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FIELD AND SCIENTIFIC DATA REPORT: SIRIUS GROUP STUDY, ALLAN HILLS, SOUTH VICTORIA LAND, ANTARCTICA NOV 1999 - JAN 2000

by

Philip Holme

Event K042 - 1999/2000

Antarctic Research Centre
in association with the
SCHOOL OF EARTH SCIENCES

VICTORIA UNIVERSITY OF WELLINGTON
Te Whare Wananga o te Upoko o te Ika a Maui

FIELD AND SCIENTIFIC DATA REPORT: SIRIUS GROUP STUDY, ALLAN HILLS, SOUTH VICTORIA LAND, ANTARCTICA

NOV 1999 - JAN 2000

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Frontispiece: Looking northwest at Allan Hills from the top of Mount Brook, Convoy Range.

ACKNOWLEDGEMENTS

I am very grateful to the VUW Faculty of Science for funding this research project and to Antarctica New Zealand for providing good logistical support. I received much help and guidance in the field from my supervisors Prof. Peter Barrett ('Is that Sirius Group?' 'No.' 'Is that Sirius Group?' 'No.' 'Is that Sirius Group?' 'No.'.....) and Dr. Stephen Hicock. Alex Pyne was a key figure in the pre-season planning and I am very grateful to him for his input. Mark Lloyd-Davies and my very capable field assistant Jeremy Mitchell were excellent field companions who made a long season bearable.

We were among the first to see the dawn of the year 2000.....but we did it with style.

Philip Holme, Wellington 2001.

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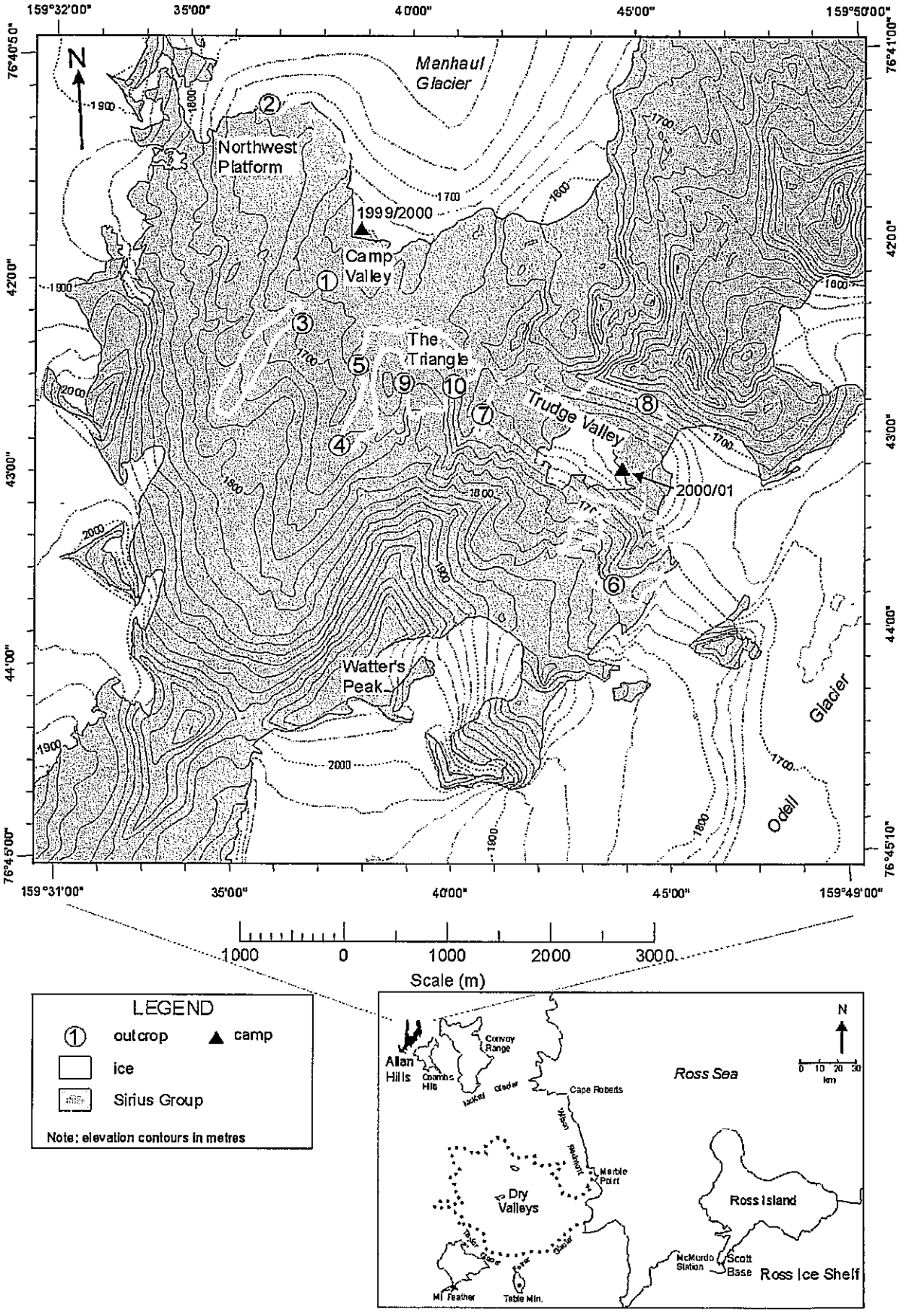


Figure 1. Location map of Allan Hills showing main geographical features named in text.

ABSTRACT

This report documents a major body of data for a detailed study of ancient glacial deposits termed the Sirius Group at Allan Hills, South Victoria Land, Antarctica. The Sirius Group is a collection of Neogene deposits that crop out at high elevations (mostly >1500 m) throughout the Transantarctic Mountains (TAM). Allan Hills occupies a low point in the TAM, making the site more susceptible to overriding by the EAIS during minor ice volume fluctuations. The aim of the study is to show whether the Sirius Group was deposited by a valley glacier or continental ice sheet, by wet- or dry-based glacial ice, by a single glacial overriding event or several, and to determine paleoflow direction.

The report extends work begun in 1997 (Atkins & Barrett 2001) by a joint Victoria University of Wellington - University of Bern party, presenting initial results and field data from the 1999-2000 field season. The Sirius Group at Allan Hills takes the form of seven patches of thin debris with a total area of ~2 km^2. From these, ten outcrops were selected for detailed description and sampling. The collected data include: orientations of 367 stones, 270 linear glacial abrasions and 96 planar deformational structures. In addition, 42 rock samples were collected for laboratory analysis. Sample processing has not yet begun but evidence indicates wet-based glacial deposition. Although the number of glacial advances is not yet known, the work thus far suggests paleo-ice flow from the southwest and west. The presence of a cirque incised into a surface capped with Sirius deposits on the south side of Trudge Valley reveals a later phase of local temperate ice before the present cold ice sheet formed.

INTRODUCTION

This study began as a collaborative project between Swiss and New Zealand researchers in 1997 and then later in 1999-2000 with Dutch researchers. For a report of the Dutch group's work in 1999-2000 see Lloyd Davies and van der Meer (2001). With the introduction of Dr. Stephen Hicock, an associate professor at the University of Western Ontario in Canada, as Holme's co-supervisor, the international scope of the program was broadened further.

The study area, central Allan Hills, is shown in Figure 1 along with the 10 locations studied in detail. The cross-section of the Transantarctic Mountains in Figure 2 shows the context for the glacial deposits, in particular how only a relatively small (hundreds of metres) rise in elevation of the East Antarctic Ice Sheet would be required for ice again to flow over the study area.

PURPOSE AND OBJECTIVES

The first major goal for the field season was to complete geological mapping of the Sirius Group at Allan Hills begun during the 1998-1999 season. This activity would also serve to familiarise the event members with the appearance and occurrence of all deposits in the field area. Secondly, detailed descriptions of the Sirius Group in outcrop were to be done for the purpose of interpreting the nature of the ice that deposited them. The third main goal for the season was to select sites for drilling to be conducted during the 2000-2001 season.

OVERVIEW

The initial tasks in this investigation were to reconnoitre (recce) the area to familiarise ourselves with it and then to continue the mapping of Sirius distribution begun the previous season (see Appendix 1). These recces proved to be very fruitful as they provided an opportunity to select major outcrops for later detailed investigation, to examine the variety of diamicts found in the area and to differentiate between the glacial and non-glacial varieties. Detailed studies of outcrops were then begun and continued until the end of the season. Data collected from the outcrop and mapping work include the following: orientational measurements of 367 clasts and 96 deformational features in the Sirius Group at both measured outcrops and stop locations, recorded orientations on 270 abraded (striated) and faceted clasts throughout the study area, collected 42 rock samples for lab analysis.

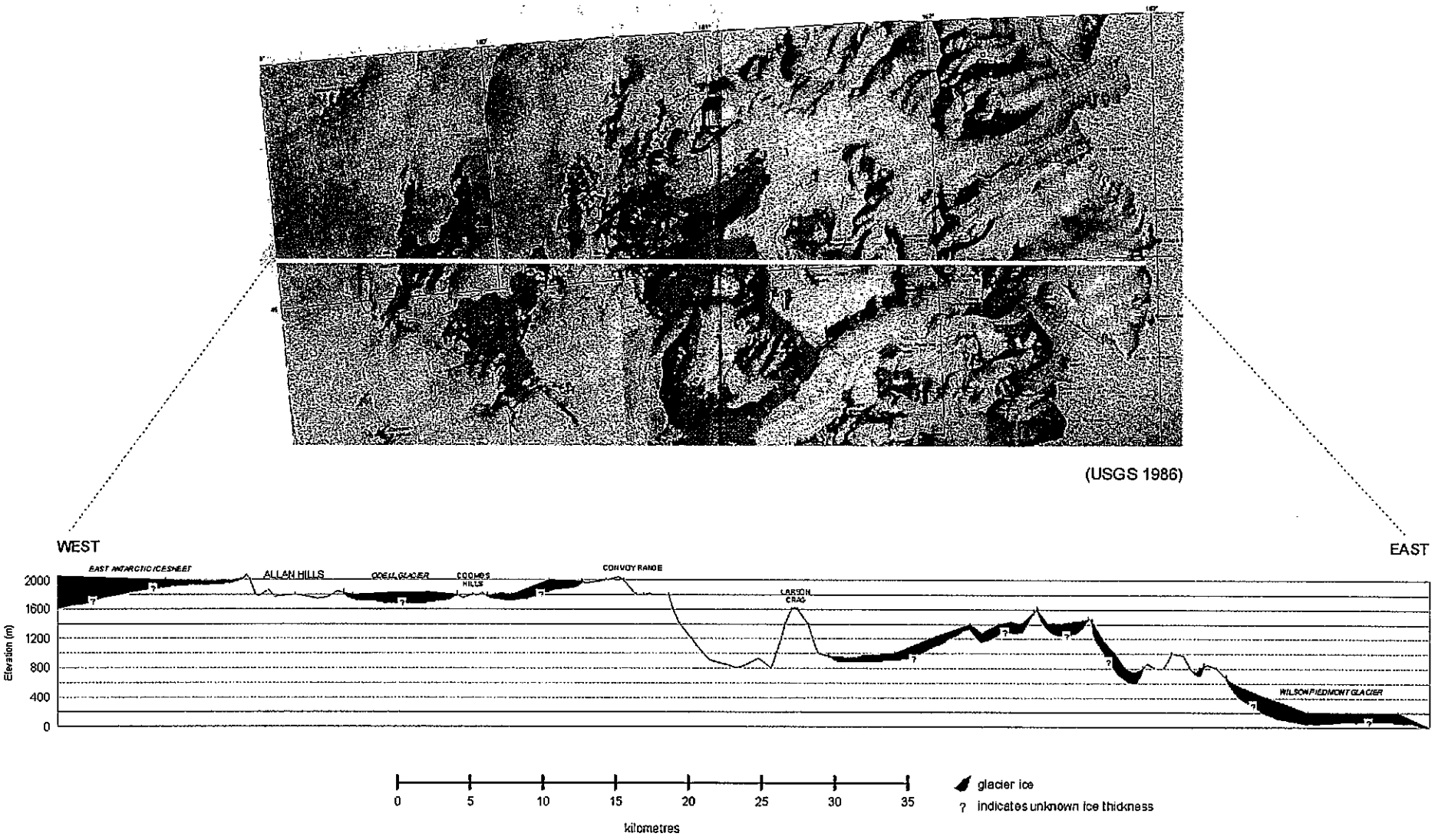


Figure 2. Cross-section of the Transantarctic Mountains showing the minimal elevation difference between the East Antarctic Ice Sheet and Allan Hills.

