.72	5.47	0.15
12.50		0.04	0.15	0.00		0.06		**0.085**	0.07	0.19	9.39	8.92	0.00	0.55	0.14
14.90	**10.86**	0.02	0.19	0.05		0.00			0.20	1.49	4.97	5.18	0.01	0.30	1.28
13.00		0.04		0.00		0.03			0.19	1.67	7.80	16.80	0.04	0.06	2.01
40.00		0.02	**0.027**	-0.15		0.10			0.10	0.53	12.60	8.75	0.02	0.29	1.86
12.70		0.01		-0.02		0.04			-0.14	6.53	7.98	13.20	0.03	0.22	1.11
0.34		0.00		-0.06		0.19			0.29	3.20	8.76	15.10	0.08	0.44	1.05
4.80		0.02							0.60	12.90	9.47	6.50	0.15	0.46	1.09
1.83		0.00				**0.017**			0.26	8.39	9.30	7.73	0.24	0.67	0.54
2.38		-0.07							2.51	3.16	9.64	19.00	0.40	2.45	0.47
0.89		-0.03								0.71	7.89	13.60	0.43	1.76	0.41
123.23		0.02							**0.18**	0.79	15.80	19.30	0.44	1.42	0.45
		-0.04								8.06	8.69	21.10	0.55	6.51	0.81
7.70		0.00								6.78	10.20	12.30	1.08	4.85	0.82
		0.00								4.66	14.60	9.83	4.58	5.65	0.67
		0.06								8.69	8.10	6.80	5.38	4.26	0.69
		0.74								1.56	5.11	3.62	9.18	8.24	0.39
		0.13								6.22	8.03	5.69	8.92	4.30	0.33
		1.36								0.70	9.15	2.32	8.12	2.01	0.38
										7.54	4.88	2.40	7.93	1.64	1.30
		0.06								84.87	219.18	244.43	71.15	87.41	0.86
															1.96
															24.37
															731.41
															4.81

Note: bold are average values
sandstones unspecified

Appendix 2 - Magnetic Susceptibility Measurements, Drillhole ST001

Metreage	Box#	Lithology	Reading
223	38	BS	0.00
		BS	0.02
		BS	0.00
		BS	-0.07
228.8	39	BS	-0.03
		DGST	-0.02
		GST/calc	0.04
		ST/calc	0.01
237.5	40	ST/gy	-0.02
		ST/gy	0.00
		ST/gy	0.00
		DGS	0.00
243.3	41	DGS	0.00
		DGS	0.00
		DGS	0.00
		DGS	0.15
249.1	42	box/core missing	
254	43	BS	0.02
		BS	-0.04
		BS	0.00
		BS	0.00
259.8	44	BS	0.06
		BS	0.74
		BS	0.13
		BS/calc	-0.17
265.4	45	GS/calc	0.01
		GS/calc	0.00
		GS/calc	0.00
		GS/calc	0.05
271.2	46	GS/calc	0.00
		GS/calc	-0.15
		GS/calc	-0.02
		BR/gy/fri/calc	-0.03
277.1	47	BR/gy/fri/calc	-0.04
		BR/gy/fri/calc	0.06
		BR/gy/fri/calc	0.00
		BR/gy/calc	0.00

Metreage	Box#	Lithology	Reading
283.1	48	BR/gy/red/calc	7.10
		BR/gy/red/calc	0.04
		BR/gy/red	0.10
		BR/gy/red	-0.14
288.6	49	BR/gy/red	0.29
		BR/gy/red	0.60
		BR/gy/red	0.26
		BR/gn	0.55
294.1	50	BR/gn	1.08
		BR/gn	4.58
		BR/gn	5.38
		BR/gn	9.18
299.8	51	BR/gn	8.92
		BR/gn	8.12
		BR/gn	7.93
		BR/gn	8.11
305.5	52	BR/gn	6.65
		BR/gn	8.87
		BR/gn	8.27
		BR/gn	3.96
311.1	53	BR/gn	5.47
		BR/gn	0.55
		BR/gn	0.30
		BR/gn	0.06
316.8	54	BR/gn	0.29
		BR/gn	0.22
		BR/gn	0.44
		BR/gn	0.46
323.2	55	BR/gn	0.67
		BR/gn	2.45
		BR/gn	1.76
		BR/gn	1.42
329	56	GRAN	4.80
		GRAN	1.83
		GRAN	2.38
		BR/gn	1.86

Metreage	Box#	Lithology	Reading
334.6	57	BR/gn	1.11
		BR/gn	1.05
		GRAN/PIT	2.23
		BR/gn	1.09
340.2	58	BR/gn	0.54
		BR/gn	0.47
		BR/gn	0.41
		BR/gn	0.45
346.2	59	BR/gn	0.81
		BR/gn	0.82
		BR/gn	0.67
		BR/gn	0.69
352.1	60	BR/gn	0.39
		GRAN/PIT	14.60
		BR/gn	0.33
		BR/gn	0.38
357.6	61	BR/gn	1.30
		GRAN	0.89
		BR/gn	0.86
		BR/gn	1.96
363.4	62	PIT	16.70
		BR/gn	6.51
		BR/gn	4.85
		BR/gn	5.65
369.2	63	BR/gn	4.26
		BR/gn	8.24
		BR/gn	4.30
		BR/gn	2.01
374.8	64	BR/gn	1.64
		BR/gn	3.07
		BR/gn	0.24
379.1	65	BR/gn	1.35
		BR/gn	0.66
		BR/gn	0.28
383.5	66	BR/gn	0.15
		BR/gn	0.14
		BR/gn	1.28
387.8	67	BR/gn	2.01
389.3	end		

Appendix 2 - Magnetic Susceptibility Measurements, Drillhole ST002

Metreage	Box#	Lithology	Reading
203.8	34	BS	0.003
		BS	0.00
		BS	0.02
		BS	0.29
209.6	35	BS	0.06
		BS	0.04
		BS	0.02
		BS	0.04
214.8	36	BS	0.02
		BS	0.01
		GS/calc	0.001
		GS/calc	0.02
220.7	37	GS/calc	0.00
		GS/calc	0.03
		GS	0.04
		BR/fri/gy/calc	0.03
226.2	38	BR/fri/gy/calc	0.10
		BR/fri/gy/calc	0.04
		BR/gy	0.04
		BR/gy	0.01

Metreage	Box#	Lithology	Reading
232.2	39	BR/gn	0.00
		BR/gn	0.01
		BR/gn	0.04
236.4	40	BR/gn	0.02
		BR/gn	0.03
		BR/gn	0.08
240.9	41	BR/gn	0.15
		BR/gn	0.24
		BR/gn	0.40
245.1	42	BR/gn	0.43
		BR/gn	0.44
		BR/gn	0.59
249.5	43	GRAN	0.34
252.1		BR/gn	0.12

