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Outcrop Fracture Mapping

March 2011

Prepared by: A. Cruden

NWMO DGR-TR-2011-43

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EXECUTIVE SUMMARY

This report describes the results of detailed structural mapping fieldwork undertaken as a part of the Neotectonics/Paleoseismology component of ongoing site characterization activities for Ontario Power Generation's proposed Deep Geological Repository (DGR) project at the Bruce nuclear site in the Municipality of Kincardine, Ontario. Structural mapping of Devonian-aged rock pavements exposed on the Lake Huron shoreline at the Bruce nuclear site and adjacent Inverhuron Provincial Park was carried out between June and September 2009. This report documents the observed nature of fracture populations in the study area.

The orientations, characteristics, and cross-cutting and abutting relationships of 610 fractures were recorded from outcrops of Lucas Formation limestone, exposed on the shoreline of Lake Huron west, southwest and south of the Bruce nuclear site. Bedding trend lines and major fracture traces were interpreted from digital air photographs and bed attitudes were measured in the field. Strata dip uniformly < 1° to the southwest, except where deflected within 1 to 100 m scale low amplitude dome and basin structures likely associated with algal mounds.

Of the observed fractures, 546 are classified as joints and 86 are calcite-filled veins. Joints and veins share common orientations and are mutually cross-cutting. The fracture population is mostly subvertical and dominated by a major NNW-trending set with a peak orientation of 350° and a range between 336° and 006°. A second population of fractures defines a broad peak trending ENE with a range between 025° and 098°. Within this broad peak, four statistically significant sub-peaks are defined with orientations 041°, 060°, 075° and 088°. A subset of fractures have moderate (< 70°) to shallow (≥ 20°) dips. Dominant peak trends are less well defined for fractures with dips < 70° and their pole distribution lies on a small circle with a vertical axis and an apical angle of 100°, defining statistically a domal or basinal arrangement.

Ten (1.6%) of the 610 joints and veins measured in the study area display horizontal offsets of intersecting fractures. Horizontal offsets range from 2 mm to 15 cm. Fractures with observed offsets are confined to those sets trending ENE and N. Both sinistral and dextral displacements are observed on these fractures, with no systematic shear sense noted for both sets. No significant faults or shear zones with map-scale displacements or associated brittle fault rocks were observed in the study area.

The common orientations of joints and veins indicates that they are contemporaneous and formed under conditions of elevated pore fluid pressure in the presence of an abundant source of carbonate rich brines. One hypothesis is that the main fracture sets developed during compaction, dewatering and diagenesis of the Lucas and underlying formations, contemporaneous with the Devonian and/or Carboniferous history of the Michigan Basin. An alternative hypothesis, with similar timing implications is that the brines were derived by lateral flow from distal sources associated with orogeny in eastern Laurentia during the Devonian Acadian or Carboniferous Alleghenian orogenies.

Regionally, the NNW-trending fracture set observed in the study areas is part of a fracture system in the Silurian and Devonian strata of the Bruce Peninsula, Manitoulin Island and northern Michigan that is concentric with respect to the outline and structure contours of the Michigan Basin. It is speculated that this concentric system of fractures formed due to radial tensile stress generated during a phase of basin-centred subsidence in the middle Devonian. The broadly ENE-trending fracture population in the study area is part of a regional system of fractures both within and outside the Michigan Basin. Based on regional correlation it is likely that these fractures are late Paleozoic in age. An alternative neotectonic interpretation for the

origin of the NNW-trending fracture set is difficult to reconcile with the presence of associated veins and therefore a source of fluids for elevated pore fluid pressures. The moderate to shallow dipping fractures are interpreted to be related to differential compaction over algal mound structures present locally within the Lucas Formation.

ACKNOWLEDGEMENTS

Field visits at the Bruce nuclear site were accompanied by Mr. Branko Semec (NWMO) and Mr. Jim McLay (NWMO) on June 4, 2009 and by Mr. McLay on July 30, 2009.

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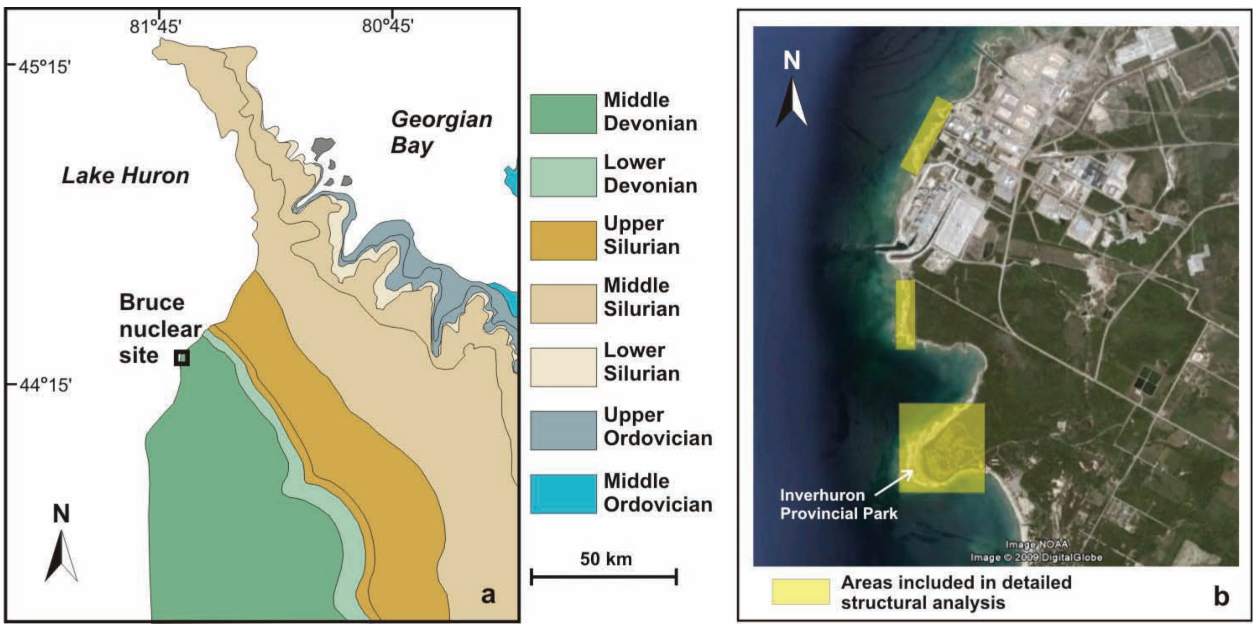
1. INTRODUCTION

1.1 Objectives and Scope

This report describes the results of detailed structural mapping fieldwork undertaken as a part of the Neotectonics/Paleoseismology component of ongoing site characterization activities for Ontario Power Generation's proposed Deep Geological Repository (DGR) project at the Bruce nuclear site near in the Municipality of Kincardine, Ontario. Structural mapping of Devonian-aged rock pavements exposed along the Lake Huron shoreline at the Bruce nuclear site and adjacent Inverhuron Provincial Park (Figure 1.1) was carried out between June and September 2009. This report documents the observed nature of fracture populations in the study area.



Note: In (a), box indicates location of the Bruce nuclear site study area. (b) Satellite image of the study area. Yellow shaded regions in (b) indicate areas covered during outcrop fracture mapping study (this report).

Figure 1.1: Paleozoic Geology of the Bruce Peninsula and Study Area Location Map

2. METHODS

Field work on coastal exposures at the Bruce nuclear site was carried out on June 4 and July 30, 2009. Field work on coastal exposures at Inverhuron Provincial Park was carried out on June 4, July 8 and September 1, 2009. The purpose of field work was to collect structural orientation data on brittle structures and bedding from available bedrock outcrops and to make additional observations of pertinent brittle structure characteristics. Additional structural information was determined from photogeological interpretation of colour orthographically corrected aerial photographs provided by NWMO.

2.1 Fracture Orientation Mapping

Dips and strikes of fracture surfaces and bedding planes were measured using a Silva Ranger compass-clinometer. The compass was corrected for a magnetic declination of 9° west (Natural Resources Canada on-line magnetic declination calculator). The UTM coordinates of outcrop locations were determined using a handheld GPS device (Garmin GPSmap 60Cx) at a nominal horizontal precision of ±4 m. Measurements were recorded in a field notebook and subsequently entered into a Microsoft Excel spreadsheet (Appendix A). Station locations were stored as waypoints in the memory of the GPS device and subsequently transferred to an Excel spreadsheet via a USB data connection to a PC.

The majority of outcrops exposed in the study area consist of elongated bedrock pavements that are oriented sub-parallel to the shoreline of Lake Huron. With the exception of small isolated outcrops, structural measurements and observations were collected along outcrop-parallel traverses (inventory or traverse mapping method; La Pointe and Hudson 1985, Davis and Reynolds 1996). Using this approach structural measurements and observations were collected systematically along a traverse line between two points with measured UTM coordinates. In order to minimise sampling bias due to the orientation of the traverse measurements of all systematic fractures were taken within a 1 to 2 m wide swath parallel to the traverse (selection method; Davis and Reynolds 1996).

2.2 Fracture Characteristics Observations

In addition to the measurement of fracture orientations, systematic observations of fracture characteristics such as fracture filling, abutting and cross-cutting relationships, displacements and fracture surface ornamentation were also made. These observations were recorded in the field note book as sketches and further documented by digital photographs using a Panasonic Lumix DMC-FZ28 digital camera.

2.3 Orientation Data Analysis

Fracture orientation data compiled in an Excel spreadsheet (Appendix A) were copied and sorted to create ASCII data files compatible with the program Spheristat 2.2 (Pangea Scientific), which was used to plot and analyse the data. Poles to fracture planes were plotted on lower hemisphere equal area stereographic projections (referred to as stereonets in the following text). Density distributions of the poles were determined using a Gaussian contouring method. The minimum contour for all plots in this report (E) corresponds to 3 standard deviations from a random distribution and subsequent contour intervals are 1 standard deviation.

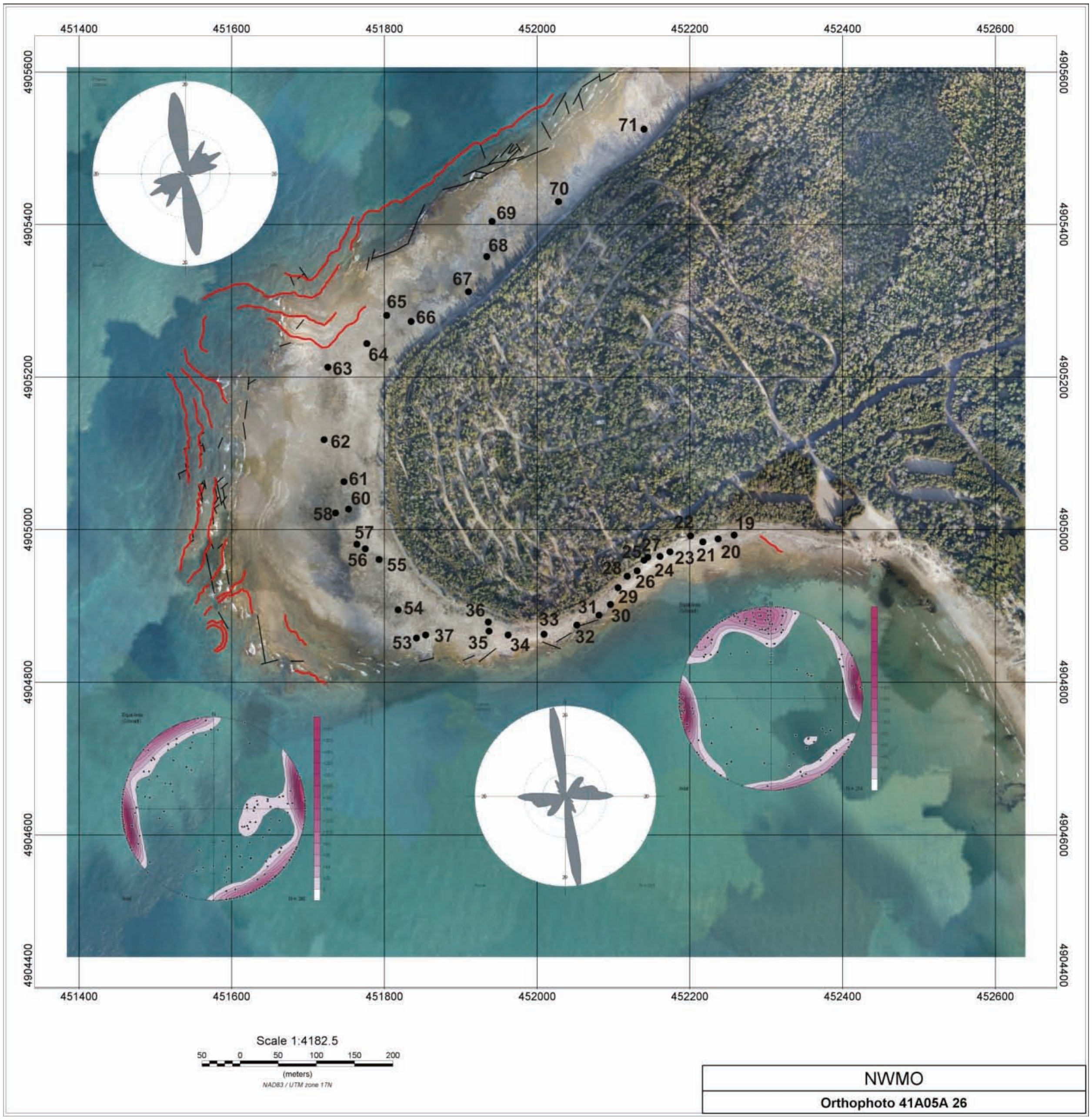
The strikes of fracture planes were also plotted on rose diagrams. No weighting was applied for the corresponding dip values of the fractures. The density distribution of strike orientations on these plots was determined by a Gaussian smoothing routine with a 10° counting interval. On the resulting “propeller diagrams” the statistical significance of orientation peaks can be evaluated by a series of concentric circles. All peaks falling outside the intermediate, solid circle (E = expected distribution of a random population of planes of the same number as the data set being analyses) are statistically significant. The outer dashed circle is the 95% confidence level for peak significance, and the inner dashed circle is the 95% confidence level for trough significance.