A concurrent study was done by Mark Lloyd-Davies, a Dutch student under the supervision of Dr. Jaap van der Meer based at the University of Amsterdam. Lloyd-Davies studied micro-scale subglacial deformational features of the Sirius Group at several sites including Allan Hills (Lloyd Davies and van der Meer 2001). Jeremy Mitchell conducted a study of ridge sets at Allan Hills to determine their depositional agent(s).

Recent glacial deposits near the edge of the Manhaul Glacier discovered by Barrett and Atkins during the 1997-1998 field season were studied in more detail this season. The deposits occur as sparse patches of crushed and comminuted material from the underlying Beacon Supergroup. This study was the focus of Atkins, while Barrett, Hicock and Holme contributed expertise as well. Work entailed documenting glacial abrasions on bedrock and stone surfaces and measuring their orientations. Additional work included delimiting the southern extent of the deposits in central Allan Hills using differentially corrected GPS. A benefit of mapping the distribution of these deposits was establishing their stratigraphic relationship to the Sirius Group. The study of these deposits was also a major focus for van der Meer and Lloyd-Davies.

Most fieldwork was conducted using standard geological field tools (e.g. rock hammers, compasses, cameras) with the exception of a Trimble Global Positioning System (GPS) rover unit to which we had access for three days. The system used was a Trimble Pro XL receiver with an MC-V datalogger running Asset Surveyor v. 3.16 which operated adequately in the cold conditions except for shortened battery life. However, preliminary attempts at differential correction post-processing of the rover data once back in New Zealand were unsuccessful. In these initial attempts, Trimble Pathfinder Office v 2.11 and then Trimble GPSurvey software were employed using McMurdo Station MCM4 base station. Although the MCM4 data provides full coverage for our rover data it proved to be incompatible with our rover data due to it lacking D1 doppler data. Subsequently, base station data was obtained from the Transantarctic Mountain Deformation Project (TAMDEF) through Mike Willis and Dr. Terry Wilson of The Ohio State University. The TAMDEF data provides coverage for 21 of our 26 sites enabling correction of those sites with Trimble Pathfinder Office v. 2.11 to <2 m horizontal precision at 95% reliability; the uncorrected rover data collected provides approximately 60 m precision.

FIELD LOGISTICS

TRANSPORT OPERATIONS

Cargo for our helo flights was largely contained in individual boxes, bags and packs. No special handling of cargo was necessary because the only dangerous cargo we had was 4 L of acetone and varnish, and fuel which was stored in the tail section of the helo with the exception of 60 L drums which were stored with the rest of the cargo. Total flight weights (estimated from weights given in the ANZ field manual and probably accurate to within 150 lbs.) are as follows:

Helo 1 (20/11/99 - insertion), aircraft - Bell 212, approx. weight 1600 lbs.

Helo 2 (06/12/99 - resupply 1), aircraft - Bell 212, approx. weight 1300 lbs.

Helo 3 (14/12/99 - resupply 2), aircraft - Bell 212, approx. weight 1470 lbs.

Helo 4 (18/12/99 - resupply 3), aircraft - Bell 212, approx. weight 1200 lbs.

Helo 5 (20/01/00 - partial pullout), aircraft - Bell 212, approx. weight 1600 lbs.

Helo 6 (21/01/00 - final pullout), aircraft - Bell 212, approx. weight 1600 lbs.

Note: the list does not include a flight which came in after Helo 4 to supply cargo which was mistakenly not included on Helo 4, nor does it include unplanned helos which removed retro.

EQUIPMENT

All equipment supplied by Antarctica New Zealand was received in good working order. For shelter we were issued Polar tents, Olympus tents and, for a brief time, an Endura tent. The Polar tents were excellent (and quite new). One of our event members slept in an Olympus tent and found it to be very noisy due to it flapping in the wind even though it was oriented correctly with respect to the prevailing wind and dug down 40 cm into the snow with a snow wall built to protect it. We had the Endura tent for only a few days in mid December when our party consisted of six members and we really appreciated its roominess compared to Polar tents, but it is not an easy tent to erect. We did not install the inner wall of the tent and found that it was warm enough without it at that time of year.

In general the suitability and performance of the field clothing issued to us by ANZ were excellent. Our fieldsite is at 1600 m elevation and experiences high winds. The clothing supplied to us enabled us to work well in the field despite these conditions.

Of all of this gear, only one crampon and two rubber seals for the thermoses failed during the field season.

FOOD

The 20 person-day ration box system provides good food and good nutrition and we do not have any major problems with it except for several food items being up to two years past their expiry dates.

COMMUNICATIONS

We had two separate radio setups: an HF unit to communicate with Scott Base, and two handheld VHF units for communicating line-of-sight amongst ourselves. During the last couple of weeks a wind storm broke the wire part of our HF aerial (without snapping the plastic casing) causing increased difficulty in contacting Scott Base. We didn't know the aerial was broken until we dismantled the camp at the end of the season. Until the aerial broke we had used 5400 kHz successfully, but had to switch to 2773 kHz for the remainder of the season.

A **very** useful addition to the VHF radios would be an inexpensive voltmeter so that we can tell how well the batteries are charged.

In general our communications with Scott Base were loud and clear. Scott Base's general efficiency in providing information during skeds was fine. We feel that it is not necessary to sked with Scott Base every 12 hours and that a sked every 24 hours would suffice.

We would like to have had a briefing at Scott Base from the Comms Operators to orient all event members with proper radio procedure. Although we did not experience any significant difficulties during our field season, all our knowledge relating to comms procedures came from the field manual.

SAFETY

No event members were injured nor were any significant safety issues raised during the 1999/2000 field season. The terrain at Allan Hills is somewhat irregular and quite rugged in places so care was taken at all times to ensure personal safety. We faced a difficulty in that we only had two VHF radios which had to be shared amongst our event members. The nature of our work was such that all event members wanted to go to different sites during the day so our solution was to discuss during breakfast our exact plans and intended locations for the upcoming day's activities and to give the radios to the two event members who would be going furthest afield from the camp. These members would conduct radio skeds with each other every two hours, with a maximum half hour overtime grace period before the other member(s) went to check on them. Although not ideal, this system proved sufficient and no problems were encountered. In retrospect we feel that each event member should have a radio.

WEATHER

The weather at Allan Hills during the 1999-2000 season did not overly hinder our party movements and decisions; the only significant restricting weather condition was wind. The average wind speed over the entire field season was approximately 10-15 knots, but daily conditions fluctuated considerably about this mean, with the strongest winds easily exceeding 50 knots (the maximum limit readable by our anemometer). On moderately windy days (25 knots gusting 35 knots) it became quite uncomfortable to remain standing at an outcrop for more than a couple of hours even when wearing full ECW gear because our hands got cold; nosewiper mitts were too cumbersome and were not used. During extreme weather conditions event members simply pursued tasks where they were less exposed. For the first couple of weeks the temperature was commonly –21 to –17°C. It gradually warmed to daily averages in the –12 to –8 °C range around Christmas and New Year's before slowly decreasing to –16 to –12°C by the time we left on January 21, 2000.

Particular note should be made here about weather conditions in Trudge Valley. It is windier there than Camp Valley, and in its eastern third the dominant wind direction is *easterly*, not southerly as it is in the rest of Allan Hills. This information should be passed on to subsequent field parties who intend to camp in Trudge Valley.

Date	Time (24hr)	Temp °C	Wind Spd (Kts)	Wind Dir.	Cloud Cover	Cloud Ht. (m)	Vis (m)	Sfc Def'n	Horiz Def'n	Wthr
30/11/99	0830	-16	10 gust 20	S	2/8	high	6000	good	good	
01/12/99	0830	-17	15 gust 30	S	0/8	unlim.	>10000	good	good	
01/12/99	2030	-18	10 gust 25	S	0/8	unlim.	>10000	fair	good	
06/12/99	-	-12	3 gust 4	ESE	8/8	>2000	>10000	good	good	
12/12/99	-	-14	8	N	8/8	1700	500	poor	poor	light snow
13/12/99	0745	-14	4 gust 5	S	8/8	1000	1000	poor	poor	
13/12/99	1200	-11	2	E	5/8	2000	5000	fair	fair	
13/12/99	2030	-12	0	-	5/8	1800	2000	good	good	
14/12/99	0700	-14	4 gust 7	NW	2/8	4000	8000	good	good	
14/12/99	0900	-14	10 gust 12	W	1/8	>4000	8000	good	good	
20/12/99	0830	-13	3	N	1/8	>2000	7000	good	good	
27/12/99	0700	-11	1 gust 4	NW	6/8	>2000	8000	good	good	
27/12/99	0900	-10	3 gust 5	NW	7/8	2000	>10000	fair	good	
27/12/99	1500	-12	8 gust 12	S	7/8	3000	-	fair	fair	
28/12/99	0700	-12	8 gust 12	SW	2/8	>3000	8000	good	good	
28/12/99	1000	-10	10 gust 12	SW	3/8	>2000	8000	good	good	
06/01/00	2030	-8	2	NW	1/8	>3000	>8000	very good	very good	
07/01/00	0700	-10	2	NW	0/8	NA	>8000	very good	very good	
14/01/00	0800	-11	3	SW	4/8	>3000	>8000	very good	very good	
14/01/00	1000	-11	3	NE	7/8	1,700	5000	good	good	
20/01/00	0830	-10	10 gust 15	S	<1/8	>3000	>10000	very good	very good	
20/01/00	1700	-10	5	N	1/8	>3000	>10000	very good	very good	
20/01/00	1900	-10	10 gust 15	S	3/8	>3000	>10000	very good	very good	
21/01/00	0830	-14	10 gust 12	S	1/8	>3000	>10000	good	good	

Note: Weather measurements were taken only on those days when helo visits were expected. These weather readings are NOT representative of average daily weather at Allan Hills as they were taken on days when a helo arrival from Marble Point was scheduled. These data represent conditions that are more favourable than average, showing wind speeds that are lower and cloud ceilings that are higher than on most days.

ADDITIONAL NOTES

During our stay at Allan Hills, we discovered an equipment cache at the east end of Trudge Valley which we believe to have been left behind by a 1972 expedition. We notified Scott Base (Peter Cleary) and asked what should be done with it, but no decision was made before our return to Scott Base in January. The cache consists of three or four wooden boxes (at least one of which contains food), three metal fuel canisters and an old, tatty pair of mountaineering boots. In addition there are many (perhaps twenty) rusty tin cans and other bits of trash tucked under nearby rocks. We suggest that the tin cans and other garbage be cleaned up but that the main cache be left for its historical significance. The site does not detract from the surrounding landscape and is in fact very difficult to spot; we only discovered it when one of our members happened to walk within 10 m of it.

GEOLOGICAL DESCRIPTIONS OF SIRIUS GROUP OUTCROPS, ALLAN HILLS

OUTCROP DESCRIPTIONS

Note. Mathematical uncertainties accompanying northing and easting grid coordinates and metres above sea-level (MSL) data are horizontal and vertical precision values at 95% confidence: those grid coordinates which do not display mathematical uncertainties were obtained by visually locating the sites on a geo-referenced airphoto in a GIS software package (ARCView) so their horizontal precision values are uncertain, but likely ± 50 m.