Appendix 2 - Magnetic Susceptibility Measurements, Drillhole ST003

Metreage	Box#	Lithology	Reading
200.5	33	BS	0.03
		BS/calc	0.00
		ST/gy/calc	-0.03
		GS/calc	0.00
206.1	34	BR/fri/gy/calc	-0.01
		BR/fri/gy/calc	0.00
		BR/fri/gy/calc	-0.01
		BR/fri/gy/calc	0.05
211.9	35	BR/gy/calc	0.29
		BR/gy/calc	0.29
		BR/gy	0.19
		BR/gy	0.10
217.5	36	BR/gn	0.07
		BR/gn	0.22
		BR/gn	0.21
		BR/gn	0.22
223.5	37	BR/gn	0.13
		BR/gn	0.25
		BR/gy/red	0.14
		BR/gy/red	0.13
229.1	38	BR/gy/red	0.12
		BR/gy/red	0.18
		BR/gy/red	0.19
		BR/gy/red	0.18
234.9	39	BR/gy/red	0.07
		BR/gy/red	0.20
		BR/gy/red	0.19
		BR/gn	0.19
240.5	40	BR/gn	1.49
		BR/gn	1.67
		BR/gn	0.53
		BR/gn	6.53
246.3	41	BR/gn	3.20
		BR/gn	12.90
		BR/gn	8.39
		BR/gn	3.16
252	42	BR/gn	0.71
		BR/gn	0.79
		GRAN/BR/gn	0.90
		GRAN/BR/gn	11.30
257.8	43	BR/gn	8.06
		BR/gn	6.78
		BR/gn	4.66
		BR/gn	8.69
263.6	44	BR/gn	1.56
		BR/gn	6.22
		BR/gn	0.70
		BR/gn	7.54
269.4	45	GRAN/BR/gn	10.10
		BR/gn	9.02
		BR/gn	5.77
		GRAN	14.90
275.2	46	BR/gn	7.18
		BR/gn	9.29
		BR/gn	6.56
		BR/gn	9.00
280.8	47	GRAN	12.50
		BR/gn	9.39
		BR/gn	4.97
		PIT	12.90
286.6	48	BR/gn	7.80
		GRAN	12.70
		BR/gn	12.60
		BR/gn	7.98
292.4	49	BR/gn	8.76
		BR/gn	9.47
		BR/gn	9.30
		BR/gn	9.64
298	50	BR/gn	7.89
		GRAN	13.00
		BR/gn	15.80
		BR/gn	8.69
304	51	BR/gn	10.20
		BR/gn	14.60
		BR/gn	8.10
		BR/gn	5.11
309.8	52	BR/gn	8.03
		BR/gn	9.15
		BR/gn	4.88
		BR/gn	12.10
315.5	53	BR/gn	8.06
		BR/gn	3.57
		BR/gn	4.58
		PIT	12.90
321.5	54	BR/gn	12.00
		BR/gn	5.98
		BR/gn	8.92
		BR/gn	5.18
327.1	55	BR/gn	16.80
		BR/gn	8.75
		BR/gn	13.20
		BR/gn	15.10
332.9	56	BR/gn	6.50
		BR/gn	7.73
		FLT	16.00
		BR/gn	19.00
338.7	57	BR/gn	13.60
		BR/gn	19.30
		BR/gn	21.10
		BR/gn	12.30
344.4	58	GRAN	40.00
		BR/gn	9.83
		GRAN/BR/gn	24.70
		GRAN/BR/gn	6.00
350	59	BR/gn	6.80
		BR/gn	3.62
		BR/gn	5.69
		BR/gn	2.32
355.8	60	BR/gn	2.40
		BR/gn	2.92
		BR/gn	4.07
		BR/gn	9.84
361.3	61	PIT	9.98
		PIT	1.82
		BR/gn	6.06
365.5	62	GRAN/BR/gn	0.77
		GRAN/BR/gn	3.25
		GRAN/BR/gn	2.72
370	63	GRAN	1.62
		GRAN	4.20
		GRAN	4.00
374.1	64	GRAN	2.40
		GRAN	2.86
		GRAN	4.81

Appendix 3 - Scintillometry Survey Results for Lithotypes

Lithology	Value range[1] (in counts/sec)
Black shale, sandstone (nonspecified)	40-50
Suevite breccia, calcareous	40-50
Suevite breccia, noncalcareous	50-60
Suevite breccia (oxidized zone)	50-60
Suevite with granite and gneiss inclusions	50-60
Granite and gneiss (basement) + pitchstone	~60 (max. 70)

[1]Measured using a McPhar scintillometer.

Appendix 4 - Description of Thin Sections

<u>Thin Sections Provided by New Claymore Ltd.</u>

<u>Drillhole ST001</u>

Sample NC 1521007 (306.9 m, 1007')
<u>Macroscopic description</u>: no hand specimen available
<u>Microscopic description</u>: breccia with dark brown lumps of amygdular glass, with inclusions and grey–olive green, clayey clastic matrix with clasts and lithoclasts; lumps of dark brown glass with schlieren and numerous vesicles lined with clay
<u>Minerals</u>:

- feldspar –occurs as shocked grains that are locally substituted by analcime; plagioclase with albitic twinning in one grain is replaced by maskelynite; in pale parts of suevite breccia, high temperature effects on some feldspars, partly melted with plastic deformation of grain boundaries, or extreme plastic flow
- quartz in some grains is recrystallized into a fine-grained mosaic; other grains show PDFs
- black grains of magnetite(?) occur in breccia and some may have formed on account of biotite
- glass in the form of argillized lenses occurs sporadically
- analcime(?) is pale yellow to isotropic with higher relief observed at two places; zeolitization of more or less diaplectic feldspars is common

<u>Rock name</u>: suevite breccia with dark brown lumps of amygdular glass

Sample NC 1631225 (373.4 m, 1225')
<u>Macroscopic description</u>: no hand specimen available
<u>Microscopic description</u>: breccia with brown nonrecrystallized glass containing lumps (Fladen) of brown glass with lighter and darker flow textures; zeolitization proceeds along streaks or schlieren in glass, but some feldspar grains are strongly fractured like the zeolites; Fladen contain small, angular, shocked quartz and feldspar fragments and larger subrounded, partly vitrified lithoclasts and numerous vesicles or amygdules lined with clay and zeolite
<u>Minerals</u>:

- feldspar grains occur with original twin lamellae and alternate lamellae; many plagioclases are strongly cataclastic; one grain observed with multiple PDFs; original albite twin lamellae are still preserved but some alternate lamellae were converted to maskelynite; PDFs crosscut the lamellae to form ‘ladder’ structure;
- quartz is mostly finely recrystallized to form mosaics, and small shocked angular fragments occur in both matrix and Fladen
- black opaque ore mineral, possibly magnetite, frequently concentrates around recrystallized quartz and/or feldspar clasts; some grains retain habit of original biotite, whereas others have rounded shapes, indicating fusion of pre-existing mineral
- montmorillonite, grey-green in colour, forms the matrix of the ‘main’ breccia, which contains small angular quartz and feldspar clasts, shocked, highly fractured and some showing PDFs; lentiform lumps of isotropic or partly devitrified glass as much as 3 mm across occur sporadically

- analcime associates with montmorillonite, especially in vesicles

Rock name: suevite breccia with brown nonrecrystallized glass

Drillhole ST002

Sample NC 243826 (251.8 m, 826')
Macroscopic description: grey–olive green brecciated rock composed of green clayey and clastic matrix, quartz and feldspar clasts, and grey lumps of more-or-less devitrified glass with mineral inclusions (suevite); clasts of carbonate (6 mm) and feldspar (4-5 mm) and shocked granite lithoclasts occur; very small disseminated sulphide (chalcopyrite?) grains
Microscopic description: breccia composed of brown glass lumps (Fladen) with schlieren and flow textures well developed over most parts, locally altered to montmorillonite; selective melting without equilibrium reached between individual grains due to very short time; numerous amygdules in melt phases are aligned with montmorillonite
Minerals:
- feldspar –occurs as shocked grains; some grains look like recrystallized diaplectic glasses, showing intensely mosaic extinction, but preserving their original form; K-feldspars occur as polycrystalline grains showing partial isotropy and development of diaplectic glass–maskelynite
- quartz grains are recrystallized to fine crystalline mosaics, at some boundaries small, high-relief minerals could be coesite and/or stishovite
- calcite clast is shocked, has cloudy undulose extinction