2.4 Mapping Software

The program Oasis Montaj (Geosoft) was used as the platform for viewing and interpretation of colour aerial photographs and annotation of bedding and fracture traces. Field station locations were plotted on the orthorectified digital photographs by importing their UTM coordinates as an ASCII file and conversion to a Geosoft database.

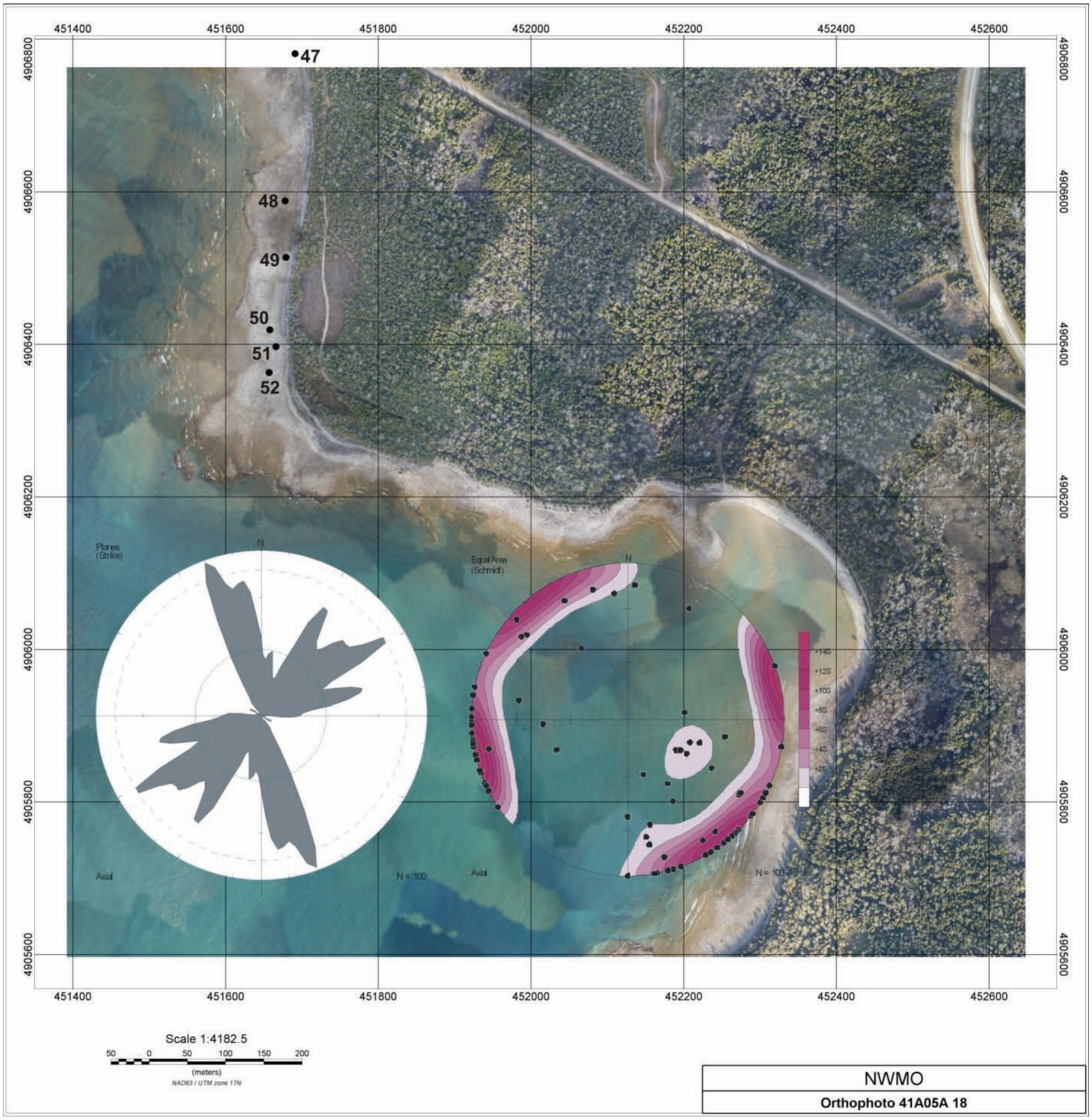
3. RESULTS

Station locations, bedding traces, fracture traces and summary stereonets and propeller diagrams are plotted on the relevant digital aerial photographs (Figures 3.1 to 3.3).



Note: Orthophoto covers most of the Inverhuron Provincial Park study area. Station locations (numbered) are plotted as black circles. Interpreted bedding traces are red. Interpreted fracture traces are black. Summary stereonets and propeller diagrams include data from the numbered locations.

Figure 3.1: Orthophoto 041A 05A 26

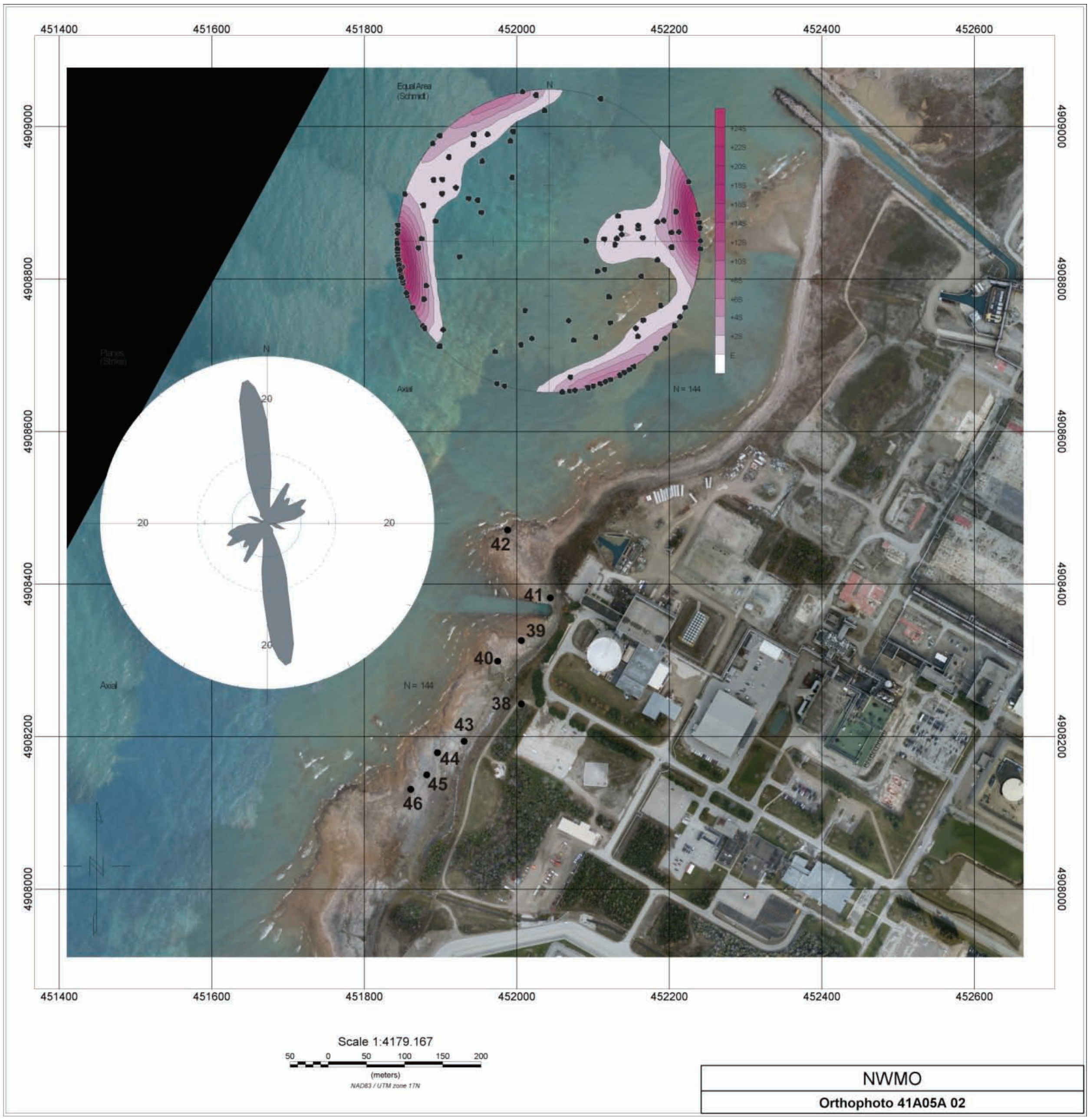


Note: Orthophoto covers the northern part of Inverhuron Provincial Park and the southern boundary of the Bruce nuclear site. Station locations (numbered) are plotted as black circles. Summary stereonets and propeller diagrams include data from the numbered locations.

Figure 3.2: Orthophoto 041A 05A 18

3.1 Lithology and Bedding

All surface outcrops in the study area comprise fine to medium grained, light grey limestone/dolostone of the Middle Devonian Lucas Formation. In most outcrops the beds are flaggy with bed thickness ranges from 10 to 50 cm. Beds are commonly differentiated based on grain size variations, with coarser grained beds being thicker than fine grained, micritic beds. Differential erosion of beds results in the exposure of benches in most outcrops. Algal mound structures (stromatolites) are common and range in diameter from 1 to 2 m (Figure 3.4). Differential compaction of beds overlying algal mounds represents the only outcrop-scale deviation of bedding attitude.



Note: Orthophoto covers the central western shoreline of the Bruce nuclear site. Station locations (numbered) are plotted as black circles. Summary stereonets and propeller diagrams include data from the numbered locations.

Figure 3.3: Orthophoto 041A 05A 02

Note: Yellow notebook in centre of photograph is for scale.

Figure 3.4: Algal Mounds Exposed on the Western Shoreline of Inverhuron Provincial Park

Where not perturbed by outcrop-scale algal mounds or map-scale dome and basin structures (discussed below) beds in the study area are almost horizontal, with dips of < 1° to 5° towards the SW (dip directions vary between 190° and 260°). Bedding traces can be determined on aerial photographs in shallow water areas adjacent to the shoreline as scarp slopes or bench boundaries (Figure 3.1).

Several dome or basin structures are observed on digital aerial photographs in shallow offshore areas. One is observed on Orthophoto 041A 05H 59 adjacent to the Bruce nuclear site at UTM 453186E, 4909266N. This structure is defined by a concentric oval pattern of bedding traces, with a long axis oriented NW, sub-parallel to the regional strike of bedding. The visible part of the structure has a long axis dimension of approximately 90 m and a short axis dimension of approximately 50 m. The morphology of the structure is interpreted here to be domal, with an indeterminate but low amplitude.

A prominent oval structure is observed offshore of Gunn Point at Inverhuron Provincial Park on Orthophoto 041A 05A 26, at UTM 451619E, 4905244N (Figure 3.1). It is less elongate than the feature observed at the Bruce nuclear site, but also has a long axis trending NW, with a maximum dimension of approximately 100 m and a minimum dimension of approximately 80 m. Bedding observed at the east margin of the structure (Station 63) dips 5° to 10° towards 120°, suggesting again that the feature is a low amplitude dome.

A small circular structure is observed off the southwest tip of Gunn Point at UTM 451577E, 4904863N (Figure 3.1). It has similar surface morphology to the two features described above, but has a maximum dimension of approximately 40 m.

3.2 Fracture Characteristics

The terminology adopted here for the description of mesoscale brittle structures is defined below.

- **Fractur**e: A naturally occurring crack.
- **Fault:** A fracture on which there is measureable slip at the scale of observation.
- **Joint:** A barren, closed fracture on which there is no measurable slip or dilation at the scale of observation (Hancock 1985).
- **Vein:** A fracture containing a mineral filling.
- **Systematic versus non-systematic fractures:** Systematic fractures tend to have relatively straight traces and typically occur in sets with a common range of orientations (Hodgson 1961). Non-systematic fractures typically have curved traces and usually occur between and abut systematic fractures. Their distribution tends to be random.

3.2.1 Joints

Only systematic joints were documented in this study. They are ubiquitous in all beds of the Lucas Formation. However, there is significant variation in the intensity of jointing, whereby thin beds of fine-grained micritic limestone (wackestone) have closely spaced fractures 1 to 20 cm, and thicker beds of medium-grained limestone (grainstone or packstone) are relatively sparsely fractured with fracture spacing between 20 cm and 2 m. The majority of joints are confined to single beds, although a significant number cross one or more beds.

Most joints do not exceed 5 m in horizontal length and either terminate when they meet other fractures or at fracture tips in the host rock mass. However, a number of joints with horizontal lengths in the range 5 to over 20 m were observed (Figure 3.5). Their vertical height could not be observed due to the flat nature of the outcrops.

Most joints are closed and tight. Joints with measurable apertures have either been widened by solution processes (i.e., karst features) or by creep adjacent to free vertical surfaces (e.g., adjacent to bench margins, shorelines, excavated faces). With the exception of carbonate mineral infilling (see below) iron oxide infilling or coatings on fracture surfaces are not observed, indicating a lack of groundwater or surface flow along joints.

3.2.2 Veins and Infilled Joints

Fractures with a white carbonate infill (calcite or dolomite) are common in the Lucas Formation. In most cases it is not possible to tell whether these are infilled joints (i.e., carbonate precipitation occurred after fracture formation) or veins formed by hydraulic fracturing (i.e., fracture propagation and mineral precipitation are synchronous). However, several observations of the latter were made. These include the occurrence of crack-seal veins (Figure 3.6), which formed by multiple cycles of hydraulic fracturing and mineral precipitation, and curved and branching vein tips (Figure 3.7). Such features are indicative of fracture propagation under conditions of elevated pore fluid pressure. Given that both joints and veins share common orientations (see Chapter 4 below), it is likely that most fractures observed in the Lucas Formation formed under conditions of elevated pore fluid pressure.