Section 1

(Grid coordinates: N 443130 ± 1.3 m, E 426304 ± 1.3 m; MSL 1660 ± 2.9 m)

Section 1 is located on the west side of Camp Valley, several hundred metres south of the snout of the Manhaul Glacier, at the end of a low ridge 1.3 m high, 4 m deep and 15 m long running 327° – 147° (bidirectional bearing). It is a small exposure about 5 m long x 1.3 m high which faces east-southeast across Camp Valley towards Boulder Ridge (Figure 2). The exposure consists of brecciated coal (Unit 1) about 1 m thick at the south end of the section and thinning to 50 cm at the north end, overlain by diamict (Unit 2) which is about 80 cm thick at the south end of the exposure, thinning northward to 5 cm and then thickening again at the section's north end due to compressional thickening of the unit along a reverse fault.

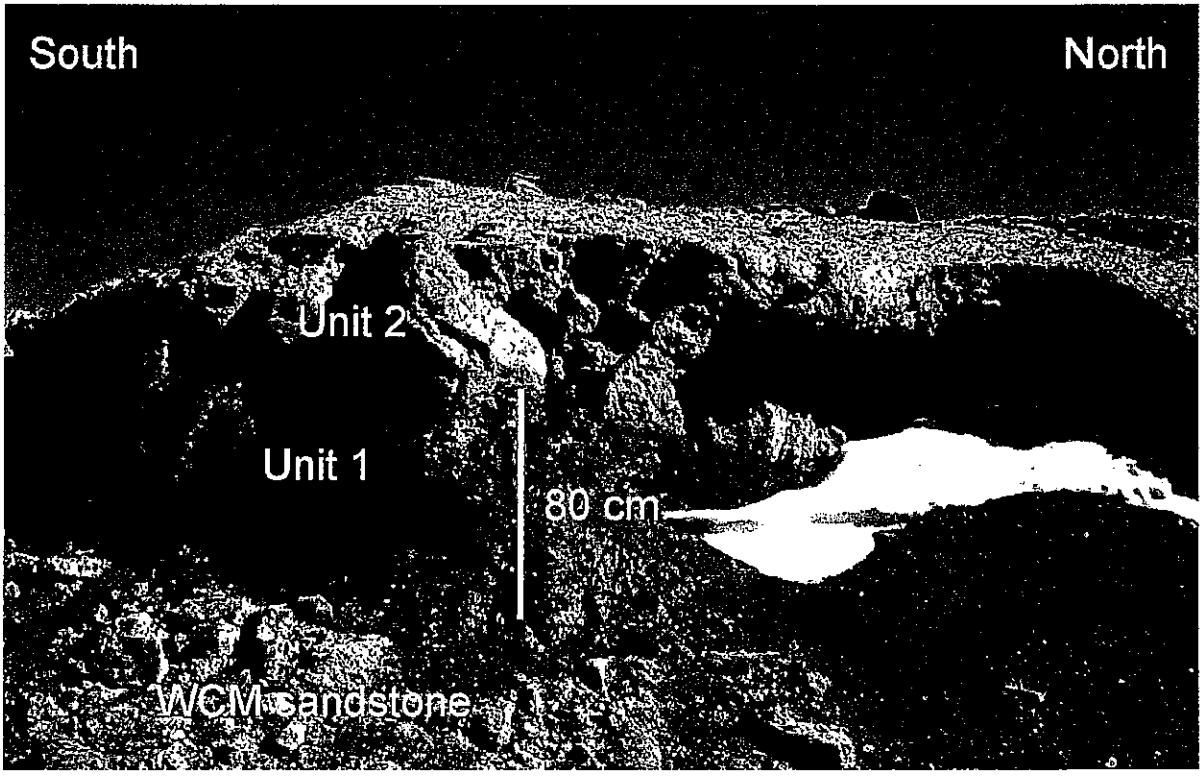


Figure 2. Section 1 showing diamictite overlying coal-rich breccia. North is to the right.

Unit 1 (brecciated coal unit): 0.5 – 1 m thick, contains almost exclusively coal fragments although some crumbly granule to cobble-size clasts of grey siltstone are also present in the lower quarter of the unit. A debris apron obscures the base of the exposure. The breccia is mainly clast-supported although it is matrix-supported in some places at the north end of the section. The matrix is grey and weathers to a light tan brown on the surface – the matrix colour is the same as that for the overlying diamict in both fresh and weathered states. In the mid part of the outcrop there is a wedge of diamict which has been forced into the coal breccia. (Figure 3) The wedge is 45 cm thick at its upper part, tapering downward to a point, and is about 1.3 m long. There is a similarly shaped and sized wedge of coal

breccia above the diamict wedge and on closer inspection a distinct shear plane can be seen running along the contact between the two, oriented 141/42 NE. The coal breccia to the south of the thrust is coarser (larger pieces of coal – commonly cobbles and pebbles) and more matrix-rich than that to the north of the thrust. At the north end of the exposure is an injection of diamict 20 cm wide that runs for 40 cm downward through the coal breccia before being obscured by a thick snow apron. The injection is matrix-rich and contains almost exclusively coal clasts from granules to small pebbles. The top part of the injection has been sheared in a northeast direction along a shallowly dipping plane oriented 129/09 NE. Note: this measurement is approximate because the plane had to be measured from the underside. Immediately overlying the shear plane is a coal bed which has been carried across the injection along the shear plane. About 8-10 cm above the shear plane is the coal/diamict contact (there is no contact immediately above the diamict injection because the diamict has been injected from diamict into coal).

Unit 2 (diamict): This unit is a matrix-rich diamict with a basal contact that is gradational over about 3 cm. There is a concave-down "bed" of matrix-rich coal breccia which arcs up from the contact until about 5 cm of diamict lies between its lower surface and the contact. The "bed" is about 3 cm thick and about 50 cm long with an irregular lensoid shape which curves down at its ends where it meets the contact. The diamict is unsorted with a sandy, medium grey matrix that weathers a light tan brown. South of the diamict wedge described in Unit 1 there are stringers of coal-laden matrix in the lower part of the diamict. Locally, clasts in the diamict range from granules to pebbles, and are subangular to rounded. Exposed in the top surface of the diamict are several boulders of Ferrar dolerite, sandstone and Mawson diamictite - one Mawson boulder, 1.4 m long by 0.6 m, is greyer than the others and has more millimetre-scale voids in it, possibly holes where mineral grains weathered out. There are joints in the diamict which are generally steeply dipping – one extends down through the diamict to the base of the exposed coal breccia. When looking at the fractures from the top of the exposure it is clear that they are all due to freeze-thaw.

On the top surface of a ridge about 10-12 m south of Section 1 there is a dolerite boulder about 50 cm x 30 cm exposed. The ridge is similar to the one exposed at Section 1 and is capped with the same diamict. A dolerite boulder there is heavily striated in several directions with many fine, <1 mm wide striae (see Appendix 3). Unable to determine cross-cutting relationships of the striae.

Measurements	
Fabric:	30 clasts in Unit 2 (see Appendix 2)
Striae:	20 striae from dolerite boulder exposed in Sirius Group diamictite on nearby ridge (see Appendix 3)
Structures:	3 (see Appendix 5)

Samples	(see Appendix 6)
VUW37429	block of diamictite from Unit 2
VUW37430	pebbles from Unit 2
VUW37431	block from striated boulder exposed in Sirius Group diamictite on nearby ridge

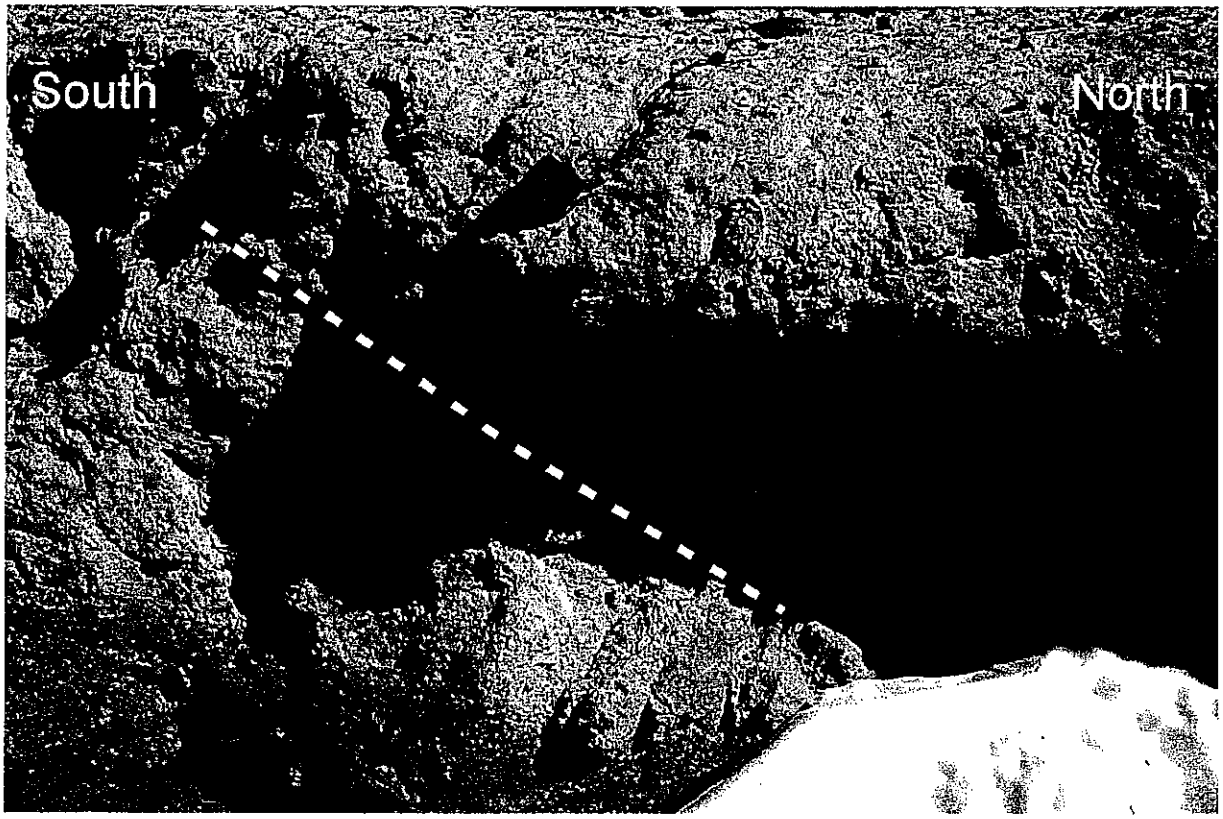


Figure 3. Section 1 showing diamict wedge forced into underlying coal breccia. Note compass for scale.

Section 2

(Grid coordinates: N 444840 m, E 425745 m)

This outcrop is in the northwest corner of the northwest platform about 20 m from the snout of the Manhaul Glacier (Figure 1). It is a small outcrop about 12-15 m long and less than 1.3 m high, consisting of brecciated Weller Coal overlain by brecciated Weller siltstone and coal that is overlain by a thin (0.5 m) veneer of diamict (Figure 4). There are large boulders of Mawson diamictite, dolerite and weathered quartzose sandstone up to 3 m long exposed in the diamict and its upper surface is littered with a dolerite lag.