Rock name: suevite breccia

Drillhole ST003

Sample NC 346917 (279.5 m, 917')
Macroscopic description: no hand specimen available
Microscopic description: breccia with a few millimetre-size lentiform clasts of argillized glass, Fladen of dark brown pumicite with vesicles lined with clay and epidote(?); one strongly thermally affected granite lithoclast
Minerals:
- feldspars were partly vitrified and glassy parts are argillized
- quartz was also locally vitrified; diaplectic parts were recrystallized to form very fine grain mosaics
- biotite was thermally affected and transformed into magnetite (+ hematite or maghemite(?) + epidote(?));
- glasses in breccia were argillized
- calcite: a few grains occur, one with PDFs and partly decorated;
- epidote(?) occurs as small grains with high interference colours in amygdules and as a biotite oxidation ‘by-product’(?)

Rock name: suevite breccia with dark brown lumps of amygdular glass and granite lithoclasts

Sample NC 3541068 (325.5 m, 1068')
Macroscopic description: no hand specimen available
Microscopic description: breccia, olive green in colour with black vesicular pitchstone and an altered granite lithoclast enveloped by pitchstone; zeolites commonly occur in amygdules and as alteration products; matrix contains partly digested grains of quartz and feldspar; striking features are radial zeolite aggregates (stilbite?) in amygdules up to 1 cm across
Minerals:
- quartz is partly melted, diaplectic
- feldspar is partly melted, diaplectic
- zeolite –occurs as radial aggregates

Microscopic description: pitchstone (Fladen), strongly vesicular, brown, irregularly shaped glass with partly melted quartz and feldspar inclusions; grain rims attacked by the melt; devitrified; zeolitization (analcime?) locally strong; chlorite and epidote are also alteration products; flow banding (schlieren) preserved locally; opaque ore mineral (magnetite, hematite);
Minerals:
- quartz –is shocked and partly melted
- feldspar –is shocked and partly melted
- analcime(?) lines up vesicles
- chlorite –occurs as an alteration product
- epidote –occurs as an alteration/devitrification product
- magnetite –occurs as a biotite oxidation product
- hematite –occurs as both a primary (biotite oxidation product) and a secondary (magnetite oxidation product)

Microscopic description: granite
Minerals:
- plagioclase has PDFs, locally decorated and grading into glass; cleavage is zeolitized
- quartz –occurs as partly digested grains
- feldspar occurs as partly digested grains
- biotite has been oxidized, partly decomposed and replaced by magnetite and hematite (maghemite?)
- amphibole has also been oxidized, partly decomposed and replaced by magnetite and hematite (maghemite?)
- zircon: one grain in the neighbourhood of magnetite appears thermally affected (black) on one side
- zeolite is mainly stilbite; progressive zeolitization

Rock name: suevite breccia with Fladen and a granite lithoclast

Sample NC 3591154 (351.7 m, 1154')
Macroscopic description: no hand specimen available
Microscopic description: breccia composed of clayey and clastic matrix and shocked clasts and brown Fladen with flow textures and schlieren; glass recrystallized to finely mosaic masses of quartz; glimpses of original grains preserved; flow textures can be observed despite zeolitization
Minerals:
- quartz –occurs as shocked grains; one grain with multiple planar deformation features (PDFs) was observed; very small, angular quartz grains in the microbreccia look less or little shocked
- feldspar occurs as shocked clasts; in some grains maskelynite domains and flow texture parts are zeolitized; vitrified lamellae in plagioclase are brown coloured after Fe^{+3}

- stilbite occurs as sheaf-like aggregates, replacing original glass and vitrified lamellae in plagioclase
- vermiculite(?) replaces original glass and also occurs in amygdules
- biotite –occurs as scarce small, brown, pleochroic flakes, some with kink bands
- opaque black mineral in the matrix is probably magnetite; grains with brown rims are probably hematite (or maghemite?)
- zeolites occur in some amygdules together with clay and chlorite(?)

Rock name: suevite breccia with Fladen

Sample NC 3611195 (364.2 m, 1195')
Macroscopic description: no hand specimen available
Microscopic description: two rock types are present: granodiorite and melt melt phase (pitchstone) brown in colour, contains amygdules filled by chlorite, vermiculite and orange zeolite; flow textures locally visible; quartz in the melt is less deformed than the quartz in granodiorite; at contacts with amphibole-biotite granodiorite, 'microbreccia' occurs with very small angular fragments of feldspar and quartz, black magnetite and brown hematite (or maghemite?); transformation of amphibole and biotite into magnetite suggests facies III in the impact classification proposed by Stöffler (1966)
Minerals:
Granodiorite:
- feldspar is shocked, with maskelynite developed in some grains
- quartz is recrystallized; diaplectic glass (lechatelierite?) has formed with round globular clusters (ballen textures?); rims of ballen are devitrified (chloritized?), some grains having strange rims and domains limited by ribbons
- biotite has kink bands and, at the contacts with melt, becomes opaque; oxidized to form magnetite (± maghemite?)
- amphibole has 2 systems of planar deformation, one grain is strongly fractured parallel to its long axis, locally loses its birefringence and pleochroism to become opaque at the crystal boundaries near the contacts with melt, and opaque disintegration products form; amphibole grains were olcally transformed into magnetite (± maghemite?)
- apatite occurs as small, high-relief, low birefringence grains that form inclusions in amphibole and biotite

Melt phase:
- quartz occurs in a form of ghost grains, almost totally melted; glassy phase locally replaced by chlorite/vermiculite; some quartz recrystallized to form fine mosaics
- feldspar in a form of ghost grains with outlines hardly visible; some feldspar grains recrystallized
- magnetite (black) and hematite (brown) occur frequently

Rock name: vesicular pitchstone and heat-shocked granodiorite

Thin Sections from AGS Samples

Drillhole ST001

Sample P12 (228.1 m, 748')
Macroscopic description: brownish grey, very fine grained sedimentary rock, homogeneous, scarce opaque mineral in lined tiny grains
Microscopic description:
Minerals:
- siderite(?) is very fine grained, grey brownish, with low birefringence; evenly distributed crystals absolutely predominate
- sulphides –occur as tiny grains in thin streaks

Rock name: ironstone (siderite?)