Note: In the centre is a > 5 m long subvertical joint trending 100°. A 350° trending joint abuts on the north side. Notebook for scale.

Figure 3.5: View Looking Westward of Bedrock Pavement close to the South Shore of Inverhuron Provincial Park

3.2.3 Joint and Vein Zones

Linear zones of closely spaced (1 to 5 mm) thin veins (< 1 mm) and joints in all outcrops in the study area (Figure 3.8). These zones are typically 10 to 40 cm wide and occur as isolated features or with a spacing that varies from 40 cm to 2 m. The field term, joint and vein zone has been employed to describe these features. Joint and vein zones are uniquely associated with the NNW-trending fracture set (see Chapter 4).

Note: The vein trends 119 degrees and is filled with calcite. A thin discontinuous seam of wall rock occurs in the centre of the vein, indicating its crack-seal nature. Coin for scale.

Figure 3.6: Crack-Seal Vein Exposed at Location 51 on the Southwest Shore of the Bruce Nuclear Site

Note: Tip interaction indicates that the veins likely propagated as fluid pressurized cracks (hydrofactures). Coin for scale.

Figure 3.7: Overlapping Crack-Seal Veins with Interacting (Bridging) Tips

Note: The structure trends 350° and is characterised by closely spaced, parallel barren joints and < 1 mm wide calcite filled veins. These structures are only associated with the NNW-trending fracture (joints and veins) set. Notebook for scale.

Figure 3.8: Joint and Vein Zone, South Shore of Inverhuron Provincial Park

3.2.4 Joint Patterns (Lozenge Zones)

Linear domains containing two intersecting and anastomosing fracture sets with dihedral angles ranging from 15° to 35° (Figure 3.9) share a common orientation with the joint and vein zones and the major NNW-trending fracture set in the study area. The field term chosen to describe these structures is lozenge zones, because the two fracture sets enclose elongate lozenge shaped domains of unfractured rock. Contemporaneous, mutually cross-cutting joint sets with dihedral angles between 10° and 50° are considered to be *conjugate hybrid joints*, which are thought to form by shear failure under transitional-tensile conditions (Hancock 1985). However, this interpretation is disputed by some authors (Engelder 1999).

Characterization of fracture system architecture involves systematic documentation of the cross-cutting and abutting relationships of fractures, and is important for the interpretation of the relative timing of fracture sets and the loading history of the rock mass (Hancock 1985).

3.2.5 Fracture Surface Ornamentation

The majority of fractures observed in the study area have no notable surface characteristics. Only one joint was observed with plumose structure, located between Stations 27 and 28 in

Inverhuron Provincial Park. Here a sub-vertical, N-striking joint surface displays plumose structure with a horizontal median line and upward and downward branching hackle marks (Figure 3.10). Such surface ornamentation indicates a horizontal fracture propagation regime. That more fractures do not have similar surface ornamentation may be due to weathering, and hence indicative of the antiquity of fractures, or because the lithologies were not conducive for development of such features.

Note: The structure is characterized by cross-cutting (conjugate?) joints trending 346 and 332 degrees. The two intersecting fracture sets bound elongate lozenge shaped bodies of intact rock. The low dihedral angle between the two intersecting sets suggests that these are conjugate hybrid joints (see text for discussion). Similar NNW-trending structures mapped on the shoreline at the Bruce nuclear site have been referred to as "shear zones", when clearly they are not. Notebook for scale.

Figure 3.9: Lozenge Fracture Zone Exposed on the Southwest Shore of Inverhuron Provincial Park

Other types of fracture surface structure, such as slickensides, slickenside lineations, groove structures and mineral fibre lineations were not observed in the study area.

Note: The joint surface is ornamented by plumose structure with a horizontal median line and outward branching hackle marks. This fracture surface ornamentation indicates that the fracture propagated horizontally in a vertical plane. Notebook for scale.

Figure 3.10: Vertical, North-Striking Joint Surface Exposed Close to the South Shore of Inverhuron Provincial Park

3.2.6 Fracture Offsets/Meso-scale Faults

10 of the 610 joints and veins measured in the study area display horizontal offsets of intersecting fractures (Figure 3.11). That is ~1.6% of the observed fracture population. Horizontal offsets range from 2 mm to 15 cm. Fractures with observed offsets are confined to those sets trending ENE and N. Both sinistral and dextral displacements are observed on these fractures, with no systematic shear sense noted for both sets. No significant faults with map-scale displacements or associated brittle fault rocks were observed in the study area.

Note: (a) Inverhuron Provincial Park, south shore. North-south trending, vertical veins and vein zones are offset left-laterally by an irregular SSW-trending vein. (b) Bruce nuclear site, central shoreline outcrop. A NNW-trending vertical joint appears to be offset by a vertical SSW-trending joint. The sense of apparent offset is left lateral. Note that the offset can only be considered to be apparent, because the NNW-trending joints could be abutting the SSW-trending joint. There are no lineations on the SSW-trending joint surface that would make the interpretation of shear offset unequivocal.

Figure 3.11: Examples of Offset Veins and Joints

4. FRACTURE ORIENTATION DATA

4.1 All Measurements

A total of 610 joint and vein measurements are available for analysis from field locations at the Bruce nuclear site and Inverhuron Provincial Park (Figure 3.1 and Appendix A). Of these data, 546 are classified as joints and 86 as veins. There is some overlap between the separated data because 22 measurements were from “joint and vein zones”, that is zones containing both joints and veins with the same orientation (Section 3.2.3). Both the joint and vein orientation populations contain well-defined sets based on strike orientations. For the purpose of this report a set is defined by a peak on a propeller diagram that falls outside the (solid) expected distribution circle (E in Section 2.3).

In general, both joints and vein sets share common orientations between the Bruce and Inverhuron sites, with some subtle variations discussed below. The characteristics of the combined datasets are presented first, followed by individual results for the Bruce and Inverhuron sites.

4.1.1 Joints

The combined joint population is dominated by a major set with a peak orientation of 350° and a range between 336° and 006° (Figure 4.1). The observed range about the peak trend defines a dihedral angle of ~30°, which corresponds to the variation in fracture orientations observed within the lozenge zones described above (Section 3.2.4). The NNW-trending joint population is dominated by subvertical fractures (dips >85°). A subset of the population is characterised by both WSW and ENE dips with inclinations ranging down to 20°.

A second population of fractures defines a broad peak trending ENE with range between 025° and 098° (Figure 4.1). Within this broad peak, four statistically significant sub-peaks can be defined with orientations 041°, 060°, 075° and 088°. Again subvertical attitudes are dominant in this population but NW and SE dips range down to 30°.

4.1.2 Veins

Two dominant vein orientations are observed in the combined data set (Figure 4.1), both with narrow peaks. The dominant trend is 350° and the secondary trend is 048°. Both of these orientations are coincident with joint sets. It is interesting to note that the narrow 350° vein set bisects the range of joints between 336° and 006°. Likewise the 048° vein set bisects the joint sub-peaks oriented 041° and 060°. This observation might add weight to the notion that the NNW trending joints and some of the NE trending joints are conjugate hybrid fractures, bisected by extensional veins.

Like the joints, most veins have subvertical attitudes. However, there is notable subset of veins that strike ~030° and dip between 30° and 50° NW (Figure 4.1).

4.2 Bruce Nuclear Site

4.2.1 Joints

The joint population (221 measurements) at the Bruce nuclear site is characterised by a major peak orientation of 351° and sub-peaks trending 030°, 043°, 060° and 075° (Figure 4.2). That is essentially the same as the combined data set, with the exception of a well-defined sub-peak trending 030°. In terms of fracture attitudes, there is a statistically significant cluster of N-S trending joints dipping 20° to 50° W (Figure 4.2).

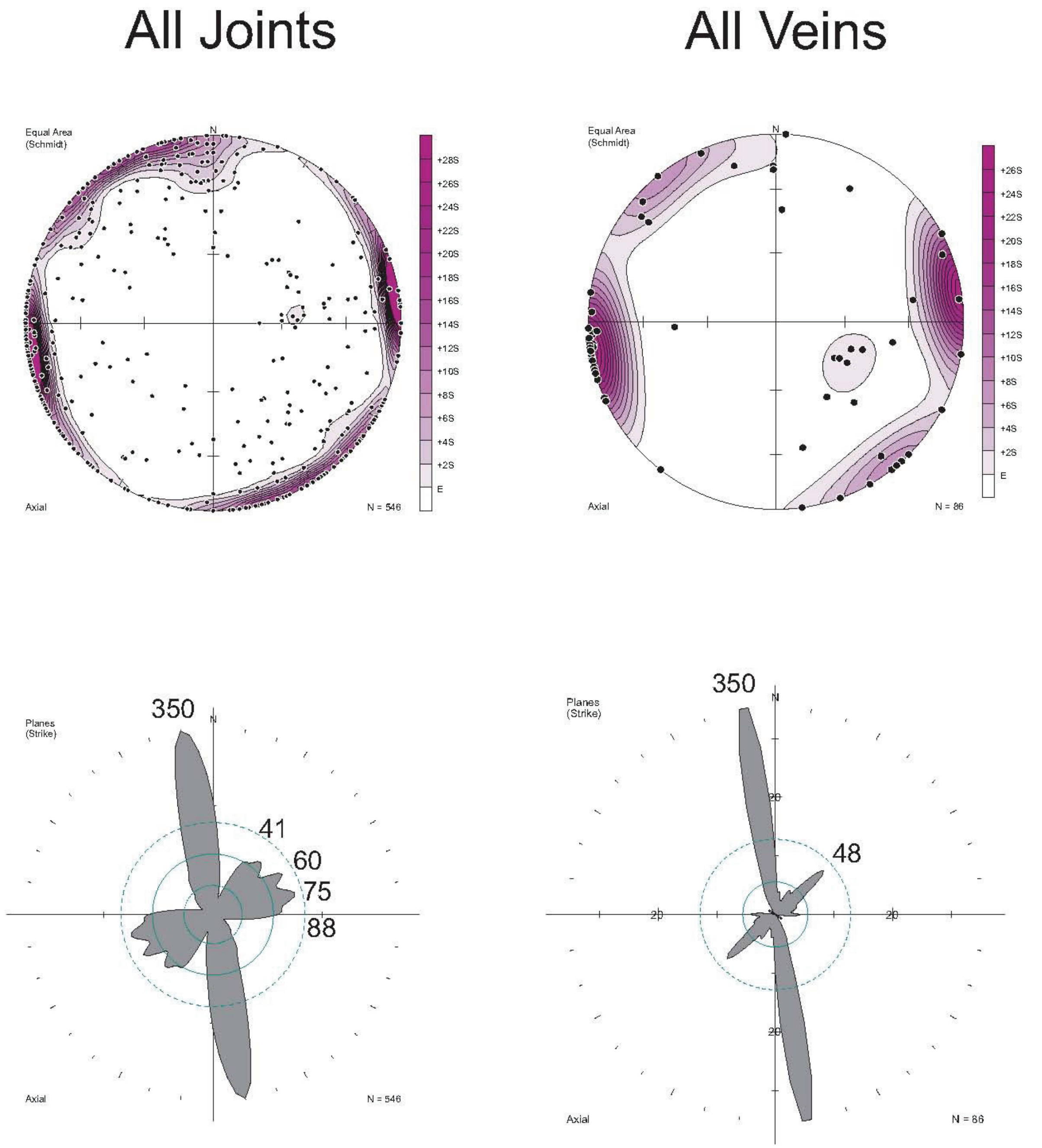


Figure 4.1: Stereonets and Propeller Diagrams for all Joints and Veins Measured in the Study Area

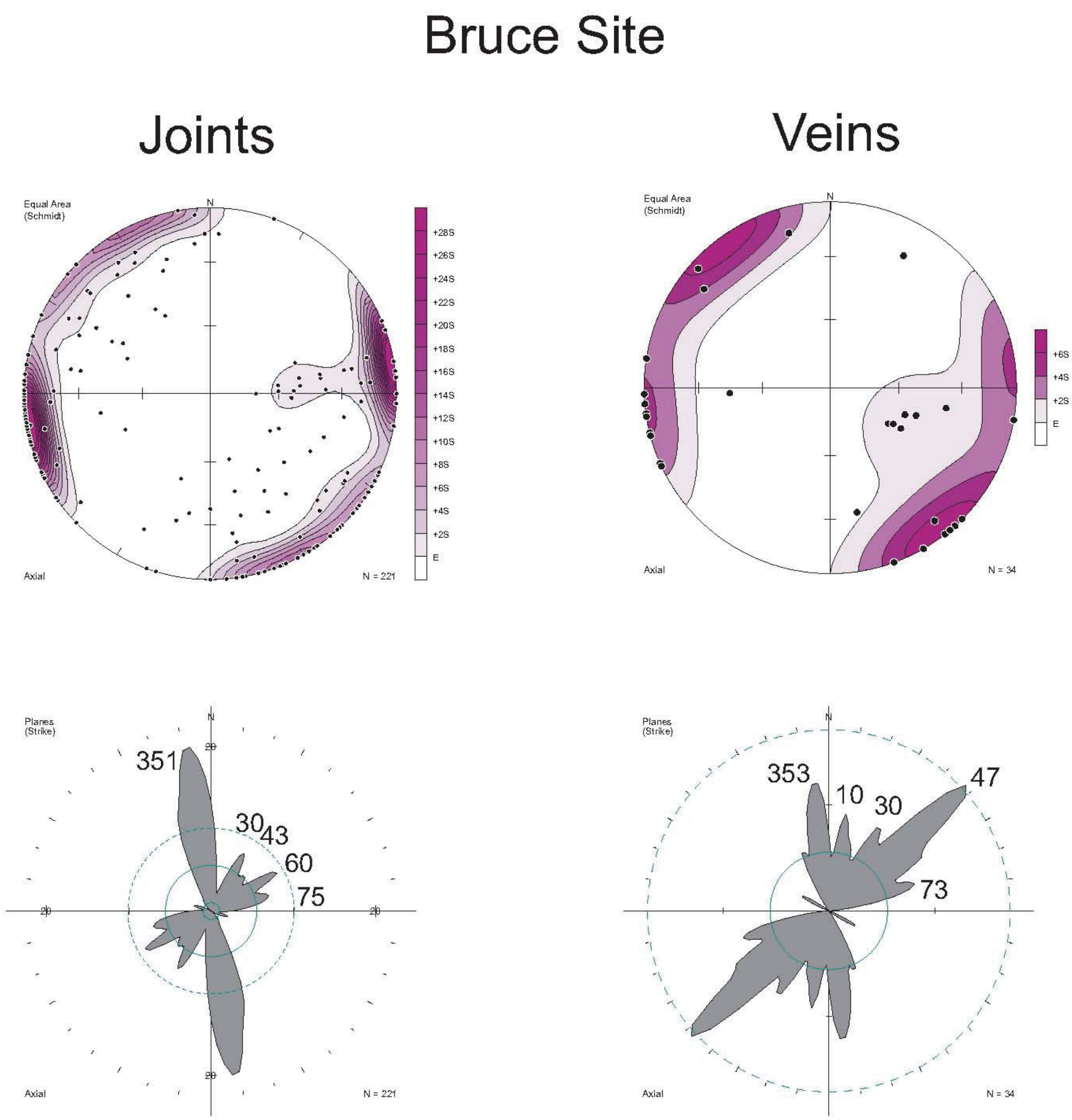


Figure 4.2: Stereonets and Propeller Diagrams for all Joints and Veins Measured in the Bruce Nuclear Site Area