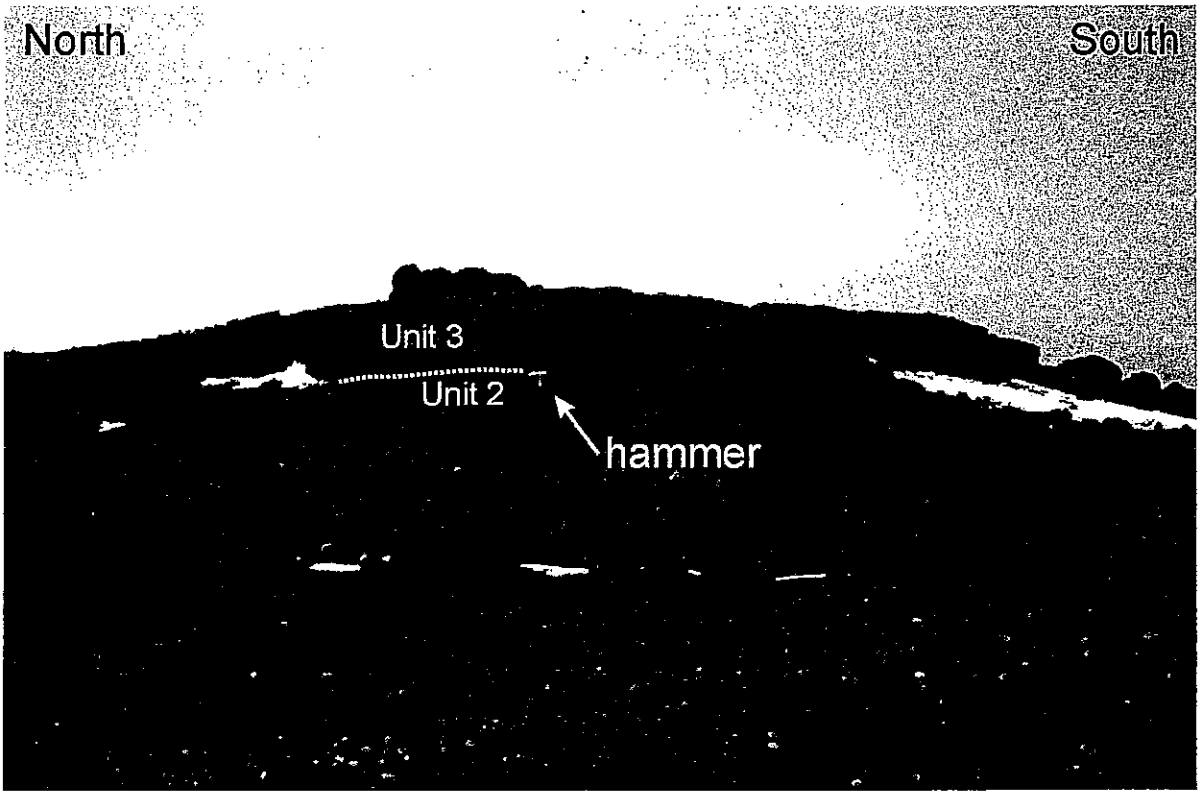


Figure 4. Section 2.

Unit 1 (coal breccia): The base of the exposure is largely obscured by slump so unit thickness is difficult to determine but is at least 20 cm thick. The breccia consists exclusively of coal and is clast-supported with a very thin grey matrix lining the clasts; clasts are angular to subangular.

Unit 2 (brecciated siltstone and coal): This unit is a brecciated zone 0-10 cm thick of siltstone and some coal with an irregular lower contact that is gradational over 5 cm (Figure 5). This breccia is unsorted and clast-supported with a light grey silty matrix. It appears to be a zone in which stratified siltstone has been comminuted. Clasts in the breccia are angular siltstone with a few angular to subangular pebble and granule-size pieces of coal.

Unit 3 (diamict): This is a medium grey sandy diamict 0-80 cm thick which weathers a lighter grey and has an irregular but fairly abrupt (gradational over 2 cm) lower contact (Figure 5). The deposit is not particularly hard which may be due to freeze-thaw action since the exposure faces southwest and is clearly eroding; there are many fractures running subparallel to the face. The diamict is moderately stony (about 12%) and ranges in thickness from 0-80 cm. Clasts in the exposure range from granules to cobbles 20 cm in diameter and are mainly subangular to subrounded and rounded. Striated clasts are present, but not abundant. No flow features or stratification are evident within the diamict. Planar structures were not measured because of the high degree of fracturing in the exposure face.

At the north end of the section where it curves around to be a north-facing exposure there is no light grey breccia (Unit 2); diamict (Unit 3) directly overlies coal breccia (Unit 1). The coal breccia here is >2 m thick and contains bedded boulder-size coal clasts up to 45 cm across. The fabric was easy to do because there are many (elongate) clasts and the diamict is poorly lithified.

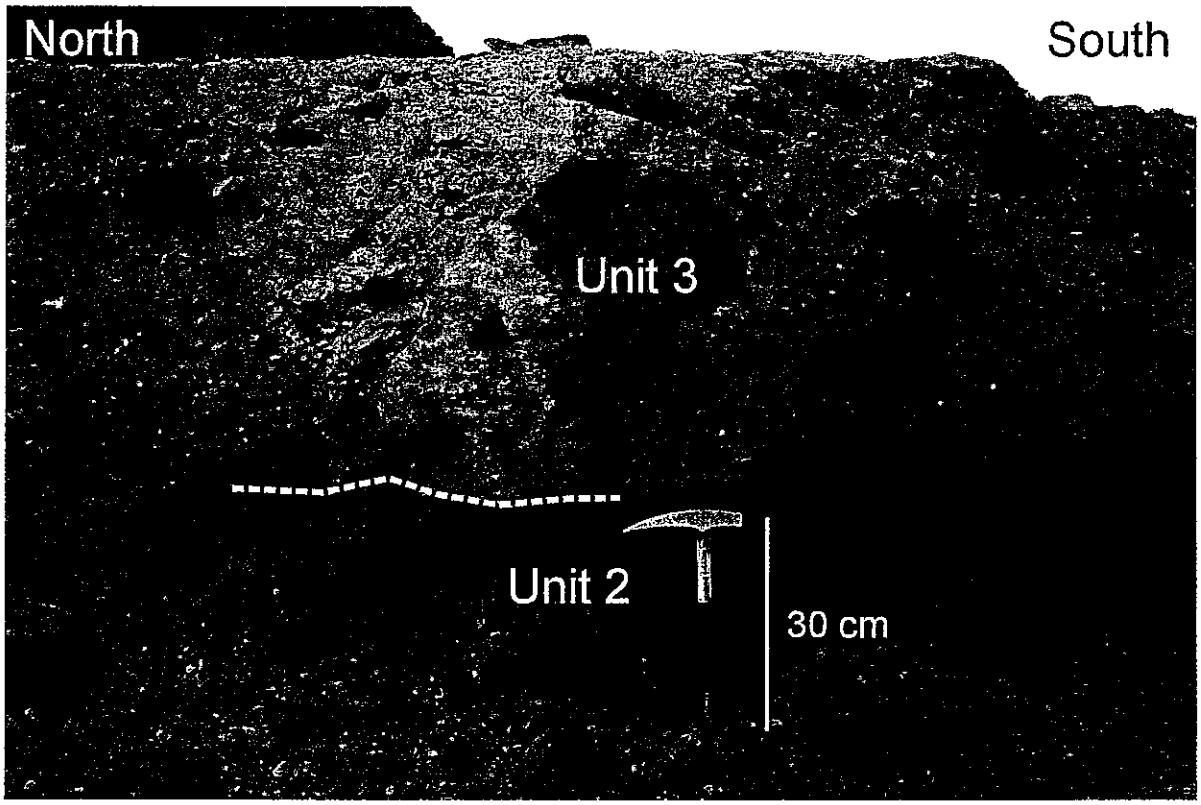


Figure 5. Section 2 showing Units 2 & 3 and nature of intervening contact.

Measurements	
Fabric:	30 clasts in Unit 3 (see Appendix 2)
Striae:	5 in Unit 3 (see Appendix 3)
Clast lee-ends:	7 in Unit 3 (see Appendix 4)

Samples	(see Appendix 6)
VUW37434	block of diamictite from Unit 3
VUW37435	pebbles from Unit 3

Section 3

(Grid coordinates: N 442718 ± 1.4 m, E 426074 ± 1.4 m; MSL 1697 ± 3.7 m)

The outcrop is several hundred metres south of Section 1 and straddles the central (Ferrar) dolerite dyke which runs westward from the north flank of Trudge Valley. The outcrop is about 100 m long and generally less than 3 m high, consisting of coal measures and sandstone beds of the Weller Coal Measures that are obscured by colluvium at their base and overlain by a diamictite unit; in most parts of the exposure the coal beds are 1-2 m thick. Stratigraphy at the exposure is greatest at the southern end of the exposure and varies considerably across it. There is much evidence of folding and thrusting due to compressive shear. Unit descriptions were begun in the southern portion of the outcrop where the stratigraphy is greatest. The units were then traced across the outcrop and any changes or significant features were noted in reference to metres north of the south end of the exposure.

Unit 1: This unit is carbonaceous siltstone which forms the ground surface in front of the outcrop and contains Glossopteris stem fragments. The unit is exposed across the southern two thirds of the outcrop but is covered by colluvium to the north.

Unit 2: This unit consists of deformed coal beds 1-2 m thick and is present only in the southern third of the exposure. Although deformed, the original bedding in the coal can usually be identified (eg. Figure 6). North of 38 m the coal has been brecciated like that above it.

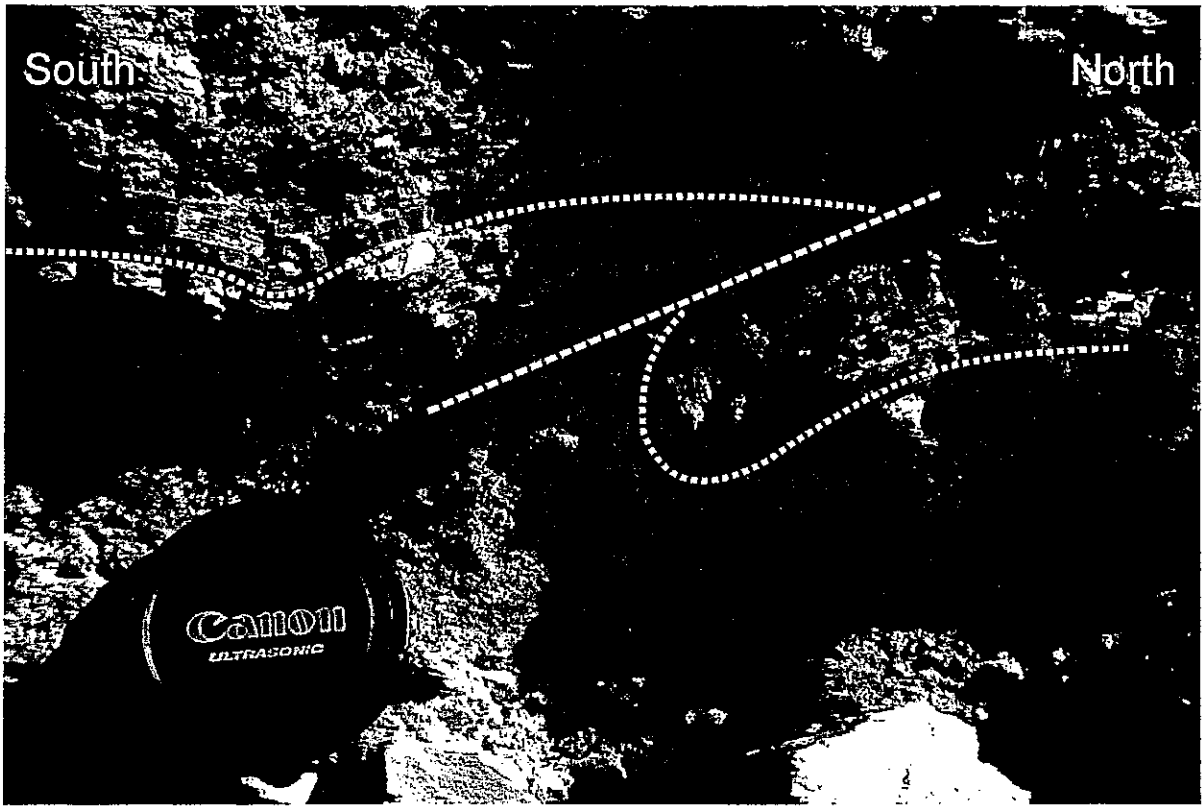
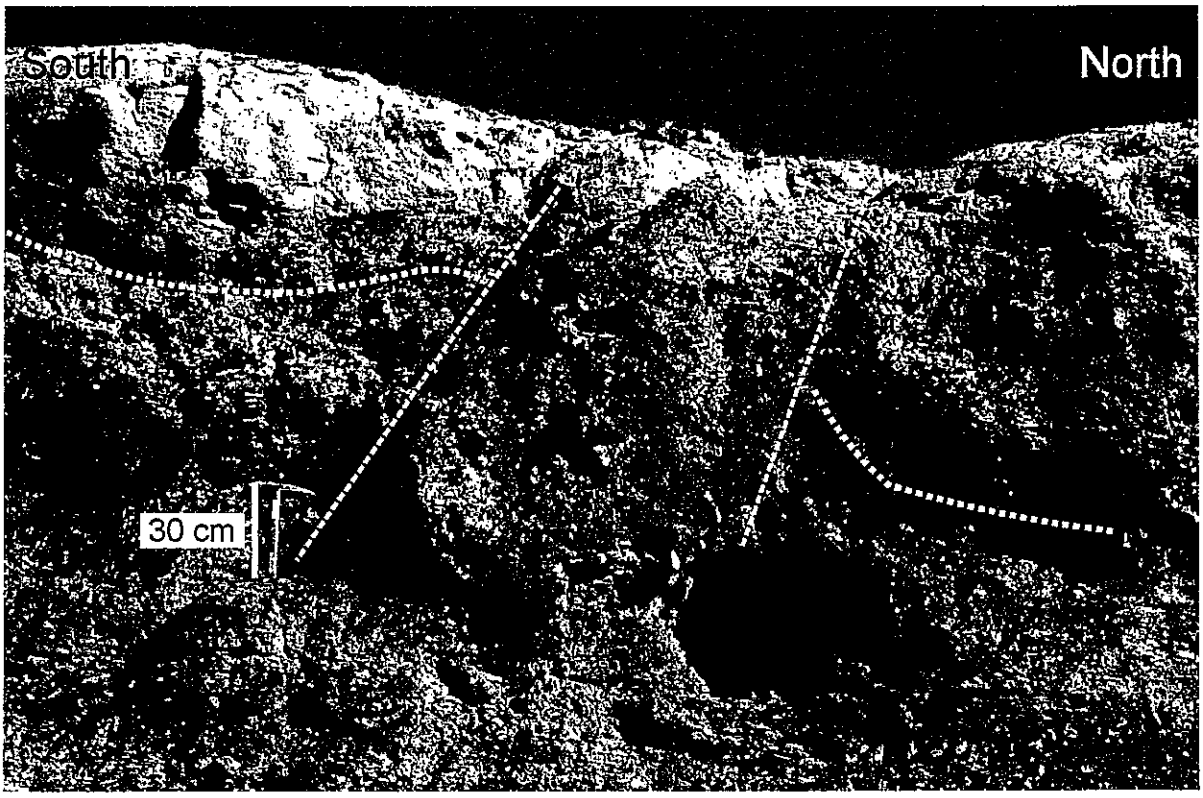