Sample P15 (243.9 m, 800')
Macroscopic description: sandstone of quartz-glauconite composition, green in colour with streaks of limonitized clay, well sorted, proportion of quartz:glauconite roughly 1:4; marine
Microscopic description:
Minerals:
- quartz is quite well sorted, suboval to subangular; most grains have simple, but some undulatory extinction; oriented mostly along the bedding
- glauconite of fresh green colour represents the matrix to quartz grains
- apatite –was found as one grain almost 1 mm across and a few others that are smaller
- carbonate –occurs as scarce suboval grains
- opaque ore minerals

Rock name: glauconitic sandstone

Sample P19 (275.6 m, 904')
Macroscopic description: carbonate breccia, grey in colour, Fladen with shocked carbonate lithoclasts
Microscopic description: streaks of very fine grained matrix, perhaps argillized glass, in which shocked carbonate fragments and agglomerate fragments predominate over the silicate grains 'float'; strips of very fine grained breccia with carbonate, scarce quartz and plagioclase, and opaque minerals
Minerals:
- carbonate is strongly shocked, with complex lamellae, twinning and frequent decoration; some grains seem to have been vitrified, some are granulated and black opaque ore replaces them irregularly
- quartz occurs as scarce shocked grains
- biotite –occurs as scarce flakes with kink banding
- opaque mineral, probably pyrite in irregular clusters or streaks of tiny grains replacing carbonate–devitrified glass clasts, elongated in shape, some resembling Fladen

Rock name: suevite carbonate breccia

Sample P28 (332.2 m, 1090')

Macroscopic description: chilled contact between granodiorite and vesicular melt phase with undigested rock and mineral fragments

Microscopic description: melt phase (pitchstone) brown in colour, contains numerous amygdules; contact with granodiorite is chilled, mostly black glass

- feldspar –occurs as fragments that are almost opaque, or strongly undulose, shocked, cataclastic, locally with PDFs; some grains are rimmed or diaplectic inside
- quartz is almost opaque, or strongly undulose, shocked, cataclastic, with PDFs, locally rimmed or diaplectic inside
- biotite is black, oxidized, substituted locally by black magnetite and brown hematite
- amphibole is also black, oxidized, locally replaced by black magnetite and brown hematite (or maghemite?)
- opaque black minerals envelop some of the fragments

Minerals:

Granodiorite:

- feldspars are shocked, most grains almost opaque, or strongly undulose, shocked, cataclastic, with PDFs
- quartz appears diaplectic and devitrified, replaced by zeolite, clay(?) and tiny opaque ore grains
- biotite is black, almost all is oxidized to form magnetite (±maghemite?), but local kink bands are still visible
- amphibole is black, almost all is oxidized and replaced by magnetite (±maghemite?)

Rock name: chilled contact between shocked granodiorite and vesicular pitchstone

Sample P30 (349.8 m, 1147.5')

Macroscopic description: shocked granodiorite lithoclast in vesicular pumicite, which is strongly argillized

Microscopic description: melt phase (pumicite) brown in colour, contains numerous amygdules lined by clay and zeolite

- feldspar –occurs as fragments that are almost opaque, or strongly undulose, shocked, cataclastic, locally with PDFs; albitic twinning sporadically preserved or disrupted by alternative lamellae
- quartz –grains are almost opaque, or strongly undulose, shocked, cataclastic, locally with PDFs; some almost digested grains are recrystallized into mosaics of tiny grains
- black ore mineral rims the remnant silicate grains

Minerals:

Biotite granite:

- feldspars are shocked, most grains almost opaque or strongly undulose; shock-vitrified lamellae are now argillized
- quartz appears diaplectic and devitrified, replaced by zeolite, clay(?) and peppered by tiny opaque ore grains
- biotite is locally preserved, without or with strong kink bands, and locally black, oxidized and replaced by magnetite (± maghemite?),
- black ore surrounds or corrodes remnant silicates

Rock name: shocked granodiorite lithoclast in vesicular argillized pumicite

Drillhole ST002

Sample P05 (229.4m, 752.5')
Macroscopic description: grey breccia with carbonate lithoclasts; carbonate originates probably from the Wabamun and other (Devonian) formations; matrix mostly calcareous, dynamofluidal, peppered with pyrite
Microscopic description:
Minerals:

- carbonate clasts are strongly shocked; some are decorated and have reduced birefringence, others are granulated; cores of some grains are opaque; flow textures indicate extreme temperatures and plasticity; clasts have been squeezed into dynamofluidal streaks and fragmented; elliptic and wedge-shaped pieces of dark aphanitic glass that probably formed from a carbonate mineral containing Fe because all aphanitic and glassy looking grains are associated with pyrite; one grain of vitrified carbonate is surrounded by pyrite; vitrified carbonates do not contain pyrite
- pyrite in patches and clusters of small grains and/or cubes accompanies shocked carbonate grains
- biotite flakes (clasts) have kink bands
- plagioclase with albitic twinning, heavily decorated
- mineral (zeolite or clay?) of light brown colour, quite widespread, is not shocked and replaces shocked and glassy parts
- apatite(?) –is strongly elongated and fractured

Rock name: suevite breccia with carbonate lithoclasts

Sample P09 (243.6 m, 799')
Macroscopic description: Suevite breccia, grey-green in colour, clayey clastic matrix
Microscopic description: quartz and feldspar grains are strongly shocked; some are isotropic or parts of grains are diaplectic, filled or decorated by tiny inclusions of unknown mineral; probably some coesite and/or stishovite are also involved; flow textures very well developed; original glass was devitrified to montmorillonite, in which tiny opaque grains or patchy/streaky micrograin agglomerates of ore minerals occur; one carbonate lithoclast also occurs; small grey Fladen with schlieren have both ends broken off, but one nice complete micro-Flade, about 3-4 mm long, with schlieren and inclusions of vitrified rock is present; original minerals are hardly recognizable, almost all are partly or totally glassy with flow textures, amygdules and streaks; this mixture is zeolitized and argillitized almost beyond recognition of original mineralogy, structure or texture; one large clast of vitrified carbonate(?), about 2 cm across, is partly devitrified, decorated, very fine grained, and enveloped by montmorillonite
Minerals:

- quartz occurs as decorated and isotropized diaplectic grains filled by tiny mineral; some are isotropic or parts of grains are diaplectic
- feldspar grains are strongly shocked
- biotite –occurs as shocked flakes with kink bands
- montmorillonite is a matrix devitrification product
- carbonate –occurs as shocked or vitrified lithoclasts
- zeolites

Rock name: suevite breccia

Sample P10A (249.4 m, 818’)
Macroscopic description: breccia, grey-green in colour, clayey clastic matrix surrounding a Flade with vitrified granite lithoclast and a lump of strongly argillized dark glass with desiccation cracks along montmorillonitic streaks and amygdules
Microscopic description: most glassy material was argillized and zeolitized; flow textures are very distinct; original glass in schlieren was replaced by montmorillonite, in which tiny opaque grains or patchy or streaky micrograin agglomerates of ore minerals occur; small grey Fladen with schlieren; original minerals are hardly recognizable because of zeolitization and argillization; streaks
Minerals:

- quartz occurs as decorated and isotropized diaplectic grains, filled or decorated by tiny inclusions of unknown mineral; some are isotropic or parts of grains are diaplectic, other grains were vitrified, then recrystallized into mosaic pattern
- plagioclase grains have albitic twinning but are strongly shocked
- biotite –occurs as shocked flakes with kink bands and remnants of oxidized flakes
- montmorillonite –is devitrification product
- carbonate –forms shocked or vitrified lithoclasts about 2 cm across, partly devitrified, decorated, and enveloped by montmorillonite
- zeolites: at least two varieties are present, one filling the amygdules and the other replacing glassy phases

Rock name: suevite breccia

Drillhole ST003

Sample P36 (213.3 m, 700’)
Macroscopic description: greenish grey breccia with carbonate lithoclasts and Fladen; carbonate probably originates from the Wabamun Formation (Devonian)
Microscopic description: matrix is pale to dark brown, aphanitic, opaque, progressively zeolitized; Fladen are composed of fine mosaic quartz, some containing tiny angular quartz and feldspar grains; elliptic and wedge-shaped pieces of dark glass that probably formed from a carbonate mineral containing Fe because all aphanitic and glassy looking grains are associated with pyrite; amygdules lined with zeolite and clay
Minerals:

- carbonate clasts are strongly shocked, with sets of intersecting fractures; decorated and have reduced birefringence; others are granulated and parts of them or entire grains are opaque; flow textures indicate extreme temperatures and plasticity; some carbonate clasts are invaded or corroded by melt; one grain of vitrified carbonate is surrounded by pyrite, whereas others are peppered
- pyrite in patches and clusters of small grains and/or cubes accompanies shocked carbonate grains
- biotite flakes (clastic) have kink bands, some are partly oxidized
- quartz in Fladen has been recrystallized into fine-grained mosaic pattern; tiny shocked grains in glass
- plagioclase with albitic twinning, almost opaque, heavily decorated
- zeolite, of light brown colour, is quite widespread; replaces glassy and locally also shocked minerals and lines up amygdules
- apatite(?) occurs as a strongly elongated, fractured prism

Rock name: greenish grey suevite breccia with carbonate lithoclasts and grey Fladen

Sample P39 (248.1 m, 814')
Macroscopic description: breccia, grey–olive green in colour, clayey clastic matrix, Fladen of brown glass, locally with abundant vesicles coalescing to form large amygdules lined by zeolite
Microscopic description: original minerals in Fladen are hardly recognizable; almost all are nearly opaque, recrystallized into fine mosaics or are totally glassy; amygdules represent almost 50% of the rock volume; in green matrix, which looks glassy, are shocked subangular and angular grains of quartz and feldspar, partly digested by melt land ocally diaplectic; superimposed zeolitization
Minerals:
- quartz grains are strongly shocked, some are almost isotropic or parts of grains are diaplectic; one grain may have lechatelierite rim around brownish almost glassy core
- feldspar grains are strongly shocked, some are almost isotropic or parts of grains are diaplectic; plagioclase grains have albitic twinning, but are strongly shocked
- opaque minerals –include 2 grains of pyrite, very fine magnetite and hematite, some as inclusions in partly vitrified silicates
- zeolites: at least two varieties are present, one filling the amygdules and the other replacing glassy phases

Rock name: suevite breccia, grey–olive green in colour with dark grey to black vesicular Fladen

Sample P40 (256.6 m, 842')
Macroscopic description: contact between granitoid– and pitchstone; melt phase (pitchstone) is brown in colour and resembles pseudotachylite; contains small vitrified clasts ('microbreccia') and large, partly diaplectic, irregularly digested grains of feldspar and quartz that are strongly undulose or almost isotropic; zeolitized, with two types of zeolite (brown and clear); flow textures in matrix are indicated by alignment of small feldspar microlites (trichytes) around larger inclusions; contacts with amphibole-biotite granodiorite include very small angular fragments of feldspar and quartz, black magnetite and brown hematite (or maghemite?); transformation of FeO in amphibole and biotite into magnetite indicates facies III shock metamorphism of Stöffler (1966)
Microscopic description:
Minerals:
Melt phase:
- quartz strongly undulose or almost isotropic, almost totally melted; glassy phase locally replaced by zeolite; some quartz recrystallized to form fine mosaics, small grains preserved or vitrified
- feldspar strongly undulose, or almost isotropic; some feldspar grains recrystallized; lathy microlites in the melt
- magnetite –is disseminated as small, scarce (black) grains

Granodiorite:
- feldspars are cloudy, patchy, brown or grey-brown opaque, almost or entirely isotropized
- quartz is recrystallized
- biotite was totally oxidized to form magnetite
- amphibole was also oxidized and magnetite developed
- analcime replaces glass phases locally

Rock name: pitchstone and shock-affected granodiorite

Sample P42A (335.8 m, 1102’)
Macroscopic description: Sintered granodiorite; dark brown to black streaks rich in magnetite, originally biotite and amphibole and melt phases alternate with pale, strongly plastically deformed or flowed quartz and feldspar; peppered or containing black specks of opaque minerals; streaks contain white isotropic mineral (lechatelierite or analcime?); small elongated lath-like crystals of feldspar occur in some streaks; black magnetite is locally globular, suggesting it was melted, and small oval grains are locally aligned around larger inclusions; amygdules lined by zeolite occur locally
Microscopic description:
Minerals:
- quartz strongly decorated, almost isotropic or almost totally melted; plastically deformed into lentiform or irregular, elongated shapes; glassy phase was locally replaced by zeolite; some quartz recrystallized to form fine mosaics, small grains more or less vitrified
- feldspar strongly undulose or almost isotropic; some feldspar grains recrystallized; rare lathy microlites
- magnetite replaces biotite and amphibole
- analcime locally replaces glass phases
- carbonate –occurs as scarce melt-corroded grains of unknown origin

Rock name: partly vitrified granodiorite

Sample P42B (335.8 m, 1102’)
Macroscopic description: Vitrified (sintered) granodiorite; dark brown to black streaks rich in magnetite (originally biotite and amphibole) and melt phase lumps of brown-grey glass almost without inclusions alternate with pale, strongly plastically deformed or flowed quartz and feldspar; peppered or containing black specks of opaque minerals; streaks contain white isotropic mineral (lechatelierite or analcime?); small elongated lath-like crystals of feldspar occur in some of the streaks; black magnetite is locally globular suggesting it was melted, and small oval grains are locally aligned in streaks of small feldspar microlites (trichytes) around larger inclusions
Microscopic description:
Minerals:
- quartz strongly decorated, brown, almost isotropic or almost totally melted; plastically deformed into lentiform or irregular, elongated shapes; glassy phase locally replaced by zeolite; some quartz recrystallized to form fine mosaics, small grains are more or less vitrified
- feldspar strongly undulose, or almost isotropic; some feldspar grains recrystallized; rare lathy microlites in the melts
- magnetite replaces biotite and amphibole
- analcime locally replaces glass phases
- carbonate –occurs as scarce melt-corroded grains of unknown origin

Rock name: vitrified granodiorite

Sample P43 (344.4 m, 1130’**)**
Macroscopic description: Biotite granite-orthogneiss with sooty black magnetite and zeolitized feldspars; bands of large pinkish feldspar grains, zeolitized, alternate with bands rich in black magnetite
Microscopic description:

Minerals:

- feldspars –occur as large grains stained by brown or grey-brown Fe-oxides and clays as glass alteration products(?); peppered with opaque minerals, mainly magnetite; locally almost isotropic, patchy and wavy extinction
- quartz was vitrified and recrystallized
- biotite was oxidized to form magnetite, skeleton-shaped magnetite locally combined with glass or an unknown mineral as a side-product of oxidation; faint cleavage is still observable in some large flakes
- amphibole: one grain was also oxidized and magnetite developed
- analcime locally replaces glass phases

Rock name: shock-heat–affected biotite granite grading to orthogneiss

Sample P44 (348.9 m, 1144.5')
Macroscopic description: contact between granitoid– and pitchstone; melt phase (pitchstone) brown in colour; flow textures in matrix indicated by alignment of small feldspar microlites (trichytes) around larger inclusions; contains very small shocked angular fragments of feldspar and quartz and small vitrified clasts ('microbreccia') and large, partly vitrified, irregularly digested grains of feldspar and quartz that are strongly undulose or almost isotropic; contact with granitoid is zeolitized; zeolitization proceeds along glassy streaks; granitoid itself is partly melted, most grains having lost their habit due to melting and plastic flow, diaplectic phases are ubiquitous; quartz grains were melted to form lechatelierite; the rock probably did not contain much biotite because of sparse oxidation products; magnetite and hematite occur
Microscopic description:
Minerals:
Melt phase

- quartz almost totally melted; melt-corroded grains with lechatelierite phase, mosaic undulation and PDFs; small shocked angular grains preserved in microbreccia
- feldspar strongly undulose or almost isotropic; some feldspar grains recrystallized; maskelynite developed along twining lamellae; lathy microlites
- magnetite –occurs as small scarce (black) grains
- zeolite of two types, brown and clear radial (stilbite?)