4.2.2 Veins

The relatively sparse dataset for veins (34 measurements) at the Bruce nuclear site make statistical inferences on the population unreliable (Figure 4.2). Nevertheless, there are two peak vein sets trending 047° and 353°, that is sub-parallel to major joint sets. Minor peaks occur with orientations 010°, 030° and 073°, again sub-parallel to joint sets with the exception of the 010° veins. Most veins are subvertical, except for a population of NE trending veins that dip ~35° to the NW (Figure 4.2).

4.3 Inverhuron Provincial Park

4.3.1 Joints

The 335 joints measured at the Inverhuron site define a peak set oriented 350° and sub-peaks oriented 088°, 075°, 040° and 330° in order of decreasing significance (Figure 4.3). The majority of fractures are subvertical, with a smaller amount showing steep to moderate NW, SE, S, SW and NE inclinations. There is a noticeable different between fracture populations between outcrops located adjacent to the southern shoreline of the park and those found near the southwest and west shoreline (Figure 4.4). The data from the western outcrops is very similar to that of the Bruce nuclear site. The fracture population in the south is generally similar but also contains a well-defined peak at ~090°, which is parallel to the east-west orientation of the shoreline.

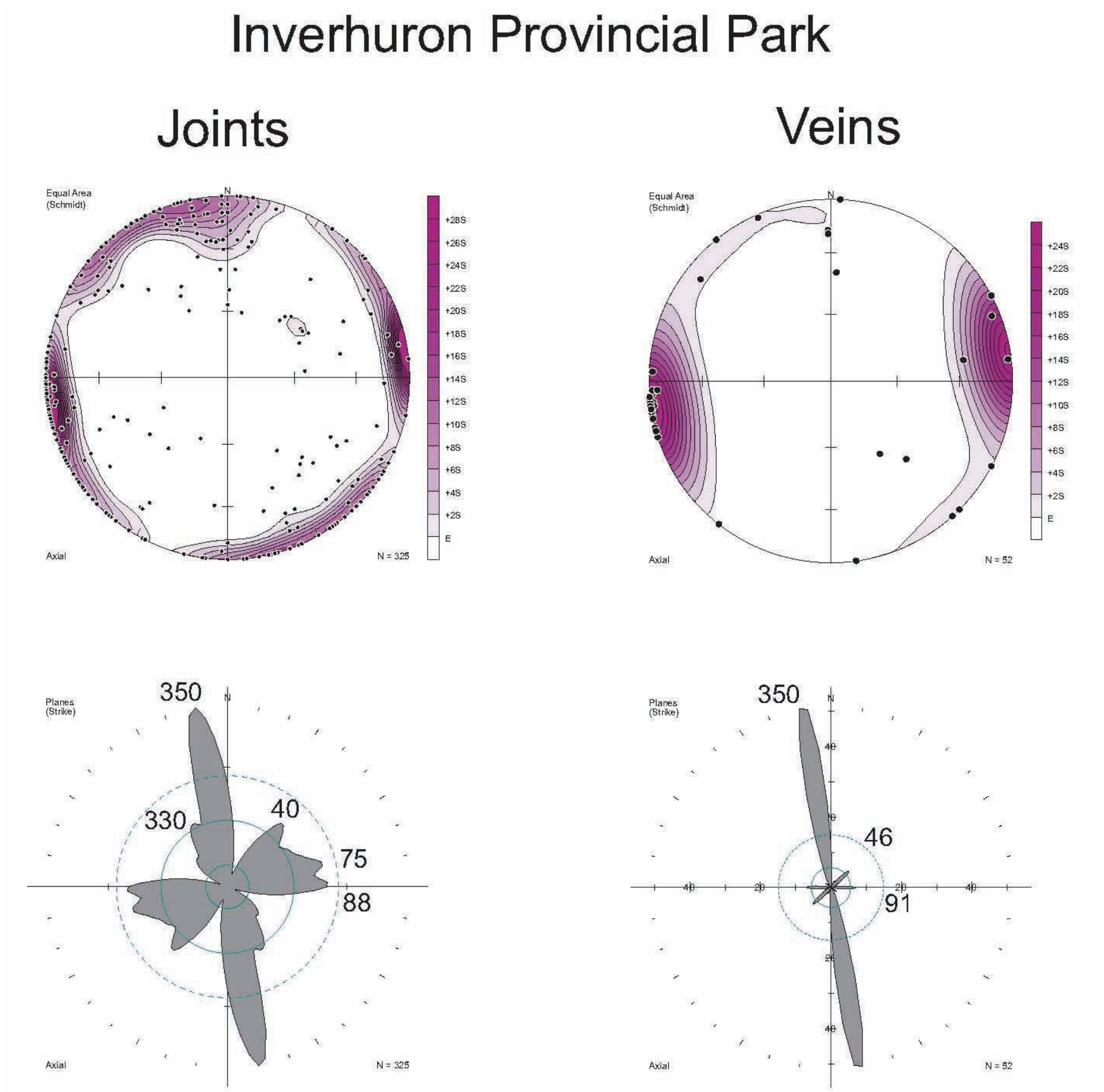


Figure 4.3: Stereonets and Propeller Diagrams for all Joints and Veins Measured in the Inverhuron Provincial Park Area

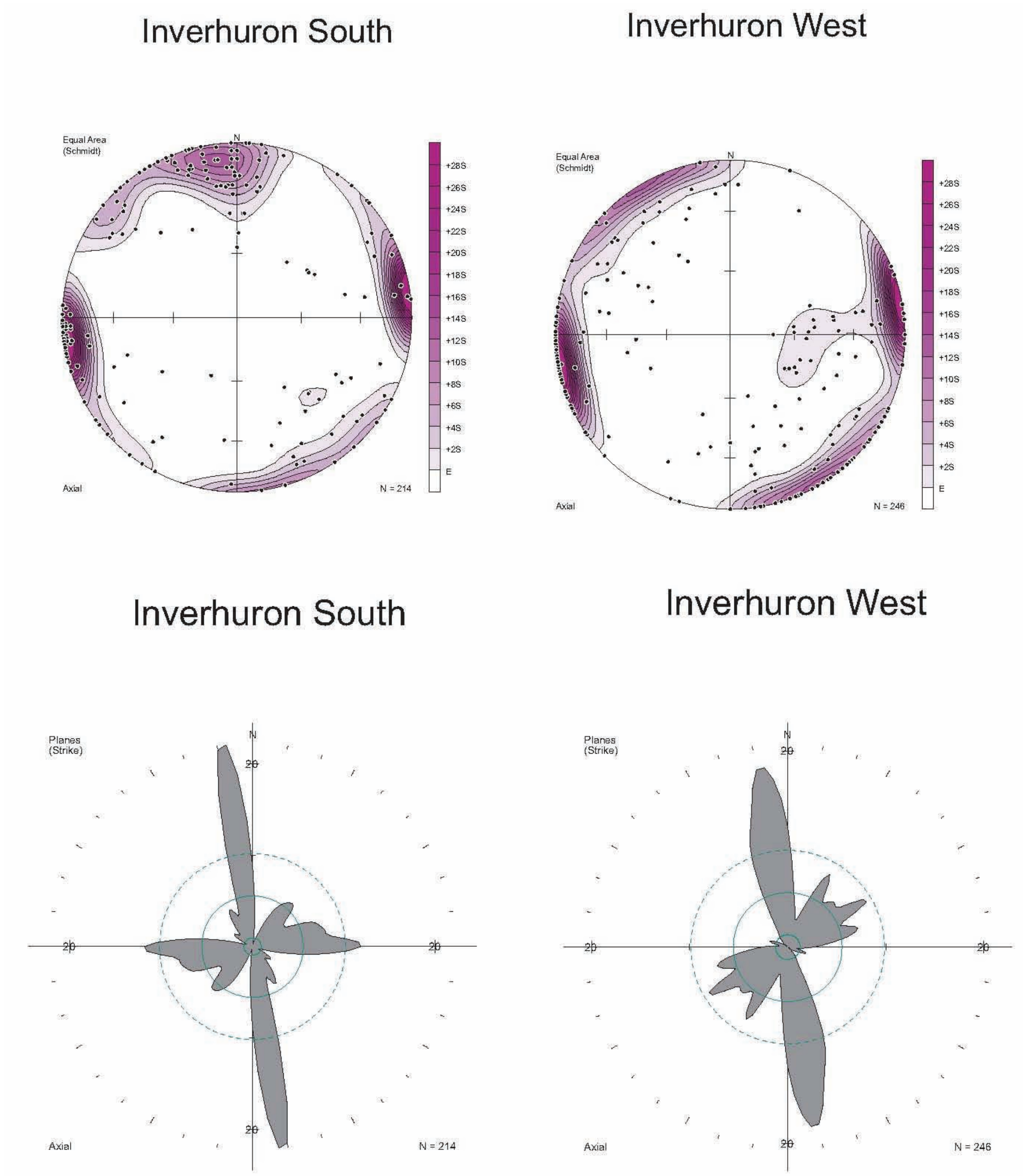


Figure 4.4: Stereonets and Propeller Diagrams for Combined Joint and Veins Data for the Inverhuron South and West Areas

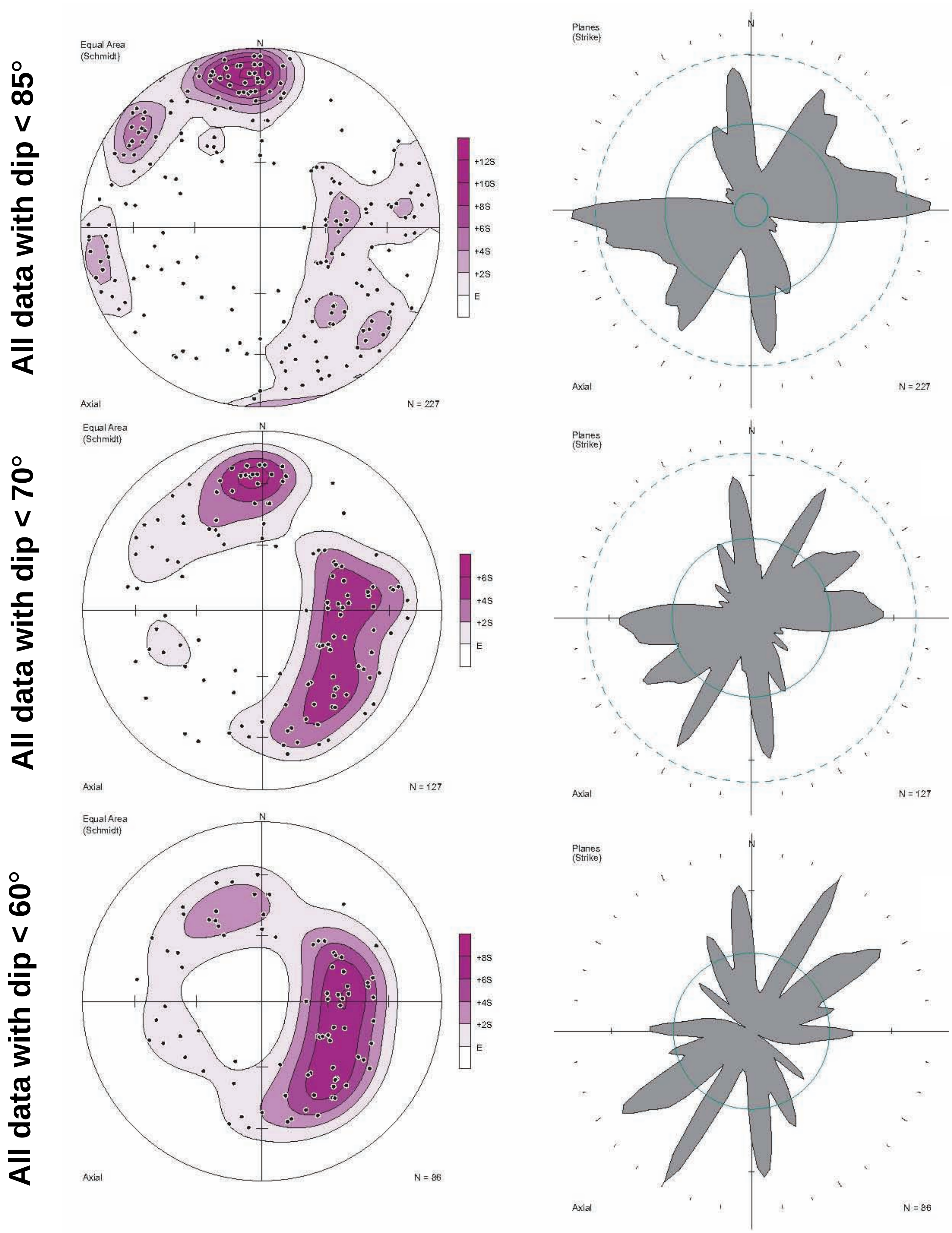


Figure 4.5: Stereonets and Propeller Diagrams for Fractures (Joints and Veins) with Dip Values < 85°

4.3.2 Veins

Veins oriented 350° dominate the population at Inverhuron (Figure 4.3). Two very minor sub-peaks are observed with orientations 046° and 090°. All veins share common orientations with joints.