Figure 6. Small sheared fold in Unit 2 coal beds where bedding is still visible.

Unit 3: This unit is brecciated coal with an abrupt, regular lower contact. There are cohesive blocks of coal up to 1 m x 0.6 m within the breccia, but generally the fragments are pebble to cobble size. There is no easily discernible matrix, but some tan coloured sand is common throughout the unit. The unit thickens northward from 0.5 – 1.5 m. From 38 - 50 m the unit becomes more compacted and a colluvial apron covers all but the upper 3-50 cm of the unit. From 50 - 65 m the coal breccia interbeds with carbonaceous siltstone breccia and has Unit 5 diamictite as a matrix in places. At 66 m the unit is 1 m thick but becomes covered in colluvium at 68 m. At 30 m north there is a large folded and sheared portion of the coal beds (Figure 7). This folded and fractured portion is about 3 m wide and extends

from the upper part of Unit 2 up to the top of the exposure (which locally is about 1.8 m high). On either side of the feature, the overlying unit (Unit 4) terminates (where it has likely been forced upward due to the compression and then eroded). Locally, there are cohesive beds in Unit 3 which are folded upward on either side of a completely brecciated area about 1 m across where shearing has occurred. There are two main folds and their fold axes are: 273-093°, 268-088°. The 2XX direction is looking into the section with the fold limbs concave up and to the right. There is a gently dipping diamictite-filled shear plane which extends across about 6 m of the breccia and tapers from 10-0 cm. It is oriented 337/08 NE. A diamictite wedge intersects the shear plane near its distal end and is oriented 341/46 NE (it is difficult to measure because the face is not vertical here). There are little branches <1 cm thick which extend at a variety of angles from the wedge suggesting fluidity. 1 mm distal to where the wedge intersects the 'shear' plane the plane begins to curve upward slightly and dip in a near opposite direction and then about 1 m further along the plane bulges and becomes a diamictite pocket 40 cm thick x 70 cm long. The whole part of the 'plane' distal to its intersection with the wedge is extremely stony (40-50% clasts).



(Figure 7. Large sheared fold in Unit 3 coal beds)

Unit 4: This unit is a finely bedded medium and fine sandstone which is very fractured throughout and brecciated in places. The unit's lower contact is very irregular and ranges from abrupt at the south end of the exposure to gradational at 38 m north. Unit thickness is variable due to very irregular upper and lower contacts and ranges from 5 – 70 cm. The unit lenses-out north of 38 m and then reappears again at 66 m. In this northern portion, the lower 80 cm of the breccia is dominated by carbonaceous fragments, but is debris covered over much of its length and so may be thicker - in places, this part of the breccia is completely covered with debris. This carbonaceous portion grades upward into quartz sandstone-dominated breccia that ranges in thickness from 1.3 – 0 m. Matrix is sand and the breccia is clast-supported in parts and matrix-supported in others. In the southern 38 m of the unit, clast size (of the sandstone blocks) ranges from about 2 m to pebble size (~2 cm), but cobble-size blocks are the most common in the brecciated parts. North of 66 m, however, the breccia contains sandstone clasts from pebbles to boulders (30 cm) in size. At several points in the southern 38 m of the exposure diamict from the overlying unit has been forced between the sandstone clasts (eg. Figure 8). Across about 3 m of the northern part of the unit's exposure, and within 50 cm of the contact with the

overlying diamictite, clasts in the breccia are imbricated. The imbricated clasts are confined to distinct gently dipping 'linear' zones 5-10 cm thick. The orientation of these shear planes are the same as for sandy diamict-filled shear planes in the overlying diamictite.

Unit 5: This unit is tan brown diamictite that ranges in thickness from 15-80 cm. From 0 - 66 m north the basal contact is gradational (over 2-10 cm) because pieces of the Unit 4 sandstone are being entrained into Unit 5 and comminuted. Where the shear planes with the imbricated clasts are found in the underlying unit, the contact between the breccia and the diamictite is gradational over about 30 cm. From 66 - 77 m the unit's lower contact is abrupt and regular (a slightly dipping plane), then from 77-88 m it becomes gradational over thicknesses up to 45 cm and then is abrupt again to the north. The matrix is quite compacted with a sandy (medium to coarse sand) matrix and lacks stratification; from 77-88 m the diamictite is moderately compacted and coal-rich, with a tan greyish brown sandy matrix. Over most of its extent the diamictite is not very stony (7-10%) and clasts are angular (mainly just the coal fragments) to subrounded. Clast size ranges from granules to boulders 70 cm long, but are mainly small pebbles (1-2 cm) and granules. There are several boulders 50-80 cm long in the diamict between 38-66 m, most are subangular to subrounded with A-axis/B-axis >3/2; a couple of the boulders are heavily striated. From 77-88 m it becomes quite stony (about 15%) and clasts are generally

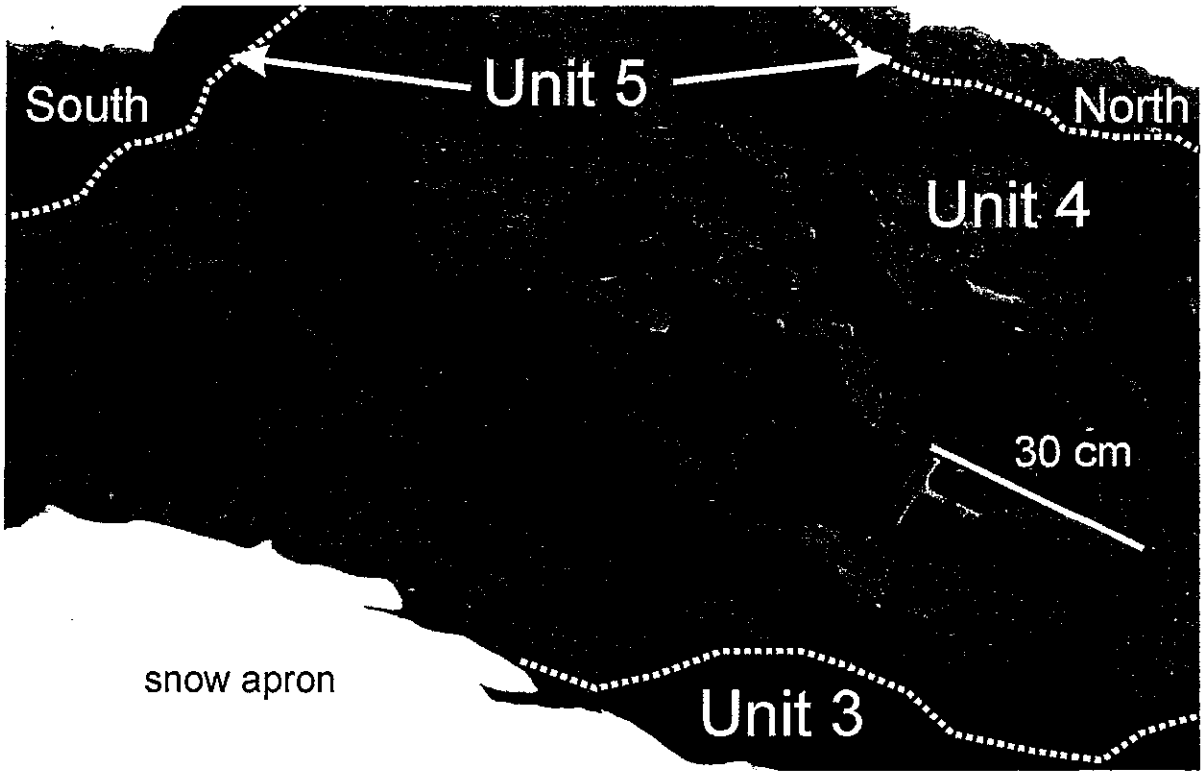


Figure 8. A fracture 2 m long in the southern 38 m of the outcrop that tapers downward from 20 cm wide at the top of Unit 5 to pierce Unit 3. Sediment in the fracture is stratified.

subangular to rounded, ranging from granules to boulders 1 m across. At 66 m, underlying a string of four boulders, there is a brecciated coal pocket from which a thin extension of coal has been pulled along a planar shear oriented 134/08 SW (Figure 9). The coal shear is 1 m long and thickens at one point to 8 cm thick although it is generally 2 cm thick. Adjacent to and about 20 cm above the shears in the breccia are shears in the diamictite that are about 1 m long and 4 cm thick. They contain a light tan brown sandy diamict which contrasts the surrounding greyish matrix. The shears are oriented: 093/17 S, (could only get one measurement, but two others are very similar).