Granite:

- feldspars are cloudy, patchy, brown or grey-brown opaque, possibly due to alteration into a mixture of clay and Fe-oxides, or almost entirely isotropized; locally plastically deformed; flow textures
- quartz almost totally melted; melt-corroded grains with lechatelierite phase; plastic deformation and squeezed flow textures
- biotite scarce, totally oxidized to form magnetite in the form of elongated, irregular grains or clusters of small grains

Rock name: pitchstone and shock-heat–affected granite

Sample P46 (ST003/364.2 m)
Macroscopic description: pitchstone; dark grey aphanitic rock with small white fragments and amygdules; dark grey-brown glass ('microbreccia') with round or oval amygdules
Microscopic description: brown-grey aphanitic melt with microscopic lathy microlites of feldspar, shocked and melted grains of feldspar and quartz, and amygdules up to 2 mm across lined with vermiculite(?) and zeolite occur in the melt and in melted parts of large grains, but their centres are mostly hollow

Minerals:
- quartz grains have mosaic extinction; insides of grains were partly or wholly melted, or melt-digested; large grains are brown, peppered or decorated, indicating clay and/or iron admixture; some grains are melt corroded, some recrystallized; small shocked angular grains are preserved in microbreccia
- feldspar grains were partly or entirely melted, or corroded by melt; large grains are brown peppered or decorated; slim lathy microlites (trichytes) are widespread in the melt and are mostly flow-vector aligned or mimic the inclusion boundaries
- magnetite –occurs as very small black grains or irregular clusters that are attached to large grains or disseminated in the melt
- zeolites line up the amygdules; zeolitization progresses in streaks and around amygdules

Rock name: pitchstone (vesicular impactite glass).

Sample P47 (375.9 m, 1233')
Macroscopic description: granodiorite; pale grey granitoid with green amphibole and biotite and pink feldspar; deformation is extreme in places and brecciation developed with angular fragments and greenish vermiculite(?) matrix and invaded by rock dust, now argillized, chloritized and zeolitized
Microscopic description:
Minerals:
- feldspars are strongly cataclastic, with PDFs and albitic twinning lamellae in slightly sericitized plagioclase (oligoclase); plagioclase affected by an oblique twinning; locally diaplectic glass maskelynite developed; brown coloration may be due to alteration to clay and iron oxides
- quartz almost totally melted, melt-corroded grains with lechatelierite phase; plastic deformation and flow textures
- biotite has kink bands and was oxidized to form magnetite and (hematite?); green chlorite or vermiculite replaces it as irregular grains or clusters of small grains
- amphibole has multiple PDFs; some grains are heavily fragmented and squeezed into bands, filled by black magnetite that developed due to high-temperature oxidation carbonate formed as a secondary product in one place
- epidote associating with biotite is fragmented
- apatite grains are fragmented and parts have been displaced
- zeolite(?) of yellow to brown colour replaces and fills the fractures

Rock name: shocked biotite-amphibole granodiorite

Appendix 5 – X-Ray Diffraction (XRD) Data

XRD SYSTEM: The samples were analyzed using a Siemens D5000 XRD unit under the following conditions:

1. Cu tube filtered with a graphite monochromator
2. Goniometer (two-circle goniometer with independent stepper motors for 0/0 movements)
3. Scintillation detector
4. Slits (divergence slit 2 mm, detector slit 2 mm, antiscatter slit 0.6 mm)
5. 45 kV, 30 mA
6. Step size 0.03 degrees

Diffraction data were collected and processed using a Pentium computer running MS-DOS version 4 with the Siemens DIFFRAC AT Basic and Search/Match Software.

STANDARD POWDER METHOD: Qualitative determination of minerals (Hutchison, 1974)

Sample Preparation Method 1: Sample ground to <125 μm in an agate mortar, packed into a standard plastic holder and analyzed.

Sample Preparation Method 2: Sample ground to <125 μm in an agate mortar, an acetone slurry of the sample is prepared and pipetted onto a glass slide, and the sample is analyzed.

Interpretation: Identification of a crystalline phase is based on matching the x-ray diffraction intensity peaks (a minimum of the three strongest reflections) to the JCPDS data cards.

CLAY MINERAL METHOD: Semi-quantitative estimation of clay mineral content (Thorez, 1976)

Sample Preparation: The <2 μm fraction of a sample is extracted by centrifuging (based on Stokes Law). Two smear-oriented slides are prepared. One is treated with ethylene glycol and second heated (550°C) before analysis.

Interpretation: Identification of the clay minerals (illite, kaolinite, chlorite and montmorillonite) is based on the behaviour of the basal reflections (001) of the clay minerals with the different diagnostic treatments. The heights of the (001) reflections above the background are measured. These data are entered into an XRD Fortran software program, which calculates the percentages for each clay mineral identified.

Appendix 5 - XRD Analysis Results

Borehole/Sample #	XRD Lab #	XRD Sample Preparation Method	XRD Results
ST001-M07	ST-1	Powder Method (Plastic Holder)	Barite (Barium Sulfate) Marcasite (Iron Sulfide) Quartz (Silicon Oxide)
ST001-M09	ST-2	Powder Method (Acetone Slurry)	Calcite (Calcium Carbonate) - strong fizz reaction on application of HCl
ST001-M11	ST-3	Powder Method (Plastic Holder)	Quartz (Silicon Oxide) Suspect presence of clay minerals - needs confirmation by Clay Mineral Analysis Method
	ST-23 (Glycolated slide) ST-24 (Heated slide)	Clay Method	Illite - 90% Kaolinite - 10% Suspect Quartz (Silicon Oxide)
ST001-M14A	ST-25 (Glycolated slide) ST-26 (Heated slide)	Clay Method	Montmorillonite - 100%
ST001-M15	ST-4	Powder Method (Acetone Slurry)	Suspect presence of clay mineral (?) - needs confirmation by Clay Mineral Analysis Method
ST001-M17	ST-5	Powder Method (Plastic Holder)	Analcime (Sodium Aluminum Silicate Hydrate) Quartz (Silicon Oxide)
ST001-M18A	ST-6	Powder Method (Plastic Holder)	Analcime (Sodium Aluminum Silicate Hydrate) Calcite (Calcium Carbonate) - strong fizz reaction on application of HCl
ST001-M18B	ST-7	Powder Method (Plastic Holder)	Analcime (Sodium Aluminum Silicate Hydrate) Calcite (Calcium Carbonate) - strong fizz reaction on application of HCl Quartz (Silicon Oxide) Unidentified peaks (could not be matched for identification)
ST001-M19A	ST-20	Powder Method (Plastic Holder)	Gypsum (Calcium Sulfate Hydrate)
ST002-M03	ST-17	Powder Method (Plastic Holder)	Pyrite (Iron Sulfide) Marcasite (Iron Sulfide) Calcite (Calcium Carbonate) - strong fizz reaction on application of HCl Quartz (Silicon Oxide)
ST002-M05A	ST-21 (Glycolated slide) ST-22 (Heated slide)	Clay Method	Montmorillonite - 100%
ST003-M22	ST-18	Powder Method (Plastic Holder)	Pyrite (Iron Sulfide) Barite (Barium Sulfate) Quartz (Silicon Oxide)
ST003-M27	ST-8	Powder Method (Plastic Holder)	Calcite (Calcium Carbonate) - strong fizz reaction on application of HCl Barite (Barium Sulfate)