4.4 Inclined Fractures

Taking the joint and vein measurements together, fractures with dips <85° make up 37% of the total dataset (Figure 4.5). 21% of fractures dip <70° and 14% dip <60°. In order to characterise the orientations of the inclined fractures they have been plotted separately from the subvertical population in groups with dips <85°, <70° and <60° (Figure 4.5). The <85° dip population shares common peak orientations with the total dataset (cf. Figure 4.1) but the peak order has been reversed. The dominant trend is 090°, followed by ~045° and 350°.

Dominant peak trends are less well defined for fractures with dips <70°; multiple peaks “box the clock”. Stereonets for both subgroups are characterized by pole distributions that lie on a small circle with a vertical axis and an apical angle of 100 (Figure 4.5). What this means is that fracture planes with dips <70° are approximately evenly distributed with dips ~50° in all directions. Statistically, they therefore define either a domal or basinal arrangement (see Section 5.3).

5. DISCUSSION

5.1 Age and Timing of Fractures

The *absolute age* of joints or veins can only be determined by radiometric dating of mineral filling material. The relative age of veins or joints can be bracketed by cross-cutting relationships with markers of known age. In this regard, all fractures in the study area must postdate the depositional age of the Middle Devonian Lucas Formation.

The *relative age* of extensional joints and veins can be determined by abutting relationships, whereby the younger fracture abuts or terminates against an older fracture. The relative age of shear fractures and transitional tensile veins may be determined by offsetting relationships. Although both abutting and offsetting relationships are observed in the study area (Section 3.2.5) no systematic relative age relationship has been determined. That is, the dominant NNW- and ENE-trending joint and vein sets are mutually cross cutting, mutually abutting and mutually offsetting.

As noted previously, all joint and vein sets share common orientations, which suggests that the jointing and veining events were contemporaneous and formed under conditions of elevated pore fluid pressure in the presence of an abundant source of carbonate rich brines. One hypothesis for the generation of brines and elevated pore fluid pressure is that the main fracture sets developed during compaction, dewatering and diagenesis of the Lucas and underlying formations. Hence the major fracturing events would be contemporaneous with the Devonian and/or Carboniferous history of the Michigan Basin. An alternative hypothesis, with similar timing implications is that the brines were derived by lateral flow from distal sources associated with orogeny in eastern Laurentia (e.g., Gross et al. 1992). In this scenario, lateral pumping of fluids would be linked to the Devonian Acadian or Carboniferous Alleghenian orogenies, in a similar fashion proposed for the origin of veins in the Lockport Formation of northern New York state, which are thought to be associated with the Ordovician Taconic orogeny (e.g., Gross et al. 1992).

The broadly ENE-trending fracture population in the study area is sub-parallel to fractures measured in the Devonian and Silurian strata in the Bruce Peninsula, Manitoulin Island and northern Michigan regions (AECOM and ITASCA CANADA 2011). It is also present as a minor, but persistent set in the Ordovician of south central Ontario and the Silurian of northern New York (AECOM and ITASCA CANADA 2011). Hence, it is part of a regional system of fractures both within and outside the Michigan Basin. In a study of jointing in the Michigan Basin, Holst (1982) noted a persistent set of ENE-trending joints with a peak orientation of 052°. He noted that these fractures are approximately orthogonal to low amplitude ESE trending folds in the basin, in which case they might represent extensional ac-joints related to folding (e.g., Hancock 1985 and references therein), which would similarly make them late Paleozoic in age.

Alternatively, both Holst (1982) and others have noted that the ENE-trending joints are sub-parallel to the present in-situ maximum horizontal stress, which could implicate a neotectonic origin (e.g., Gross and Engelder 1991). The current in-situ stress in eastern North America is attributed to ridge push generated by the mid-Atlantic ridge, which is thought to have been broadly constant since the end of the Cretaceous (AECOM and ITASCA CANADA 2011). However, a neotectonic origin for the contemporaneous NNW-trending fracture set is difficult to reconcile with the presence of associated veins and therefore a source of fluids for elevated pore fluid pressures. Therefore the origin of the vein filling material and the timing of the main fracture forming event, for both the NNW and ENE fracture sets, is likely to be late Paleozoic.

5.2 Lithological Control of Fracture Populations

As noted in Section 3.1 the Lucas Formation comprises thinly bedded (laminated) fine-grained dolostone and more thickly bedded medium-grained dolostone and limestone layers. Fracture frequency is locally very high in fine-grained beds, with fracture spacing on the order of 1-2 cm to 20 cm. Conversely, medium-grained beds can locally be characterised as sparsely fractured with spacing ranging from 20 cm to 2 m. All fracture and vein orientation sets are observed in all lithologies of the Lucas Formation.

Fracture intensity control by bed thickness is a commonly observed phenomenon in flat-lying platform sedimentary rocks. Fracture frequency is higher in thin beds in layered sequences due to enhanced stress build up during regional loading and unloading events and the joint-stress shadow effect (van der Pluijm and Marshak 2004, Bai and Pollard 2000). Joint spacing is also controlled by layer stiffness with closer spacing occurring in lithologies with higher elastic moduli.

5.3 Significance of Inclined Fractures

Fractures with dips < 80° are relatively uncommon in the Paleozoic platform sediments of south central Ontario (e.g., Andjelkovic et al. 1997) and in the Michigan Basin (Holst 1982). In the Ordovician strata of south central Ontario, inclined joints tend to be restricted to upwarped units (low amplitude anticlines) located adjacent to or overlying Precambrian basement highs. The upwarping of strata and the development of inclined fractures have been attributed to differential compaction and local stress rotation above elongate basement ridges preserved at the unconformity at the base of the Paleozoic sediments (Andjelkovic and Cruden 1998).

It is unlikely that the inclined fractures in the study area can be linked to basement highs because the Lucas Formation lies at least 850 m above the Paleozoic unconformity. The tendency for the inclined fracture population to define, statistically, a domal or basinal distribution implies a local, rather than regional control on their orientation. A reasonable speculation is that these fractures are related to differential compaction of beds over algal mounds or reefs within the Lucas and/or Amherstburg formations. These features are circular to elliptical in plan and based on field observations and aerial photograph interpretation they range in diameter from 1 m to 100 m. The larger scale mounds are of similar width and amplitude to the basement highs of south central Ontario, which suggests that a differential compaction hypothesis for inclined fractures in the study area is not unreasonable. However, in south central Ontario the basement highs are elongate and parallel to the related NNE- to NE-trending fracture set. In the study area the algal mounds are quasi-circular leading to an essentially circular distribution of inclined fracture strikes.

An alternative hypothesis for the circular to elliptical structures observed on aerial photographs and the circular distribution of inclined joints is that they are related to collapse features associated with dissolution of evaporates within the underlining Salina formation.

5.4 Presence of Shear Zones and Faults

As noted in Section 3.2.6 approximately 2% of the fractures observed in the study area are associated with offsets (<15 cm, most <2 cm). Although, these structures can be classified as mesoscale faults (Hancock 1985) they are sporadic in occurrence and are not associated with significant map-scale faults or fault zones that offset the stratigraphy in the study area.

Previous work at the Bruce nuclear site suggested the presence of shear zones in the exposed bedrock. Specifically, a study of shoreline outcrops west of the Bruce A heavy water plant on the west shore of Douglas Point reports the presence of several NNW-trending shear zones (ONTARIO HYDRO 1973). These localities were visited on June 4, and despite high lake levels a number of features were observed that likely correspond to the structures previously interpreted as shear zones. In the context of the present report, these NNW-trending structures are zones of intense NNW joints and NNW-trending lozenge zones. They are not shear zones, which in brittle rocks are characterized by linear en-echelon arrays of tension gashes or veins that face against the sense of shear (Hancock 1985).

5.5 Tectonic Interpretation of Fractures

There are two major fracture sets; a well defined NNW-trending set and a more diffuse ENE-trending set.

1. Joints and veins share common orientations, suggesting that fracturing occurred under conditions of elevated pore fluid pressure, most likely in the late Paleozoic.
2. Fault offsets are a very minor and non-systematic feature of the brittle deformation history and no shear zones are observed.

The fracture spectrum is generally similar to other exposures of Silurian and Devonian rocks in the Bruce Peninsula and the northern Michigan basin. It is significantly different to the fracture spectra measured in Ordovician strata of south central Ontario (Andjelkovic et al. 1997) and Silurian strata of northern New York State (AECOM and ITASCA CANADA 2011).

The dominant NNW-trending fracture set is also associated with vein zones and lozenge zones. The former can be interpreted as localised zones of Mode I (opening) fractures formed under conditions of elevated pore fluid pressure with an effective tensile minimum principal stress oriented ENE. As noted earlier the lozenge zones may represent conjugate hybrid joints, formed by shear failure under transitional-tensile conditions (Hancock 1985). Acknowledging that this interpretation is disputed (Engelder 1999), following Hancock (1985) the lozenge zones may have formed with an effective tensile minimum principal stress oriented ENE and a compressive maximum principal stress oriented NNW.

Regionally, the NNW-trending fracture set appears to be part of a fracture system in the Silurian and Devonian strata of the Bruce Peninsula, Manitoulin Island and northern Michigan that is concentric with respect to the outline and structure contours of the Michigan Basin (e.g., Figure 1 in Howell and van der Pluijm 1999). It is speculated here that this concentric system of fractures formed due to radial tensile stress generated during a phase of basin-centred subsidence. The Middle Devonian (Dundee formation and Traverse group) and the early Carboniferous (Sunbury shale formation) represent, respectively, the penultimate and final periods of well-defined, broad basin-centred subsidence (Howell and van der Pluijm 1999) in the evolution of the Michigan Basin. Radial tensile stress generated during either or both of these periods is a logical candidate for the basin-concentric fracture set in general, and the NNW-trending fracture set in the study area in particular.

A neotectonic origin for the ENE-trending fractures is difficult to reconcile with an interpreted late Paleozoic timing for formation of the NNW-trending fractures given that detailed fracture mapping suggests these two sets formed contemporaneously. Therefore there is no genetic significance to the similarity in orientation between the ENE-trending fracture population and the present in-situ maximum horizontal stress. The origin of the vein filling material and the timing of the main fracture forming event, for both the NNW and ENE fracture sets, is best interpreted as late Paleozoic in age.

6. REFERENCES

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APPENDIX

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Appendix A: TABLE OF ALL STATION NUMBERS, UTM COORDINATES, DIP AND STRIKE MEASUREMENTS AND COMMENTS

Date	Location	Station	Easting	Northing	Strike	Dip	Comment
Jul-08	Inverhuron	19	452258	4904993	348	90	
Jul-08	Inverhuron	19	452258	4904993	78	90	
Jul-08	Inverhuron	20	452237	4904988	342	90	
Jul-08	Inverhuron	20	452237	4904988	358	90	
Jul-08	Inverhuron	21	452217	4904984	73	90	
Jul-08	Inverhuron	21	452217	4904984	318	90	
Jul-08	Inverhuron	21	452217	4904984	324	90	
Jul-08	Inverhuron	22	452201	4904992	276	60	
Jul-08	Inverhuron	22	452201	4904992	358	90	
Jul-08	Inverhuron	22	452201	4904992	341	56	
Jul-08	Inverhuron	22	452201	4904992	322	90	
Jul-08	Inverhuron	22	452201	4904992	236	90	
Jul-08	Inverhuron	22	452201	4904992	298	90	
Jul-08	Inverhuron	22	452201	4904992	234	56	
Jul-08	Inverhuron	22	452201	4904992	106	86	
Jul-08	Inverhuron	22	452201	4904992	345	90	Hairline vein
Jul-08	Inverhuron	22	452201	4904992	348	90	Hairline vein
Jul-08	Inverhuron	22	452201	4904992	350	90	Hairline vein
Jul-08	Inverhuron	22	452201	4904992	262	90	Hairline vein, offsets previous set
Jul-08	Inverhuron	23	452174	4904971	353	90	Calcite filled joints
Jul-08	Inverhuron	23	452174	4904971	88	90	
Jul-08	Inverhuron	23	452174	4904971	60	90	
Jul-08	Inverhuron	23	452174	4904971	131	90	
Jul-08	Inverhuron	23	452174	4904971	83	88	
Jul-08	Inverhuron	23	452174	4904971	272	85	
Jul-08	Inverhuron	24	452161	4904965	223	72	Main set
Jul-08	Inverhuron	24	452161	4904965	86	65	
Jul-08	Inverhuron	24	452161	4904965	150	75	
Jul-08	Inverhuron	24	452161	4904965	156	75	
Jul-08	Inverhuron	24	452161	4904965	243	70	
Jul-08	Inverhuron	24	452161	4904965	245	80	
Jul-08	Inverhuron	24	452161	4904965	218	80	
Jul-08	Inverhuron	24	452161	4904965	158	85	Calcite filled joint
Jul-08	Inverhuron	25	452140	4904960	343	85	East end of outcrop = waypoint 27
Jul-08	Inverhuron	25	452140	4904960	138	90	
Jul-08	Inverhuron	25	452140	4904960	356	88	Hairline vein zone
Jul-08	Inverhuron	25	452140	4904960	100	85	
Jul-08	Inverhuron	25	452140	4904960	351	86	
Jul-08	Inverhuron	25	452140	4904960	208	63	
Jul-08	Inverhuron	25	452140	4904960	146	40	
Jul-08	Inverhuron	25	452140	4904960	3	88	Hairline vein zone
Jul-08	Inverhuron	25	452140	4904960	225	56	
Jul-08	Inverhuron	25	452140	4904960	174	90	
Jul-08	Inverhuron	25	452140	4904960	303	90	
Jul-08	Inverhuron	25	452140	4904960	352	90	Hairline vein zone
Jul-08	Inverhuron	25	452140	4904960	248	55	
Jul-08	Inverhuron	25	452140	4904960	354	90	Thin calcite vein
Jul-08	Inverhuron	25	452140	4904960	208	90	Irregular vein
Jul-08	Inverhuron	25	452140	4904960	330	80	
Jul-08	Inverhuron	25	452140	4904960	43	78	
Jul-08	Inverhuron	25	452140	4904960	1	85	