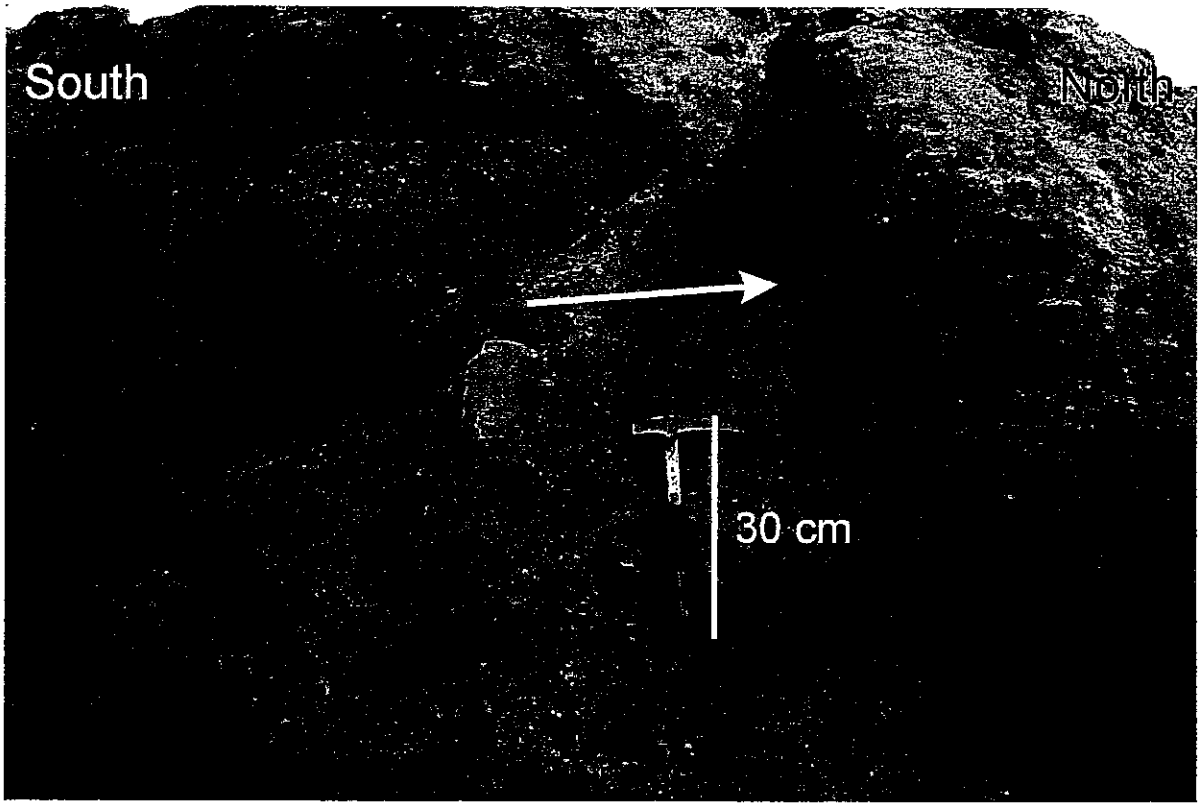


Figure 9. Coal pocket sheared along a fault plane through Sirius Group diamictite.

Measurements	
Fabric:	30 clasts in Unit 5 (see Appendix 2)
Striae:	22 in Unit 5 (see Appendix 3)
Clast lee-ends:	3 in Unit 5 (see Appendix 4)
Structures:	5 in Unit 3, 5 in Unit 4, 11 in Unit 5 (see Appendix 5)

Samples	(see Appendix 6)
VUW37436	block of diamictite from Unit 5
VUW37437	pebbles from Unit 5

Section 4

(Grid coordinates: N 441539 ± 1.4 m, E 426435 ± 1.4 m; MSL 1722 ± 2.9 m)

Section 4 is at the southeast end of the contra ridge. The exposure is 0.4 m high at the north end thickening to 1.7 m in the middle and then thinning to 1 m at the south end; the describable outcrop is about 12.4 m long (Figure 10). The outcrop consists of a quartzose granular sandstone of the WCM <0.5 m thick and overlain by an interstratified complex of diamicts up to 1.3 m thick which is overlain by diamictite. This full stratigraphy is only present in the central 3/5 of the exposure; unit contacts dip gently to the north where the sandstone is completely obscured by a colluvial apron while the beds in the interstratified unit lens-out in the southern portion leaving diamictite to directly overlie WCM sandstone.

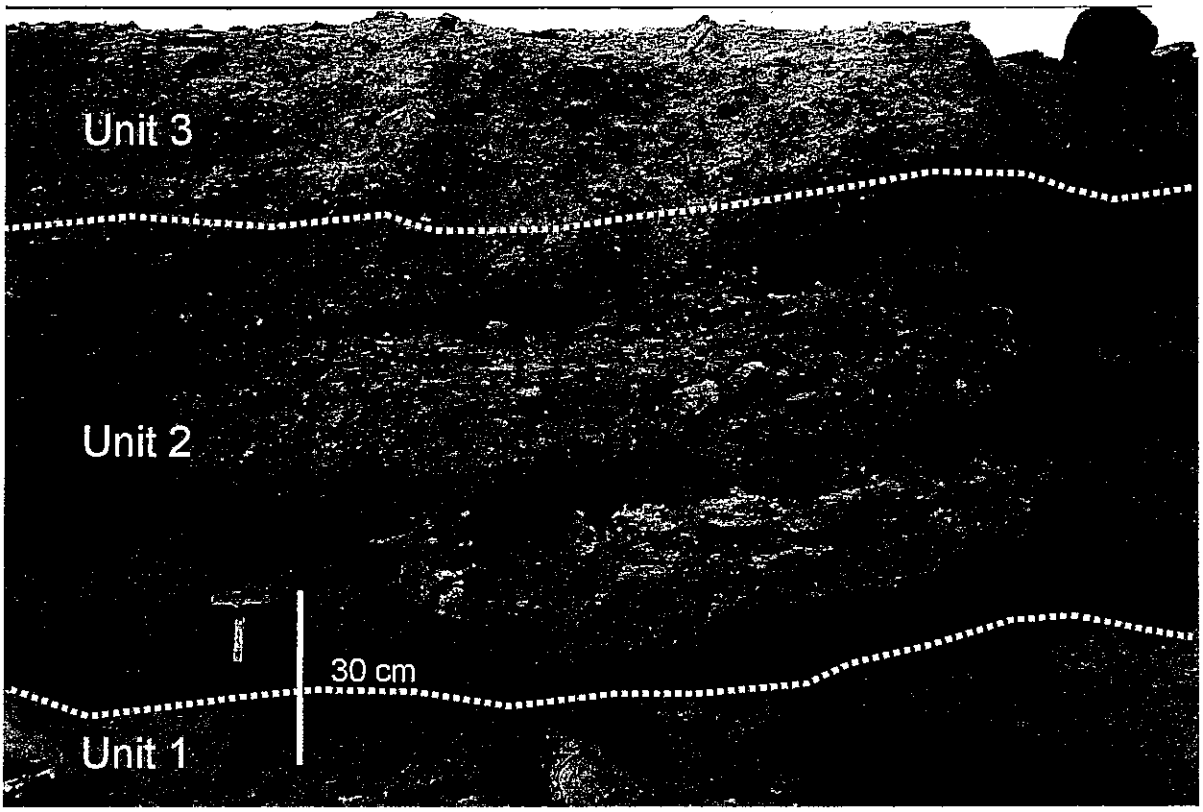


Figure 10. Section 4 showing inclined stratification.

Unit 1: This unit is highly fractured granular quartz sandstone of the Weller Coal Measures. It is less than 50 cm thick and has a colluvial apron at its base that obscures the lower contact. In the central portion of the exposure, the sandstone appears to have been irregularly eroded by the overlying unit to expose an underlying bed of carbonaceous siltstone; it is difficult to tell because debris obscures the outcrop here. The unit (and the rest of the exposed stratigraphy) dips gently (oriented 264/17 N) to the north where the colluvial apron becomes thicker and completely obscures the unit. There are numerous offset thin stringers or lenses of coal <20 cm long and about 1 cm thick in the unit.

Unit 2: This unit is largely a stratified complex of sediments, showing significant lateral changes in lithology (Figure 10). At the north end of the exposure, the unit is unstratified carbonaceous breccia; in the central part of the unit there are several lenses and discontinuous beds of breccia and sandy diamict; at the south end of the section, the unit consists of a breccia of carbonaceous siltstone which is itself overlain by a diamict consisting of coarse quartz sandstone that can be seen about 1 m north to be part of a stratified unit with flow (fluvial) features in it. The unit's basal contact differs across the outcrop from very abrupt and quite regular in the south to gradational in the central part of the exposure. In the central part of the section, where the sediments are most complex, the base of the unit

consists of a breccia of carbonaceous siltstone or shale which reaches 70 cm thickness in the north and 50 cm thickness in the south. The breccia's matrix generally consists of crushed carbonaceous material. Clasts (or rock fragments) range from granule to cobble-size, but pebbles are most common. A lens of sheared and occasionally brecciated laminated coal and sandstone beds occurs in the lower central part of the exposure and is up to 40 cm thick and about 5.2 m long with abrupt, irregular contacts (Figure 11). About 15 cm above the lens is a series of tan brown, stony sand beds interstratified with the carbonaceous breccia. Above this is about 15 cm of carbonaceous breccia and then the contact with the overlying Sirius Group diamictite (Unit 3). The lenses within the interstratified section are irregular, often diffuse, and have gradational contacts. This interstratified section extends across about 3.5 m of the central part of the section. At the south end of the outcrop the carbonaceous lenses pinch out into the sandstone breccia/diamict mentioned earlier. The uppermost 15-20 cm of the carbonaceous breccia that underlies the Sirius Group has the trace of a shear plane which extends to the north of the interstratified unit.

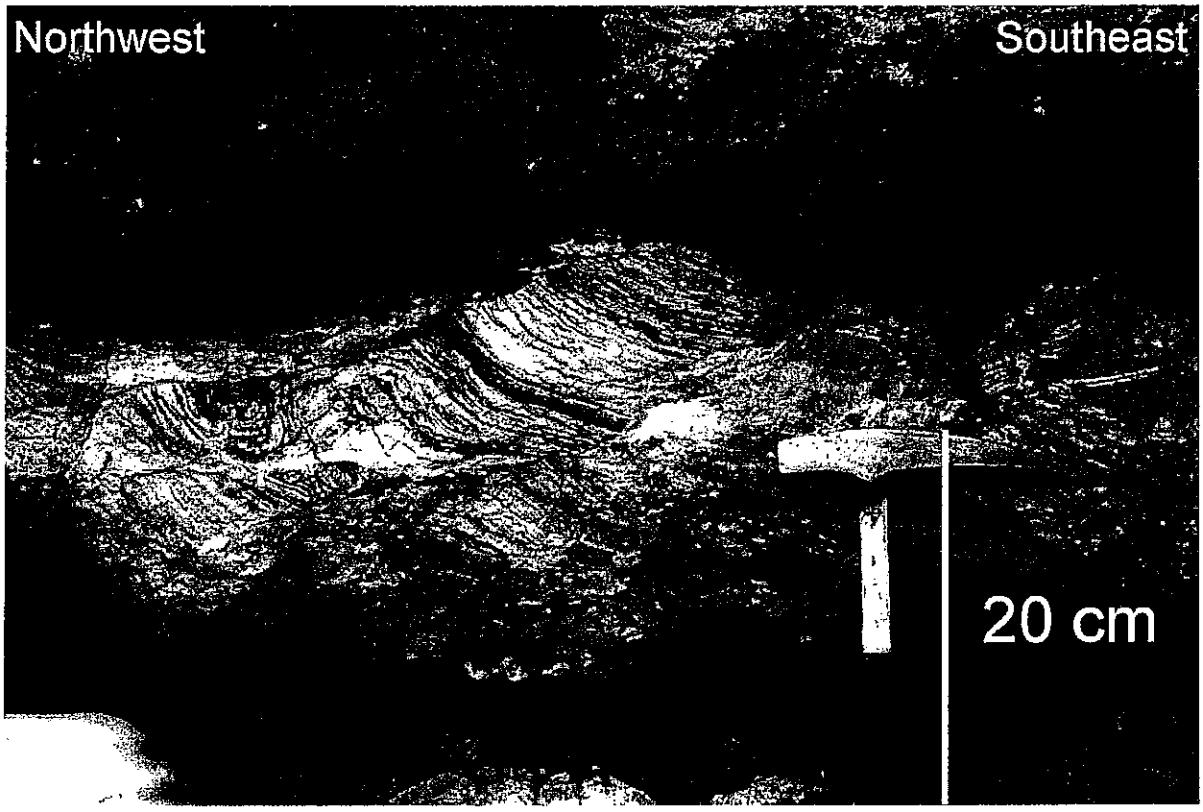


Figure 11. Sheared lens of laminated coal and sandstone.