Appendix 5 - XRD Analysis Results

Borehole/Sample #	XRD Lab #	XRD Sample Preparation Method	XRD Results
ST003-M30	ST-9	Powder Method (Acetone Slurry)	Calcite (Calcium Carbonate) - strong fizz reaction on application of HCl Quartz (Silicon Oxide) Suspect presence of clay mineral (Chlorite) - needs confirmation by Clay Mineral Analysis Method Unidentified peaks (could not be matched for identification)
ST003-M31	ST-10	Powder Method (Acetone Slurry)	Calcite (Calcium Carbonate) - strong fizz reaction on application of HCl Suspect presence of clay minerals - needs confirmation by Clay Mineral Analysis Method Unidentified peaks (could not be matched for identification)
ST003-M32	ST-11	Powder Method (Acetone Slurry)	Calcite (Calcium Carbonate) - strong fizz reaction on application of HCl Suspect presence of Quartz (Silicon Oxide) Suspect presence of clay minerals (Chlorite, Kaolinite) - needs confirmation by Clay Mineral Analysis Method Unidentified peaks (could not be matched for identification)
ST003-M34	ST-19	Powder Method (Acetone Slurry)	Pyrite (Iron Sulfide)
ST003-M34A	ST-27 (Glycolated slide) ST-28 (Heated slide) ST-29 (Untreated slide)	Clay Method	Suspect Mixed Layer Clay: V-Cg (Vermiculite - Swelling Chlorite) or C-M (Chlortie-Montmorillonite)
ST003-M35	ST-12	Powder Method (Acetone Slurry)	Magnetite (Iron Oxide) - strong magnetic properties Quartz (Silicon Oxide) Suspect Hematite (Iron Oxide) Suspect Plagioclase Feldspar (Sodium and/or Calacium Aluminum Silicate) Unidentified peaks (could not be matched for identification)
ST003-M36	ST-13	Powder Method (Plastic Holder)	Stilbite (Sodium Calcium Aluminum Silcate Hydrate)
ST003-M36A	ST-14	Powder Method (Acetone Slurry)	Laumontite - leonhardite (Calcium Aluminum Silicate Hydrate) Unidentified peaks (could not be matched for identification)
ST003-M37	ST-15	Powder Method (Acetone Slurry)	Stilbite (Sodium Calcium Aluminum Silcate Hydrate) Quartz (Silicon Oxide) Suspect presence of clay mineral (Chlorite) - needs confirmation by Clay Mineral Analysis Method Unidentified peaks (could not be matched for identification)
ST003-M38	St-16	Powder Method (Plastic Holder)	Stilbite (Sodium Calcium Aluminum Silcate Hydrate)

Appendix 6 - Oxide and Trace-Element Analytical Results

Sample No.	Au	Ag	As	Ba	Br	Ca	Co	Cr	Cs	Fe	Hf	Hg	Ir	Mo	Ni	Rb	Sb
	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppb	ppm	ppm	ppm	ppm
G02	-2	-5	7.3	8700	5.8	2	11	53	4	1.55	7	-1	-5	2	-20	59	0.4
G11	2	-5	0.8	1800	7.1	2	13	30	2	3.80	4	-1	-5	2	-27	160	-0.1
G13	-2	-5	1.1	540	0.9	6	9	16	-1	31.40	-1	-1	-5	-1	-25	38	0.2
G16	5	-5	41.0	470	8.3	-1	31	100	6	8.69	3	-1	-5	-1	-26	170	0.5
G18	-2	-5	32.1	20000	4.8	19	8	33	3	7.00	5	-1	-5	6	-20	42	0.4
G22	-2	-5	1.4	920	8.3	2	12	43	2	3.38	4	-1	-5	-1	-29	166	0.2
G32	-2	-5	-0.5	870	7.1	2	12	39	-1	3.34	4	-1	-5	-1	-25	153	0.2
G33	-2	-5	-0.5	480	4.1	2	16	55	2	3.86	3	-1	-5	-1	-31	157	0.2
G35	-2	-5	24.3	480	2.2	27	4	20	2	9.98	2	-1	-5	17	-20	28	0.2
G38	5	-5	2.5	-50	15.6	11	9	17	1	8.51	3	-1	-5	10	-34	56	0.3
G39	4	-5	1.1	1100	11.4	1	5	41	2	2.18	5	-1	-5	-1	-32	192	0.4
G40	-2	-5	-0.5	840	16.5	1	14	42	3	4.03	6	-1	-5	8	-30	161	0.2
G41	-2	-5	-0.5	1100	8.8	2	10	15	3	4.38	9	-1	-5	-1	-30	142	0.2
G52 (=G32)	4	-5	0.8	860	14.7	2	11	36	1	3.29	5	-1	-5	6	-32	130	0.3
G69 (=G39)	-2	-5	-0.5	720	10.4	2	18	46	2	3.28	4	-1	-5	-1	-33	141	0.3
G70 (=G40)	-2	-5	1.2	800	14.3	1	17	51	1	3.92	5	-1	-5	-1	-34	172	-0.1
G70 (DUP)	-2	-5	1.3	830	14.5	1	18	50	-1	4.01	5	-1	-5	-1	-34	113	-0.1

Sample No.	Sc	Se	$Sn_{(x)}$	$Sr_{(x)}$	Ta	Th	U	W	Zn	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
	ppm	ppm	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
G02	7.4	-3	-0.01	0.05	-0.5	7.1	1.8	-1	57	23.2	39	14	3.1	0.7	-0.5	1.6	0.29
G11	11.3	-3	-0.01	0.26	-0.5	8.9	2.7	-1	-50	38.3	68	22	4.6	1.1	-0.5	1.3	0.22
G13	4.4	-3	-0.01	-0.05	-0.5	1.3	2.3	-1	149	25.4	31	11	2.9	0.8	-0.5	1.8	0.30
G16	14.0	-3	-0.01	-0.05	-0.5	8.4	1.2	-1	159	39.9	96	31	7.4	1.4	0.5	1.2	0.17
G18	6.8	-3	-0.01	-0.05	0.5	4.4	-0.5	-1	89	18.8	34	13	3.2	0.8	-0.5	1.4	0.23
G22	11.8	-3	-0.01	-0.05	-0.5	14.9	4.2	-1	-50	44.2	75	21	5.0	1.1	-0.5	1.4	0.24
G32	11.7	-3	-0.01	-0.05	-0.5	15.0	4.8	-1	101	57.6	96	32	5.5	1.0	-0.5	1.8	0.27
G33	15.1	-3	-0.01	0.07	-0.5	10.7	7.9	-1	-50	7.8	19	10	2.8	0.8	-0.5	1.8	0.29
G35	3.5	-3	-0.01	-0.05	-0.5	2.7	1.0	-1	-50	10.9	24	7	2.0	0.4	-0.5	0.9	0.12
G38	11.3	-3	-0.01	0.21	-0.5	10.9	-0.5	-1	111	202.0	367	122	23.2	4.0	2.0	3.5	0.61
G39	10.6	-3	-0.01	-0.05	-0.5	16.4	5.4	-1	103	83.8	130	35	6.5	1.2	-0.5	1.8	0.28
G40	13.4	-3	-0.01	-0.05	1.9	15.6	4.0	-1	69	41.6	86	38	6.0	1.0	-0.5	1.9	0.30
G41	13.7	-3	-0.01	0.05	-0.5	8.4	1.6	-1	-50	59.7	102	36	7.2	1.4	-0.5	2.2	0.37
G52 (=G32)	10.9	-3	-0.01	-0.05	-0.5	14.9	6.2	-1	-50	60.1	102	33	5.2	1.1	-0.5	1.5	0.26
G69 (=G39)	14.3	-3	-0.01	-0.05	-0.5	13.1	4.3	-1	129	38.9	76	26	5.5	1.1	-0.5	1.8	0.25
G70 (=G40)	15.1	-3	-0.01	-0.05	-0.5	15.7	4.2	-1	173	44.9	85	35	6.5	1.2	-0.5	2.1	0.31
G70 (DUP)	15.1	-3	-0.01	-0.05	-0.5	15.0	4.4	-1	151	45.3	85	33	6.4	1.2	-0.5	2.1	0.32