Date	Location	Station	Easting	Northing	Strike	Dip	Comment
Jul-08	Inverhuron	25	452140	4904960	358	88	Joint with plumose structure
Jul-08	Inverhuron	25	452140	4904960	151	42	
Jul-08	Inverhuron	25	452140	4904960	208	90	
Jul-08	Inverhuron	25	452140	4904960	357	88	Hairline vein zone
Jul-08	Inverhuron	25	452140	4904960	354	88	
Jul-08	Inverhuron	25	452140	4904960	35	88	
Jul-08	Inverhuron	26	452131	4904946	236	40	
Jul-08	Inverhuron	26	452131	4904946	66	88	Calcite filled joint
Jul-08	Inverhuron	26	452131	4904946	198	75	
Jul-08	Inverhuron	26	452131	4904946	73	78	
Jul-08	Inverhuron	26	452131	4904946	324	44	
Jul-08	Inverhuron	26	452131	4904946	172	80	
Jul-08	Inverhuron	26	452131	4904946	41	66	
Jul-08	Inverhuron	26	452131	4904946	338	85	
Jul-08	Inverhuron	26	452131	4904946	212	60	
Jul-08	Inverhuron	26	452131	4904946	48	55	
Jul-08	Inverhuron	26	452131	4904946	210	55	
Jul-08	Inverhuron	26	452131	4904946	248	75	
Jul-08	Inverhuron	26	452131	4904946	226	50	Irregular vein
Jul-08	Inverhuron	26	452131	4904946	348	90	Hairline vein zone
Jul-08	Inverhuron	26	452131	4904946	173	88	Hairline vein zone
Jul-08	Inverhuron	28	452118	4904939	71	75	Curved joint
Jul-08	Inverhuron	28	452118	4904939	353	88	Spaced calcite veins
Jul-08	Inverhuron	28	452118	4904939	357	90	
Jul-08	Inverhuron	28	452118	4904939	352	90	Vein
Jul-08	Inverhuron	28	452118	4904939	228	90	Vein, offsets previous LL
Jul-08	Inverhuron	28	452118	4904939	236	40	Vein
Jul-08	Inverhuron	28	452118	4904939	352	90	
Jul-08	Inverhuron	28	452118	4904939	1	90	
Jul-08	Inverhuron	28	452118	4904939	78	75	
Jul-08	Inverhuron	28	452118	4904939	331	90	
Jul-08	Inverhuron	28	452118	4904939	353	90	Joints and veins
Jul-08	Inverhuron	28	452118	4904939	348	90	Joints and veins
Jul-08	Inverhuron	28	452118	4904939	132	35	
Jul-08	Inverhuron	28	452118	4904939	88	75	
Jul-08	Inverhuron	28	452118	4904939	353	90	Hairline vein zone
Jul-08	Inverhuron	28	452118	4904939	255	65	
Jul-08	Inverhuron	28	452118	4904939	208	85	Curved joint
Jul-08	Inverhuron	28	452118	4904939	349	75	
Jul-08	Inverhuron	28	452118	4904939	349	90	Veins
Jul-08	Inverhuron	28	452118	4904939	40	90	
Jul-08	Inverhuron	28	452118	4904939	88	60	
Jul-08	Inverhuron	28	452118	4904939	348	90	Hairline vein zone
Jul-08	Inverhuron	28	452118	4904939	348	90	Hairline vein zone
Jul-08	Inverhuron	28	452118	4904939	308	90	Hairline vein zone
Jul-08	Inverhuron	28	452118	4904939	353	75	
Jul-08	Inverhuron	28	452118	4904939	72	78	
Jul-08	Inverhuron	28	452118	4904939	68	85	
Jul-08	Inverhuron	28	452118	4904939	90	85	
Jul-08	Inverhuron	28	452118	4904939	98	90	
Jul-08	Inverhuron	28	452118	4904939	78	80	
Jul-08	Inverhuron	28	452118	4904939	88	75	
Jul-08	Inverhuron	29	452106	4904924	45	80	
Jul-08	Inverhuron	29	452106	4904924	254	90	
Jul-08	Inverhuron	29	452106	4904924	217	90	

Date	Location	Station	Easting	Northing	Strike	Dip	Comment
Jul-08	Inverhuron	29	452106	4904924	44	85	
Jul-08	Inverhuron	29	452106	4904924	348	90	
Jul-08	Inverhuron	29	452106	4904924	352	88	Hairline vein zone
Jul-08	Inverhuron	29	452106	4904924	86	75	
Jul-08	Inverhuron	29	452106	4904924	90	80	
Jul-08	Inverhuron	29	452106	4904924	227	50	
Jul-08	Inverhuron	29	452106	4904924	351	90	Joints and veins
Jul-08	Inverhuron	29	452106	4904924	78	80	
Jul-08	Inverhuron	29	452106	4904924	348	90	
Jul-08	Inverhuron	29	452106	4904924	347	90	
Jul-08	Inverhuron	29	452106	4904924	68	80	
Jul-08	Inverhuron	29	452106	4904924	350	90	
Jul-08	Inverhuron	29	452106	4904924	82	80	
Jul-08	Inverhuron	29	452106	4904924	148	40	
Jul-08	Inverhuron	29	452106	4904924	88	80	
Jul-08	Inverhuron	29	452106	4904924	68	80	
Jul-08	Inverhuron	29	452106	4904924	90	85	
Jul-08	Inverhuron	29	452106	4904924	351	90	
Jul-08	Inverhuron	29	452106	4904924	88	85	
Jul-08	Inverhuron	29	452106	4904924	4	90	
Jul-08	Inverhuron	29	452106	4904924	63	90	
Jul-08	Inverhuron	29	452106	4904924	78	85	
Jul-08	Inverhuron	29	452106	4904924	356	85	
Jul-08	Inverhuron	29	452106	4904924	66	90	End of traverse at waypoint 30
Jul-08	Inverhuron	31	452081	4904888	73	80	
Jul-08	Inverhuron	31	452081	4904888	358	90	
Jul-08	Inverhuron	31	452081	4904888	359	90	
Jul-08	Inverhuron	31	452081	4904888	351	90	Hairline vein zone
Jul-08	Inverhuron	31	452081	4904888	48	90	
Jul-08	Inverhuron	31	452081	4904888	58	90	
Jul-08	Inverhuron	31	452081	4904888	63	47	
Jul-08	Inverhuron	31	452081	4904888	46	90	
Jul-08	Inverhuron	31	452081	4904888	212	90	
Jul-08	Inverhuron	31	452081	4904888	221	80	
Jul-08	Inverhuron	31	452081	4904888	38	80	
Jul-08	Inverhuron	31	452081	4904888	355	90	
Jul-08	Inverhuron	31	452081	4904888	248	80	
Jul-08	Inverhuron	31	452081	4904888	347	90	
Jul-08	Inverhuron	31	452081	4904888	98	80	
Jul-08	Inverhuron	31	452081	4904888	231	75	
Jul-08	Inverhuron	31	452081	4904888	32	75	
Jul-08	Inverhuron	31	452081	4904888	93	90	
Jul-08	Inverhuron	31	452081	4904888	355	90	
Jul-08	Inverhuron	31	452081	4904888	75	90	
Jul-08	Inverhuron	31	452081	4904888	38	80	Joint and vein
Jul-08	Inverhuron	31	452081	4904888	349	90	Hairline vein zone
Jul-08	Inverhuron	31	452081	4904888	88	75	
Jul-08	Inverhuron	31	452081	4904888	353	90	Hairline vein zone
Jul-08	Inverhuron	31	452081	4904888	89	72	Calcite filled joint
Jul-08	Inverhuron	31	452081	4904888	89	70	Calcite filled joint
Jul-08	Inverhuron	31	452081	4904888	78	80	
Jul-08	Inverhuron	31	452081	4904888	350	90	Hairline vein zone
Jul-08	Inverhuron	31	452081	4904888	125	90	
Jul-08	Inverhuron	31	452081	4904888	168	53	
Jul-08	Inverhuron	31	452081	4904888	99	62	

Date	Location	Station	Easting	Northing	Strike	Dip	Comment
Jul-08	Inverhuron	31	452081	4904888	351	90	Joint and vein
Jul-08	Inverhuron	31	452081	4904888	81	65	
Jul-08	Inverhuron	31	452081	4904888	302	70	
Jul-08	Inverhuron	31	452081	4904888	352	90	
Jul-08	Inverhuron	31	452081	4904888	85	64	
Jul-08	Inverhuron	31	452081	4904888	86	50	
Jul-08	Inverhuron	31	452081	4904888	88	65	
Jul-08	Inverhuron	31	452081	4904888	304	75	
Jul-08	Inverhuron	31	452081	4904888	352	85	Traverse ends at waypoint 32
Jul-08	Inverhuron	32	452052	4904875	78	80	
Jul-08	Inverhuron	32	452052	4904875	357	85	Joint and vein
Jul-08	Inverhuron	32	452052	4904875	171	63	Calcite filled joint
Jul-08	Inverhuron	32	452052	4904875	351	90	Hairline vein zone
Jul-08	Inverhuron	32	452052	4904875	91	70	
Jul-08	Inverhuron	32	452052	4904875	338	65	
Jul-08	Inverhuron	32	452052	4904875	98	70	
Jul-08	Inverhuron	32	452052	4904875	351	90	
Jul-08	Inverhuron	32	452052	4904875	91	40	
Jul-08	Inverhuron	32	452052	4904875	342	90	Joint and vein
Jul-08	Inverhuron	32	452052	4904875	323	70	
Jul-08	Inverhuron	32	452052	4904875	93	50	Calcite filled joint
Jul-08	Inverhuron	32	452052	4904875	351	90	Hairline vein zone
Jul-08	Inverhuron	32	452052	4904875	78	70	
Jul-08	Inverhuron	32	452052	4904875	38	80	
Jul-08	Inverhuron	32	452052	4904875	348	90	Hairline vein zone
Jul-08	Inverhuron	32	452052	4904875	34	75	
Jul-08	Inverhuron	32	452052	4904875	83	65	
Jul-08	Inverhuron	32	452052	4904875	51	90	Joint and vein
Jul-08	Inverhuron	32	452052	4904875	93	90	Calcite filled joint
Jul-08	Inverhuron	32	452052	4904875	352	90	Hairline vein zone
Jul-08	Inverhuron	32	452052	4904875	94	50	
Jul-08	Inverhuron	32	452052	4904875	294	30	
Jul-08	Inverhuron	32	452052	4904875	100	65	
Jul-08	Inverhuron	32	452052	4904875	152	90	Calcite filled joint
Jul-08	Inverhuron	32	452052	4904875	355	90	Joint and vein
Jul-08	Inverhuron	32	452052	4904875	94	65	
Jul-08	Inverhuron	32	452052	4904875	169	85	
Jul-08	Inverhuron	32	452052	4904875	351	90	Calcite filled joint. Traverse ends at waypoint 34
Jul-08	Inverhuron	34	451962	4904862	350	90	
Jul-08	Inverhuron	34	451962	4904862	98	80	
Jul-08	Inverhuron	34	451962	4904862	68	90	
Jul-08	Inverhuron	34	451962	4904862	83	80	
Jul-08	Inverhuron	34	451962	4904862	74	90	
Jul-08	Inverhuron	34	451962	4904862	357	90	
Jul-08	Inverhuron	34	451962	4904862	36	70	
Jul-08	Inverhuron	34	451962	4904862	56	90	
Jul-08	Inverhuron	34	451962	4904862	139	90	
Jul-08	Inverhuron	34	451962	4904862	90	33	
Jul-08	Inverhuron	34	451962	4904862	94	90	
Jul-08	Inverhuron	34	451962	4904862	359	90	
Jul-08	Inverhuron	34	451962	4904862	90	80	
Jul-08	Inverhuron	35	451937	4904867	148	80	Outcrop ends at waypoint 35
Jul-30	Bruce	39	452006	4908326	0	90	Start of traverse. X-ing set
Jul-30	Bruce	39	452006	4908326	24	66	abuts prev. frac.
Jul-30	Bruce	39	452006	4908326	316	90	crosses intersection of prev two