Unit 3: This unit is stony (about 12%), extremely indurated diamictite with a basal contact that varies from regular and gradational to abrupt – the most gradational contact is about 8 cm. The unit is about 1 m thick at the north end and thins southward to 40 cm thick. The diamictite has a silty sand matrix which is medium grey when fresh and weathers a tan brown. Clasts are from granules to boulders 45 cm long locally, but larger clasts are present in situ nearby. Many clasts are striated and clasts in general are subangular to subrounded. A cobble can be seen in the top of the carbonaceous breccia that appears to have been emplaced there from the overlying diamictite based on the amount of diamictic material surrounding it (Figure 12). The diamictite is massive, but some shear planes can be seen: 117/08 SW, 202/24 NW, 170/78 W – this is a fracture that runs down into the basal sandstone unit. At the south end of the section there is a 1.3 m long diamict-filled fracture oriented approximately 278/82 N that penetrates down through all three units. The fracture is 45 cm thick at the top of Unit 3 and tapers downward through the underlying sandstone diamict (Unit 2) to the top of the carbonaceous breccia. It is about 3 cm thick where it passes through the carbonaceous breccia and then thickens to 18 cm when it enters the fractured sandstone at the base of the exposure where it tapers downward to 6

cm wide before being debris-covered. Material in the fracture is diamict similar to Unit 3 but has a crudely stratified appearance parallel to the strike plane. The portion of the fracture overlying the carbonaceous breccia does not contain any of the carbonaceous breccia, but the portion of the fracture within and about 20 cm below the carbonaceous breccia unit contains about 50% carbonaceous breccia clasts (50% of the total number of clasts).

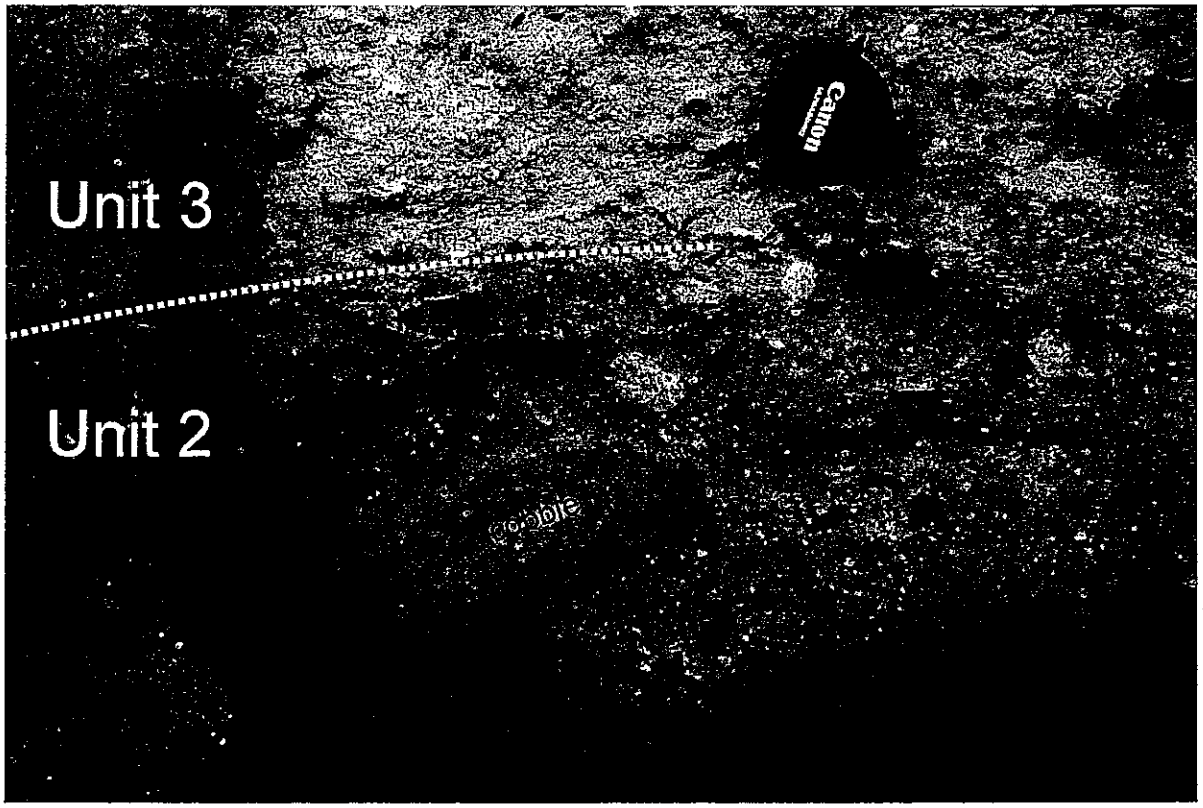


Figure 12. Cobble in Unit 3 emplaced in a water-saturated material.

Measurements

Fabric:	30 clasts in Unit 3 (see Appendix 2)
Striae:	9 in Unit 3 (see Appendix 3)
Clast lee-ends:	10 in Unit 3 (see Appendix 4)
Structures:	1 in Unit 1, 2 in Unit 2, 3 in Unit 3 (see Appendix 5)

Samples	(see Appendix 6)
VUW37444	block of diamictite from Unit 3
VUW37445	pebbles from Unit 3

Further notes:

In the Weller Coal Measures exposed in the cliff below section 4 there is a lot of diamict and granular mud that has been injected into the sandstone and coal beds.

About 30 m north of Section 4 an outcrop 9 m high reveals Weller Coal Measures overlain by a crudely stratified complex of heavily deformed sandstone and coal that is overlain by Sirius Group diamictite which is relatively clast-poor in its lower part and very stony in its upper part.

Section 5

(Grid coordinates: N 442317 ± 1.2 m, E 426614 ± 1.2 m; MSL 1695 ± 2.9 m)

This exposure is at the northwest edge of the contra ridge and is 23.2 m across by 3.2 m high, but the mid-part is heavily weathered and unfit for description (Figure 13). The outcrop will thus be described in two parts: the main exposure site, 5a (Figure 14), at the southern end of the outcrop where both total stratigraphy and Sirius Group are thickest shall be described first, followed by a smaller site, 5b, at the north end. The complete stratigraphy at the site consists of Weller sandstone that forms the platform in front of the exposure, overlain by a carbonaceous breccia that is debris covered at its base and overlain by Sirius Group diamictite.

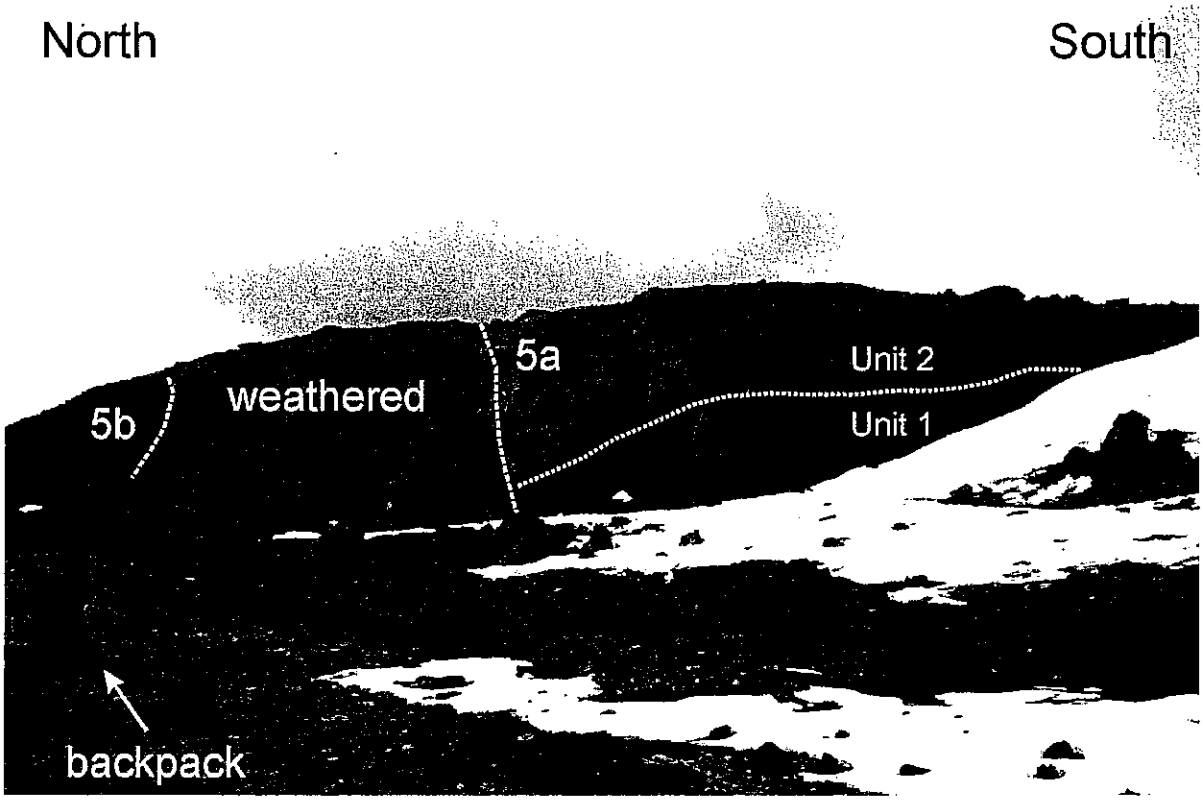


Figure 13. Section 5.

Section 5a

Unit 1: This unit is extremely brecciated carbonaceous siltstone, coal and sandstone that ranges in thickness from about 30 cm at the south end of the exposure to 1.6 m to the north. The matrix generally appears to consist of comminuted carbonaceous siltstone which gives it a bluish grey colour, however, in many places it is lighter brown where sandstone dominates, or darker grey where coal is more prevalent. The breccia is very consolidated and very hard to dig in; it is much easier to shatter the coal and shale/siltstone clasts than the matrix that holds them in place. Clasts range in size from granules to cobbles 15 cm across and are angular except for some subangular sandstones. The breccia is stratified where gently dipping shears have carried material across the exposure and concentrated material of a given lithology within the shear zone. The dominant shears that stand out are a 10 cm thick coal-dominated shear oriented 200/07 NW, a sand and coal dominated shear 20 cm above the first also oriented 200/07 NW, and a thin (2 cm) fracture that extends from the overlying Sirius Group diamictite down to the coal shear and is oriented 320/42 NE. There is a diamictite-injected fracture that intrudes down into the breccia and is buried by debris at the base. It is 15 cm wide at the top and then splits into two branches that taper downward. Orientations: north branch 250/66 NW, south branch 138/84 SW. Note: diamictite in the fracture is identical to the overlying Sirius Group diamictite.