Appendix 6 - Oxide and Trace-Element Analytical Results

Sample No.	Ag	Be	Bi	Cd	Cu	Mn	Mo	Ni	Pb	Sr	V	Y	Zn	Al	Ca	K	P	Mg	Ti	S	Na	Mass
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	%	%	%	%	%	%	%	g
G02	-0.3	1	-2	1.0	28	836	1	31	15	496	82	13	61	3.76	2.40	0.89	0.018	0.33	0.26	0.359	0.14	30.56
G02/R	-0.3	-1	-2	0.3	27	827	-1	29	14	475	82	12	59	3.50	2.38	0.88	0.018	0.31	0.26	0.362		
G11	-0.3	2	-2	-0.3	27	430	-1	15	10	2810	61	14	68	6.68	1.99	4.00	0.050	5.43	0.26	0.214	2.13	25.22
G13	-0.3	2	10	2.5	19	8477	6	45	17	198	27	37	113	1.05	6.90	0.29	0.715	2.07	0.05	0.100	0.14	38.47
G16	-0.3	6	-2	3.5	22	170	2	26	23	92	249	15	145	3.31	0.62	2.83	0.066	0.69	0.12	0.240	0.29	24.88
G18	-0.3	-1	-2	-0.3	19	894	4	27	6	206	39	11	41	2.12	15.66	0.72	0.049	0.32	0.14	5.898	0.12	25.80
G22	-0.3	2	-2	-0.3	30	522	1	20	14	328	58	15	63	6.94	1.98	4.06	0.049	3.23	0.28	0.038	2.36	23.22
G32	-0.3	2	-2	-0.3	28	695	-1	18	20	300	56	14	64	6.77	1.86	2.96	0.050	2.47	0.27	0.024	3.38	22.03
G33	-0.3	2	-2	-0.3	19	569	1	18	17	328	83	11	55	5.85	2.03	2.56	0.056	1.86	0.33	0.051	2.85	21.54
G35	-0.3	-1	-2	2.5	17	2562	15	18	3	124	26	7	-1	1.40	22.21	0.44	0.026	0.21	0.09	8.446	0.08	24.57
G38	-0.3	5	6	2.0	14	1468	1	5	5	1622	97	46	74	7.63	9.43	0.94	0.027	2.06	0.19	0.020	1.93	28.46
G39	-0.3	2	-2	-0.3	33	541	-1	15	16	420	59	13	107	5.27	1.05	2.87	0.053	0.49	0.32	0.012	3.85	25.41
G40	-0.3	2	-2	0.5	27	675	1	32	21	242	86	17	127	6.42	1.30	2.88	0.055	1.61	0.32	0.009	3.10	26.38
G41	-0.3	2	-2	-0.3	26	702	1	8	25	330	46	21	77	7.43	1.85	2.68	0.063	1.24	0.41	0.063	2.67	24.99
G52 (=G32)	-0.3	2	-2	-0.3	19	698	-1	19	20	308	58	15	67	6.89	1.76	3.04	0.050	2.59	0.29	0.016	3.47	24.56
G69 (=G39)	-0.3	2	-2	0.4	23	604	2	29	24	261	78	14	87	6.65	1.68	2.34	0.060	1.01	0.34	0.009	3.41	22.79
G69/R	-0.3	2	-2	1.5	27	635	1	29	21	268	79	13	94	5.40	1.72	3.01	0.057	0.84	0.35	0.010		
G70 (=G40)	-0.3	2	-2	-0.3	32	608	2	33	25	261	90	16	135	5.34	1.45	3.21	0.060	1.21	0.35	0.008	3.48	23.07
G70 (DUP)	-0.3	2	-2	0.3	30	615	-1	32	25	263	90	15	132	5.30	1.45	2.91	0.060	1.17	0.35	0.009	3.47	22.35

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	TOTAL
	%	%	%	%	%	%	%	%	%	%	%	%
G02	79.34	7.46	1.97	0.111	0.49	3.00	0.20	1.00	0.403	0.05	6.86	100.89
G11	54.63	13.33	4.38	0.056	8.14	2.59	2.65	4.53	0.438	0.13	7.94	98.79
G13	6.42	2.07	43.58	1.095	3.38	9.35	0.20	0.37	0.087	2.17	30.42	99.15
G16	67.33	6.88	11.50	0.022	1.09	0.86	0.40	3.35	0.202	0.18	7.21	99.03
G18	33.90	4.51	8.53	0.123	0.57	22.89	0.17	0.75	0.258	0.16	15.26	87.11
G22	60.32	14.22	3.69	0.068	4.97	2.64	2.87	4.50	0.452	0.13	4.81	98.66
G32	62.45	15.02	4.32	0.096	4.07	2.59	4.42	4.07	0.462	0.15	3.31	100.98
G33	64.05	15.57	4.89	0.077	3.34	2.85	3.58	3.13	0.566	0.17	2.15	100.37
G35	17.74	2.75	12.31	0.324	0.33	32.65	0.10	0.37	0.147	0.05	19.42	86.18
G38	48.41	15.52	10.87	0.178	3.18	11.89	2.45	1.05	0.310	0.08	4.68	98.62
G39	66.68	15.76	2.86	0.071	1.12	1.45	4.94	4.74	0.509	0.16	1.79	100.07
G40	62.86	15.38	5.14	0.086	2.72	1.70	4.05	4.57	0.521	0.15	2.62	99.78
G41	64.02	15.45	5.65	0.091	1.96	2.40	3.45	4.65	0.645	0.18	1.95	100.45
G52 (=G32)	62.51	15.06	4.09	0.092	4.01	2.33	4.53	3.84	0.460	0.14	3.28	100.34
G69 (=G39)	62.87	16.76	4.24	0.086	1.88	2.37	4.49	4.69	0.570	0.17	2.30	100.42
G69/R	62.96	16.75	4.23	0.087	1.88	2.37	4.48	4.66	0.570	0.18	2.30	100.46
G70 (=G40)	61.96	16.16	5.10	0.082	2.46	2.00	4.32	4.57	0.575	0.18	2.23	99.64
G70 (DUP)	61.69	15.86	5.17	0.083	2.38	2.01	4.33	4.50	0.596	0.18	2.25	99.04