Date	Location	Station	Easting	Northing	Strike	Dip	Comment
Jul-30	Bruce	39	452006	4908326	356	90	
Jul-30	Bruce	39	452006	4908326	334	90	abuts prev. frac.
Jul-30	Bruce	39	452006	4908326	326	90	
Jul-30	Bruce	39	452006	4908326	356	90	
Jul-30	Bruce	39	452006	4908326	287	90	confined betw. NS-NNW sets
Jul-30	Bruce	39	452006	4908326	280	55	confined betw. NS-NNW sets
Jul-30	Bruce	39	452006	4908326	348	90	
Jul-30	Bruce	39	452006	4908326	340	75	
Jul-30	Bruce	39	452006	4908326	244	60	
Jul-30	Bruce	39	452006	4908326	180	20	bedding parallel?
Jul-30	Bruce	39	452006	4908326	170	40	
Jul-30	Bruce	39	452006	4908326	183	36	
Jul-30	Bruce	39	452006	4908326	357	90	
Jul-30	Bruce	39	452006	4908326	340	90	
Jul-30	Bruce	39	452006	4908326	350	50	
Jul-30	Bruce	39	452006	4908326	225	90	
Jul-30	Bruce	39	452006	4908326	350	90	
Jul-30	Bruce	39	452006	4908326	247	90	offsets 350 set 1-10 cm dextrally
Jul-30	Bruce	39	452006	4908326	40	75	
Jul-30	Bruce	39	452006	4908326	172	50	
Jul-30	Bruce	39	452006	4908326	170	90	
Jul-30	Bruce	39	452006	4908326	250	90	
Jul-30	Bruce	39	452006	4908326	236	90	
Jul-30	Bruce	39	452006	4908326	170	90	cuts through subhoriz. bedding plane
Jul-30	Bruce	39	452006	4908326	170	62	Upper bench (i.e., above prev. measurements)
Jul-30	Bruce	39	452006	4908326	359	90	Fracture intensity much less
Jul-30	Bruce	39	452006	4908326	246	90	
Jul-30	Bruce	39	452006	4908326	340	90	
Jul-30	Bruce	39	452006	4908326	350	90	
Jul-30	Bruce	39	452006	4908326	178	52	
Jul-30	Bruce	39	452006	4908326	178	30	
Jul-30	Bruce	39	452006	4908326	160	40	
Jul-30	Bruce	39	452006	4908326	350	90	
Jul-30	Bruce	39	452006	4908326	210	74	conjugate pair. Offsets 242 joint 4 cm sinistrally
Jul-30	Bruce	39	452006	4908326	30	45	conjugate pair
Jul-30	Bruce	39	452006	4908326	242	90	
Jul-30	Bruce	39	452006	4908326	167	75	
Jul-30	Bruce	39	452006	4908326	28	75	
Jul-30	Bruce	39	452006	4908326	349	90	
Jul-30	Bruce	39	452006	4908326	170	66	
Jul-30	Bruce	39	452006	4908326	170	66	
Jul-30	Bruce	39	452006	4908326	347	90	
Jul-30	Bruce	39	452006	4908326	85	86	
Jul-30	Bruce	39	452006	4908326	350	88	
Jul-30	Bruce	39	451975	4908299	178	37	End of traverse at waypoint 40 (452044, 4908382)
Jul-30	Bruce	41	452044	4908382	72	65	Start of traverse
Jul-30	Bruce	41	452044	4908382	69	60	
Jul-30	Bruce	41	452044	4908382	296	70	Confined betw. prev. set
Jul-30	Bruce	41	452044	4908382	4	90	
Jul-30	Bruce	41	452044	4908382	190	62	
Jul-30	Bruce	41	452044	4908382	180	90	Offsets next fract. 15 cm sinistrally
Jul-30	Bruce	41	452044	4908382	256	57	
Jul-30	Bruce	41	452044	4908382	183	90	Offsets next fract. 15 cm sinistrally
Jul-30	Bruce	41	452044	4908382	220	70	
Jul-30	Bruce	41	452044	4908382	225	70	> 5 m long

Date	Location	Station	Easting	Northing	Strike	Dip	Comment
Jul-30	Bruce	41	452044	4908382	170	90	
Jul-30	Bruce	41	452044	4908382	23	40	
Jul-30	Bruce	41	452044	4908382	173	90	
Jul-30	Bruce	41	452044	4908382	214	90	conjugate pair?
Jul-30	Bruce	41	452044	4908382	180	90	conjugate pair?
Jul-30	Bruce	41	452044	4908382	212	31	
Jul-30	Bruce	41	452044	4908382	30	70	
Jul-30	Bruce	41	452044	4908382	356	90	
Jul-30	Bruce	41	452044	4908382	207	34	
Jul-30	Bruce	41	452044	4908382	52	70	
Jul-30	Bruce	41	452044	4908382	352	90	> 20 m long
Jul-30	Bruce	41	452044	4908382	240	90	
Jul-30	Bruce	41	452044	4908382	290	90	
Jul-30	Bruce	41	452044	4908382	28	50	
Jul-30	Bruce	41	452044	4908382	354	90	
Jul-30	Bruce	41	452044	4908382	340	90	
Jul-30	Bruce	41	452044	4908382	256	45	Confined betw. NNW joints
Jul-30	Bruce	41	452044	4908382	350	90	
Jul-30	Bruce	41	452044	4908382	238	90	
Jul-30	Bruce	41	452044	4908382	10	65	
Jul-30	Bruce	41	452044	4908382	339	90	
Jul-30	Bruce	41	452044	4908382	354	90	
Jul-30	Bruce	41	452044	4908382	357	90	
Jul-30	Bruce	41	452044	4908382	240	90	
Jul-30	Bruce	41	452044	4908382	175	40	
Jul-30	Bruce	41	452044	4908382	340	90	
Jul-30	Bruce	41	452044	4908382	253	90	
Jul-30	Bruce	41	452044	4908382	30	60	
Jul-30	Bruce	41	452044	4908382	346	90	Joint with 1 mm thick calcite fill/vein
Jul-30	Bruce	41	452044	4908382	285	60	
Jul-30	Bruce	41	452044	4908382	359	90	
Jul-30	Bruce	41	452044	4908382	227	75	
Jul-30	Bruce	41	452044	4908382	60	40	
Jul-30	Bruce	41	452044	4908382	289	40	
Jul-30	Bruce	41	452044	4908382	357	90	Conjugate pair?
Jul-30	Bruce	41	452044	4908382	223	45	Conjugate pair?
Jul-30	Bruce	41	452044	4908382	233	57	
Jul-30	Bruce	41	452044	4908382	353	90	
Jul-30	Bruce	41	452044	4908382	240	90	
Jul-30	Bruce	41	452044	4908382	210	90	
Jul-30	Bruce	41	452044	4908382	50	58	
Jul-30	Bruce	41	452044	4908382	40	90	
Jul-30	Bruce	41	452044	4908382	60	70	
Jul-30	Bruce	41	452044	4908382	44	90	
Jul-30	Bruce	41	452044	4908382	170	50	
Jul-30	Bruce	41	452044	4908382	55	75	
Jul-30	Bruce	41	452044	4908382	3	90	
Jul-30	Bruce	41	452044	4908382	248	90	Traverse ends at waypoint 42 (451988, 4908471)
Jul-30	Bruce	43	451931	4908194	347	90	Start of traverse. Main x-cutting sets
Jul-30	Bruce	43	451931	4908194	262	90	Main x-cutting sets
Jul-30	Bruce	43	451931	4908194	255	90	
Jul-30	Bruce	43	451931	4908194	357	90	
Jul-30	Bruce	43	451931	4908194	176	75	
Jul-30	Bruce	43	451931	4908194	206	90	
Jul-30	Bruce	43	451931	4908194	346	90	

Date	Location	Station	Easting	Northing	Strike	Dip	Comment
Jul-30	Bruce	43	451931	4908194	253	90	
Jul-30	Bruce	43	451931	4908194	350	90	Anastomosing set
Jul-30	Bruce	43	451931	4908194	344	90	Anastomosing set
Jul-30	Bruce	43	451931	4908194	357	75	
Jul-30	Bruce	43	451931	4908194	176	70	Main set at end of traverse
Jul-30	Bruce	43	451931	4908194	183	70	Offsets next fract. 1 cm dextrally
Jul-30	Bruce	43	451931	4908194	110	90	
Jul-30	Bruce	43	451931	4908194	320	80	
Jul-30	Bruce	43	451931	4908194	6	90	
Jul-30	Bruce	43	451931	4908194	335	80	
Jul-30	Bruce	43	451931	4908194	325	90	Traverse ends at waypoint 44 (451896, 4908179)
Jul-30	Bruce	45	451882	4908150	175	90	Start of traverse
Jul-30	Bruce	45	451882	4908150	80	90	
Jul-30	Bruce	45	451882	4908150	157	90	
Jul-30	Bruce	45	451882	4908150	220	90	
Jul-30	Bruce	45	451882	4908150	255	90	
Jul-30	Bruce	45	451882	4908150	340	90	
Jul-30	Bruce	45	451882	4908150	345	90	
Jul-30	Bruce	45	451882	4908150	238	90	
Jul-30	Bruce	45	451882	4908150	201	55	
Jul-30	Bruce	45	451882	4908150	345	90	
Jul-30	Bruce	45	451882	4908150	16	75	
Jul-30	Bruce	45	451882	4908150	88	75	
Jul-30	Bruce	45	451882	4908150	351	90	
Jul-30	Bruce	45	451882	4908150	349	90	
Jul-30	Bruce	45	451882	4908150	261	80	
Jul-30	Bruce	45	451882	4908150	260	90	
Jul-30	Bruce	45	451882	4908150	265	90	
Jul-30	Bruce	45	451882	4908150	346	90	
Jul-30	Bruce	45	451882	4908150	18	90	
Jul-30	Bruce	45	451882	4908150	1	73	Traverse ends at waypoint 46 (451861, 4908131)
Jul-30	Bruce	47	451691	4906781	240	90	Start of traverse. 50 cm spaced joints and veins
Jul-30	Bruce	47	451691	4906781	345	90	50 cm wide zone of 1-5 cm spaced joints
Jul-30	Bruce	47	451691	4906781	238	90	
Jul-30	Bruce	47	451691	4906781	232	90	Thin vein offset 2 cm by next vein
Jul-30	Bruce	47	451691	4906781	250	90	Thin vein
Jul-30	Bruce	47	451691	4906781	341	90	Abundant dm spaced joints
Jul-30	Bruce	47	451691	4906781	240	90	dm spaced veins
Jul-30	Bruce	47	451691	4906781	10	60	
Jul-30	Bruce	47	451691	4906781	258	58	Calcite coated joint
Jul-30	Bruce	47	451691	4906781	232	80	Calcite coated joint
Jul-30	Bruce	47	451691	4906781	225	90	Joints and veins
Jul-30	Bruce	47	451691	4906781	340	90	
Jul-30	Bruce	47	451691	4906781	360	90	
Jul-30	Bruce	47	451691	4906781	270	52	Conjugate pair?
Jul-30	Bruce	47	451691	4906781	40	73	Conjugate pair?
Jul-30	Bruce	47	451691	4906781	260	70	
Jul-30	Bruce	47	451691	4906781	255	80	
Jul-30	Bruce	47	451691	4906781	347	90	Abundant dm spaced joints
Jul-30	Bruce	47	451691	4906781	348	80	
Jul-30	Bruce	47	451691	4906781	25	90	~ 75 m south of waypoint 47
Jul-30	Bruce	47	451691	4906781	341	90	
Jul-30	Bruce	47	451691	4906781	333	90	
Jul-30	Bruce	47	451691	4906781	238	80	
Jul-30	Bruce	47	451691	4906781	340	90	

Date	Location	Station	Easting	Northing	Strike	Dip	Comment
Jul-30	Bruce	47	451691	4906781	218	90	
Jul-30	Bruce	47	451691	4906781	225	90	~150 m south of waypoint 47. Joints and veins
Jul-30	Bruce	47	451691	4906781	355	90	Joints and veins
Jul-30	Bruce	47	451691	4906781	230	90	
Jul-30	Bruce	47	451691	4906781	358	90	Joints and veins
Jul-30	Bruce	47	451691	4906781	217	90	> 5 m long
Jul-30	Bruce	47	451691	4906781	341	90	
Jul-30	Bruce	47	451691	4906781	253	90	
Jul-30	Bruce	47	451691	4906781	353	90	
Jul-30	Bruce	47	451691	4906781	337	41	
Jul-30	Bruce	47	451691	4906781	4	90	
Jul-30	Bruce	47	451691	4906781	62	75	
Jul-30	Bruce	47	451691	4906781	241	50	
Jul-30	Bruce	47	451691	4906781	9	90	Joints and veins
Jul-30	Bruce	47	451691	4906781	1	90	
Jul-30	Bruce	47	451691	4906781	212	90	
Jul-30	Bruce	47	451691	4906781	93	75	
Jul-30	Bruce	47	451691	4906781	214	75	
Jul-30	Bruce	47	451691	4906781	355	90	Traverse ends at waypoint 48 (451678, 4906588)
Jul-30	Bruce	49	451679	4906514	341	90	Start of traverse. Main sets
Jul-30	Bruce	49	451679	4906514	259	90	Main sets
Jul-30	Bruce	49	451679	4906514	210	90	
Jul-30	Bruce	49	451679	4906514	355	90	Main set locally
Jul-30	Bruce	49	451679	4906514	350	90	Closely spaced (<1 cm) joint zones
Jul-30	Bruce	49	451679	4906514	250	90	> 5 m long, 1 to 4 m spaced
Jul-30	Bruce	49	451679	4906514	240	90	> 5 m long, 1 to 4 m spaced
Jul-30	Bruce	49	451679	4906514	340	90	
Jul-30	Bruce	49	451679	4906514	240	90	
Jul-30	Bruce	49	451679	4906514	352	90	Vein zone and joints
Jul-30	Bruce	49	451679	4906514	260	90	
Jul-30	Bruce	49	451679	4906514	57	45	Conjugate pair?
Jul-30	Bruce	49	451679	4906514	235	90	Conjugate pair?
Jul-30	Bruce	49	451679	4906514	350	90	Main set, dm spaced
Jul-30	Bruce	49	451679	4906514	213	75	
Jul-30	Bruce	49	451679	4906514	238	40	Traverse ends at waypoint 50 (451658, 4906419)
Jul-30	Bruce	51	451666	4906397	12	90	Start of traverse
Jul-30	Bruce	51	451666	4906397	210	52	Conjugate pair?
Jul-30	Bruce	51	451666	4906397	255	90	Conjugate pair?
Jul-30	Bruce	51	451666	4906397	254	30	
Jul-30	Bruce	51	451666	4906397	190	90	Joints and veins
Jul-30	Bruce	51	451666	4906397	42	85	Veins
Jul-30	Bruce	51	451666	4906397	350	90	2 - 7 mm spaced joints
Jul-30	Bruce	51	451666	4906397	240	90	Wavy dm spaced joints
Jul-30	Bruce	51	451666	4906397	261	65	
Jul-30	Bruce	51	451666	4906397	84	70	
Jul-30	Bruce	51	451666	4906397	190	53	Vein
Jul-30	Bruce	51	451666	4906397	357	45	Vein
Jul-30	Bruce	51	451666	4906397	345	90	Vein zone and joints
Jul-30	Bruce	51	451666	4906397	351	90	Vein zone and joints
Jul-30	Bruce	51	451666	4906397	226	90	
Jul-30	Bruce	51	451666	4906397	210	36	Vein
Jul-30	Bruce	51	451666	4906397	198	40	Vein
Jul-30	Bruce	51	451666	4906397	326	90	
Jul-30	Bruce	51	451666	4906397	75	75	Vein
Jul-30	Bruce	51	451666	4906397	212	30	Vein

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Jul-30	Bruce	51	451666	4906397	38	75	Vein
Jul-30	Bruce	51	451666	4906397	119	70	Crack seal vein
Jul-30	Bruce	51	451666	4906397	200	35	Vein
Jul-30	Bruce	51	451666	4906397	270	90	
Jul-30	Bruce	51	451666	4906397	160	90	
Jul-30	Bruce	51	451666	4906397	210	90	
Jul-30	Bruce	51	451666	4906397	340	90	
Jul-30	Bruce	51	451666	4906397	208	90	
Jul-30	Bruce	51	451666	4906397	210	32	Vein
Jul-30	Bruce	51	451666	4906397	335	90	
Jul-30	Bruce	51	451666	4906397	227	90	
Jul-30	Bruce	51	451666	4906397	228	90	Vein
Jul-30	Bruce	51	451666	4906397	173	30	
Jul-30	Bruce	51	451666	4906397	205	90	
Jul-30	Bruce	51	451666	4906397	336	90	Vein zone
Jul-30	Bruce	51	451666	4906397	228	90	Crack seal vein
Jul-30	Bruce	51	451666	4906397	240	90	Crack seal vein
Jul-30	Bruce	51	451666	4906397	341	90	
Jul-30	Bruce	51	451666	4906397	250	90	Joint and vein zones
Jul-30	Bruce	51	451666	4906397	230	90	Vein
Jul-30	Bruce	51	451666	4906397	335	90	Vein. Traverse ends at waypoint 52 (451657, 4906363)
Sep-01	Inverhuron	53	451842	4904858	345	90	cm - 30 cm spaced joints
Sep-01	Inverhuron	53	451842	4904858	270	90	> 1 m spaced joints
Sep-01	Inverhuron	54	451818	4904895	350	90	Start of traverse. Dominant 5-20 cm spaced set
Sep-01	Inverhuron	54	451818	4904895	0	90	
Sep-01	Inverhuron	54	451818	4904895	235	90	
Sep-01	Inverhuron	54	451818	4904895	349	90	0.5-1 m wide joint zones, 2 mm spaced
Sep-01	Inverhuron	54	451818	4904895	227	90	
Sep-01	Inverhuron	54	451818	4904895	358	90	
Sep-01	Inverhuron	54	451818	4904895	220	90	
Sep-01	Inverhuron	54	451818	4904895	346	90	Lozenge sets
Sep-01	Inverhuron	54	451818	4904895	332	90	Lozenge sets
Sep-01	Inverhuron	54	451818	4904895	346	90	
Sep-01	Inverhuron	54	451818	4904895	346	90	Lozenge sets
Sep-01	Inverhuron	54	451818	4904895	332	90	Lozenge sets
Sep-01	Inverhuron	54	451818	4904895	76	58	
Sep-01	Inverhuron	55	451793	4904961	353	90	
Sep-01	Inverhuron	55	451793	4904961	260	90	
Sep-01	Inverhuron	55	451793	4904961	277	90	
Sep-01	Inverhuron	55	451793	4904961	308	90	
Sep-01	Inverhuron	55	451793	4904961	214	90	
Sep-01	Inverhuron	55	451793	4904961	165	80	
Sep-01	Inverhuron	55	451793	4904961	8	90	
Sep-01	Inverhuron	55	451793	4904961	60	43	
Sep-01	Inverhuron	55	451793	4904961	6	90	
Sep-01	Inverhuron	55	451793	4904961	265	90	
Sep-01	Inverhuron	55	451793	4904961	325	90	
Sep-01	Inverhuron	55	451793	4904961	250	90	Traverse ends at waypoint 56 (451775, 4904975)
Sep-01	Inverhuron	57	451764	4904981	345	90	Main set
Sep-01	Inverhuron	57	451764	4904981	246	90	
Sep-01	Inverhuron	59	451736	4905022	3	90	
Sep-01	Inverhuron	59	451736	4905022	20	90	
Sep-01	Inverhuron	59	451736	4905022	347	90	
Sep-01	Inverhuron	60	451753	4905027	353	90	Lozenge sets. Start of traverse
Sep-01	Inverhuron	60	451753	4905027	8	90	Lozenge sets

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Sep-01	Inverhuron	60	451753	4905027	345	90	
Sep-01	Inverhuron	60	451753	4905027	211	90	
Sep-01	Inverhuron	60	451753	4905027	27	80	
Sep-01	Inverhuron	60	451753	4905027	10	90	
Sep-01	Inverhuron	60	451753	4905027	337	90	
Sep-01	Inverhuron	60	451753	4905027	278	90	
Sep-01	Inverhuron	60	451753	4905027	255	90	
Sep-01	Inverhuron	60	451753	4905027	233	90	
Sep-01	Inverhuron	60	451753	4905027	8	90	
Sep-01	Inverhuron	60	451753	4905027	247	90	
Sep-01	Inverhuron	60	451753	4905027	3	90	
Sep-01	Inverhuron	60	451753	4905027	30	90	
Sep-01	Inverhuron	60	451753	4905027	333	90	
Sep-01	Inverhuron	60	451753	4905027	10	90	
Sep-01	Inverhuron	60	451753	4905027	342	90	
Sep-01	Inverhuron	60	451753	4905027	310	90	
Sep-01	Inverhuron	60	451753	4905027	297	90	
Sep-01	Inverhuron	60	451753	4905027	13	90	
Sep-01	Inverhuron	60	451753	4905027	337	50	
Sep-01	Inverhuron	60	451753	4905027	345	90	Lozenge sets
Sep-01	Inverhuron	60	451753	4905027	311	90	Lozenge sets
Sep-01	Inverhuron	60	451753	4905027	234	90	
Sep-01	Inverhuron	60	451753	4905027	220	90	
Sep-01	Inverhuron	60	451753	4905027	219	90	dm spaced
Sep-01	Inverhuron	60	451753	4905027	320	90	Main sets at N end of traverse
Sep-01	Inverhuron	60	451753	4905027	220	90	Main sets at N end of traverse
Sep-01	Inverhuron	60	451753	4905027	10	80	
Sep-01	Inverhuron	60	451753	4905027	335	32	
Sep-01	Inverhuron	60	451753	4905027	225	90	
Sep-01	Inverhuron	60	451753	4905027	264	90	Conjugate pair?
Sep-01	Inverhuron	60	451753	4905027	223	90	Conjugate pair?
Sep-01	Inverhuron	60	451753	4905027	230	52	
Sep-01	Inverhuron	60	451753	4905027	182	75	
Sep-01	Inverhuron	60	451753	4905027	345	80	
Sep-01	Inverhuron	60	451753	4905027	226	85	Traverse ends at waypoint 61 (451747, 4905063)
Sep-01	Inverhuron	62	451721	4905118	260	90	dm to m spacing betw. all sets
Sep-01	Inverhuron	62	451721	4905118	346	90	
Sep-01	Inverhuron	62	451721	4905118	270	80	
Sep-01	Inverhuron	62	451721	4905118	336	90	
Sep-01	Inverhuron	63	451726	4905213	154	60	Start of traverse
Sep-01	Inverhuron	63	451726	4905213	246	90	
Sep-01	Inverhuron	63	451726	4905213	192	90	
Sep-01	Inverhuron	63	451726	4905213	328	90	
Sep-01	Inverhuron	63	451726	4905213	240	90	
Sep-01	Inverhuron	63	451726	4905213	346	90	
Sep-01	Inverhuron	63	451726	4905213	354	90	
Sep-01	Inverhuron	63	451726	4905213	334	90	
Sep-01	Inverhuron	63	451726	4905213	360	90	
Sep-01	Inverhuron	63	451726	4905213	256	90	
Sep-01	Inverhuron	63	451726	4905213	346	90	
Sep-01	Inverhuron	63	451726	4905213	220	90	
Sep-01	Inverhuron	63	451726	4905213	256	90	
Sep-01	Inverhuron	63	451726	4905213	346	90	
Sep-01	Inverhuron	63	451726	4905213	257	90	End
Sep-01	Inverhuron	64	451777	4905244	333	90	dm spaced lozenge zones

Date	Location	Station	Easting	Northing	Strike	Dip	Comment
Sep-01	Inverhuron	64	451777	4905244	5	90	dm spaced lozenge zones
Sep-01	Inverhuron	64	451777	4905244	230	90	
Sep-01	Inverhuron	64	451777	4905244	240	90	
Sep-01	Inverhuron	64	451777	4905244	348	90	
Sep-01	Inverhuron	65	451803	4905281	270	90	
Sep-01	Inverhuron	65	451803	4905281	220	90	
Sep-01	Inverhuron	65	451803	4905281	240	90	
Sep-01	Inverhuron	65	451803	4905281	230	90	
Sep-01	Inverhuron	65	451803	4905281	225	90	
Sep-01	Inverhuron	66	451835	4905273	344	90	Joints and veins
Sep-01	Inverhuron	66	451835	4905273	240	90	
Sep-01	Inverhuron	66	451835	4905273	217	90	
Sep-01	Inverhuron	66	451835	4905273	240	90	
Sep-01	Inverhuron	66	451835	4905273	204	90	
Sep-01	Inverhuron	66	451835	4905273	340	90	
Sep-01	Inverhuron	67	451910	4905312	353	90	Start of traverse
Sep-01	Inverhuron	67	451910	4905312	303	90	
Sep-01	Inverhuron	67	451910	4905312	225	90	Vein
Sep-01	Inverhuron	67	451910	4905312	260	90	
Sep-01	Inverhuron	67	451910	4905312	235	90	
Sep-01	Inverhuron	67	451910	4905312	345	90	
Sep-01	Inverhuron	67	451910	4905312	230	90	
Sep-01	Inverhuron	67	451910	4905312	360	90	dm spaced set
Sep-01	Inverhuron	67	451910	4905312	316	90	
Sep-01	Inverhuron	67	451910	4905312	323	90	
Sep-01	Inverhuron	67	451910	4905312	356	90	
Sep-01	Inverhuron	67	451910	4905312	351	90	
Sep-01	Inverhuron	67	451910	4905312	320	90	
Sep-01	Inverhuron	67	451910	4905312	350	90	dm spaced set
Sep-01	Inverhuron	67	451910	4905312	325	90	
Sep-01	Inverhuron	67	451910	4905312	331	75	Waypoint 68 (451934, 4905358)
Sep-01	Inverhuron	67	451910	4905312	102	30	
Sep-01	Inverhuron	67	451910	4905312	346	90	
Sep-01	Inverhuron	67	451910	4905312	303	75	
Sep-01	Inverhuron	67	451910	4905312	310	42	
Sep-01	Inverhuron	67	451910	4905312	326	90	
Sep-01	Inverhuron	67	451910	4905312	350	90	
Sep-01	Inverhuron	67	451910	4905312	136	40	
Sep-01	Inverhuron	67	451910	4905312	247	70	
Sep-01	Inverhuron	67	451910	4905312	255	90	
Sep-01	Inverhuron	67	451910	4905312	350	90	dm spaced joint zone
Sep-01	Inverhuron	67	451910	4905312	154	36	
Sep-01	Inverhuron	67	451910	4905312	350	90	
Sep-01	Inverhuron	67	451910	4905312	350	90	
Sep-01	Inverhuron	67	451910	4905312	250	90	
Sep-01	Inverhuron	67	451910	4905312	284	90	Traverse ends at waypoint 69 (451941, 4905404)
Sep-01	Inverhuron	70	452028	4905430	356	90	
Sep-01	Inverhuron	70	452028	4905430	344	90	
Sep-01	Inverhuron	70	452028	4905430	325	90	
Sep-01	Inverhuron	70	452028	4905430	133	38	
Sep-01	Inverhuron	70	452028	4905430	60	35	
Sep-01	Inverhuron	70	452028	4905430	255	90	
Sep-01	Inverhuron	70	452028	4905430	348	90	
Sep-01	Inverhuron	70	452028	4905430	3	90	
Sep-01	Inverhuron	71	452140	4905525	0	90	

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Sep-01	Inverhuron	71	452140	4905525	130	60	
Sep-01	Inverhuron	71	452140	4905525	240	90	
Sep-01	Inverhuron	71	452140	4905525	270	90	
Sep-01	Inverhuron	71	452140	4905525	175	35	
Sep-01	Inverhuron	71	452140	4905525	347	90	
Sep-01	Inverhuron	71	452140	4905525	3	90	
Sep-01	Inverhuron	71	452140	4905525	312	90	
Sep-01	Inverhuron	71	452140	4905525	236	90	
Sep-01	Inverhuron	71	452140	4905525	355	90	