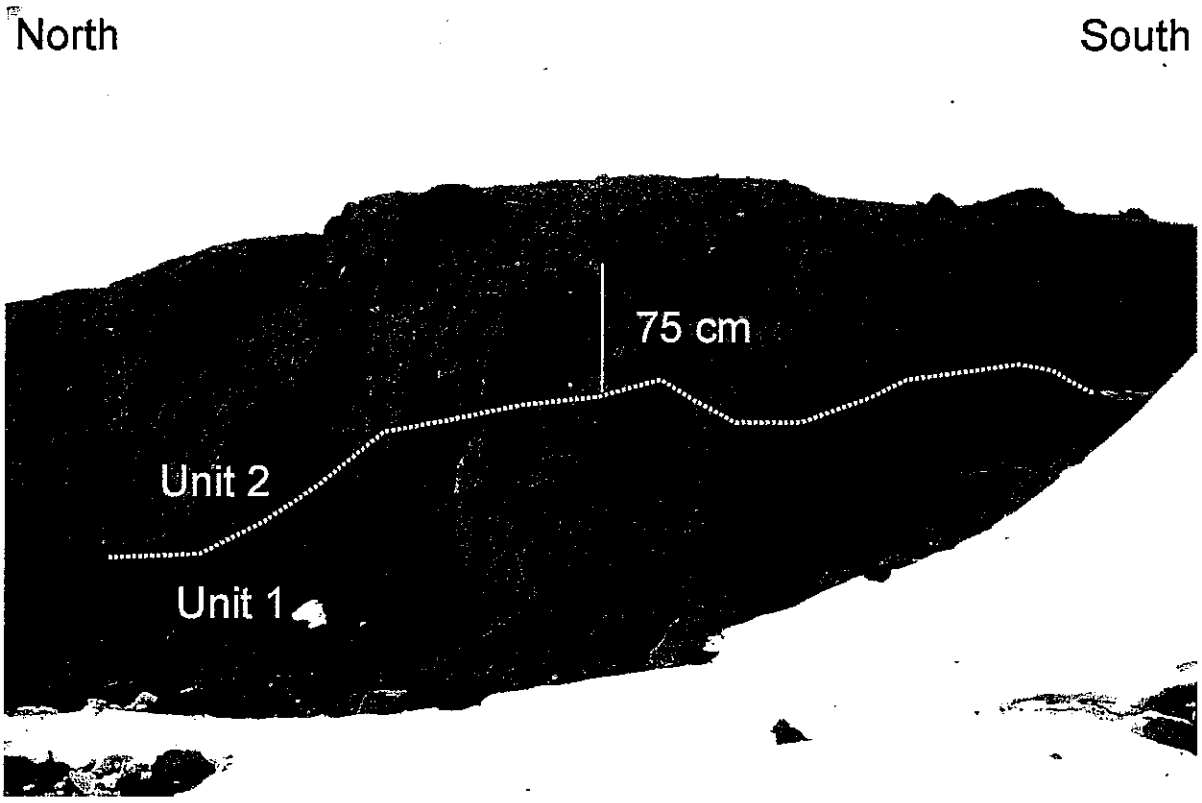


Figure 14. Section 5a.

Unit 2: This unit is a light grey diamictite that weathers a light tan brown. The diamict ranges from about 50 cm thick at the south end to about 3.2 m in the middle. The diamictite's lower contact is irregular and is generally gradational over about 3 cm, but becomes abrupt in places and is gradational over 40 cm at the south end of the exposure. The contact is inclined (orientation 289/13 NE) over most of the exposure, but it is very irregular and curved where the diamict has eroded down into the breccia. The matrix is a mud-rich sand which may account for its high degree of induration. The diamict is not very stony (about 7%) containing clasts from granules to boulders 50 cm long locally although larger boulders can be seen in situ on the surface nearby (on the walking surface of the contra ridge). The diamict is not stratified but there are several fractures evident and at the lower contact with the breccia some small shears can be seen. The face here is not particularly fresh so many fractures appears as cracks a few centimetres across. Within a fracture immediately above the breccia at the north end of the exposure there are several stratified, well-sorted and thin sand beds. These beds are curvilinear with orientations ranging from about 334/05 NE to 334/20 NE. This feature occurs where the diamict has apparently eroded down into the breccia and follows the curve of the contact.

Section 5b

This is a small outcrop 6 m across by 1.6 m high at the north end of the exposure that lies north of the weathered part of the face. The entire exposure consists of Sirius Group diamictite (Unit 2 at Section 5a) which is even less stony than that at section 5a. The matrix is highly indurated and compacted, medium grey muddy sand that weathers a light brown. Clasts are almost exclusively granules and small pebbles <1 cm except in the lower 60 cm of the exposure where some larger pebbles are present. Throughout the diamict there are occasional larger pebbles and even cobbles, but these are concentrated mainly in the bottom part. No stratification can be seen except along inclined shear planes. There is an inclined, abrupt, linear colour change along what appears to be a shear plane oriented 055/34 SE at the north end of 5b. In the lower part of the south end of 5b there is a very distinct shear plane oriented 321/28 NE below which diamict like that above the shear plane has flow features.

Comment about the contra ridge.

There appears to be a gradational change from a less stony diamictite at the north end of the contra ridge to a very stony diamictite that crops out near the south end of the ridge. Most of the change appears to occur in the northern part of the ridge, based simply on the fact that the Sirius Group exposed on the contra ridge appears to be quite stony over most of its length. There is a lot of lag which covers the surface of the ridge and obscures the underlying Sirius Group, but there is a little gap in this cover near the north end that might be where it occurs if it is abrupt, but there is no Sirius Group in the gap to check – it does seem to be stonier on the south side though. However, it becomes extremely stony in outcrops near the south end of the contra ridge.

Measurements

Section 5a

Fabric:	30 clasts from Unit 2 (see Appendix 2)
Striae:	12 from Unit 2 (see Appendix 3)
Lee-ends:	11 from Unit 2 (see Appendix 4)
Structures:	5 from Unit 1, 11 from Unit 2 (see Appendix 5)

Section 5b

Structures:	3 from Unit 2 (see Appendix 5)

Samples	(See Appendix 6)
VUW37446	block of diamictite from Unit 2
VUW37447	pebbles from Unit 2

Section 6

(Grid coordinates: N 440200 m, E 429100 m)

This outcrop occurs along the south/southwest rim of the major gully in the southeast corner of Trudge Valley where the Sirius Group forms a continuous exposure extending for about 300 m around the gully rim and is snow covered in many places. There is a pink- and grey-banded diamict present across about half the entire exposure, generally in the eastern to central portion where the total thickness of Sirius Group deposits is greatest. The pink-banded diamict is present from about 30 m west of the end of a large dolerite dyke and runs westward to the other side of the gully from which the following description is taken. The description site (in the western-central part of the exposure) was chosen where the pink bands are most numerous. This portion of the exposure is 12.4 m high from the basal contact with underlying Feather Conglomerate (locally a pebbly, coarse-grained sandstone) to the top of the exposure (Figure 15). The entire exposure face is gullied with mini snow erosion channels and networks making the exposure rather difficult to describe because there is not a vertical flat surface anywhere except in a notch about 50 cm wide and 1 m long near the top of Unit 2.

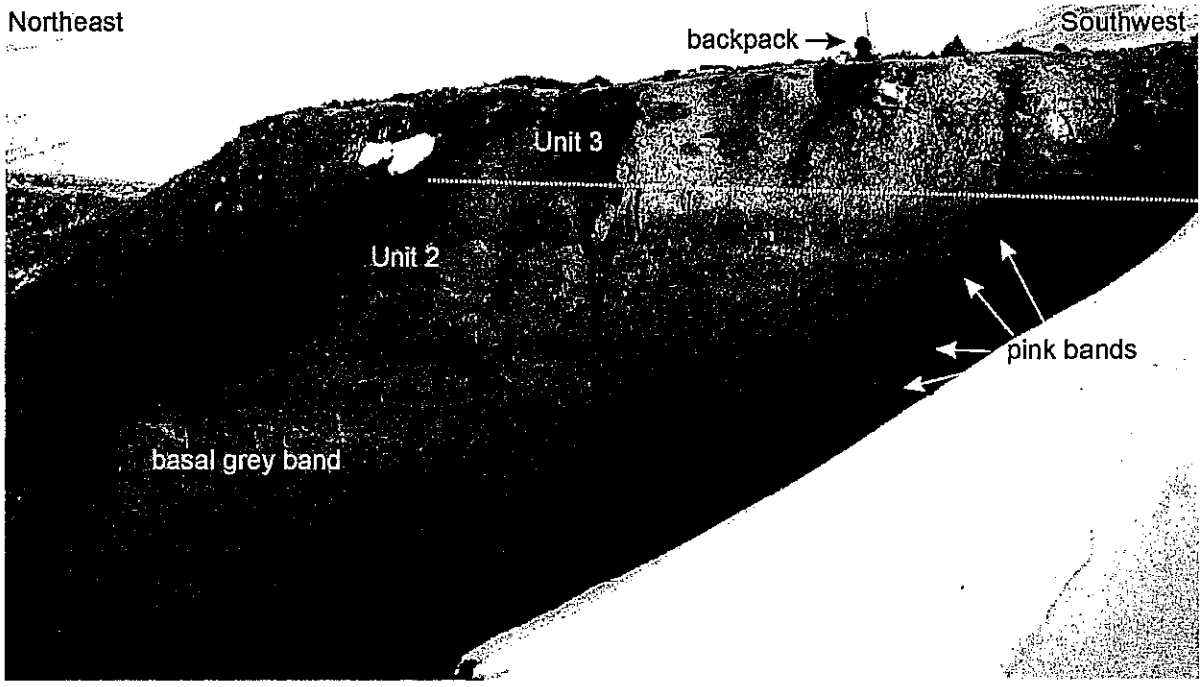


Figure 15. Section 6 showing banding in Unit 2; backpack at top for scale.

Unit 1: This unit consists of a comminution zone up to 1 m thick and consisting largely of comminuted angular cobbles of Feather Conglomerate in a friable sandy matrix and is slightly darker brown than the overlying unit. This unit can be traced across about 2 m of the exposure and occurs at the downvalley (northeast) end where the exposure rapidly thins out on a nose of the Feather Conglomerate.

Unit 2: This unit consists of bands of alternating grey and pink diamict and is 8.6 m thick. The lower 5.4 m of the unit is a sandy brownish grey diamict with a basal contact that is gradational over 3 cm, regular, and oriented 063/46 SE. The matrix in this part of the unit is muddy sand and moderately consolidated. Clast content is <10% (perhaps even as low as 5%) it is hard to tell since the clasts are so small. Clasts in the diamict are mainly granules to small pebbles <2 cm long, with rare cobbles and boulders; clasts are mainly subangular to rounded. Many white quartzites (mainly granules and small pebbles) are rounded to well-rounded, but these are likely reworked from the Feather Conglomerate. Above 5.4 m the grey diamict alternates with four bands of pink diamict - for the purpose of sampling and measurements, the bands are referred by their colour and order up from the base of the unit (e.g. 3-pink is the third pink diamict band up from the base of the unit). In general, the pink bands are 30-50

cm thick and parallel to subparallel, running horizontally or dipping very gently northeast across the face; the bottom-most pink band is oriented 049/14 SE while the topmost pink band oriented 015/36 SE. Diamict in the pink bands appears identical to that in the grey bands, other than in colour which is still pink when freshly broken off so the colour is not due to weathering. Contacts between the bands are regular and generally gradational over 5-10 cm, with the exception of the base of the topmost pink band which is abrupt.

Unit 3: This unit is 3.8 m thick, overlies the 5-grey (topmost grey diamictite band) subunit of Unit 2 and is an unstratified, sandy, slightly greenish brown diamict. The unit's lower contact is regular across the exposure and is gradational over about 10 cm. (When looking at the exposure from 30 m distance it is possible to visually differentiate between this unit and the one below because this one is a darker, slightly greenish grey colour and is markedly stonier.) The diamictite is clearly less compacted and stiff than the underlying unit and displays no fissility. Clast content is about 12-15% with clasts ranging from granules to large boulders 2-3 m long. Clasts are angular to well-rounded (well-rounded clasts are mainly quartzite pebbles from the Lashly and Feather Formations). The diamict is quite fractured and often will come away from the face in blocks along fracture planes, but this fracturing is likely due to slope failure activity. Little evidence of deformation is apparent, but the erosion on the outcrop face could easily obscure any that is present. The sole sign of deformation is a clast which has been sheared into two pieces along a fracture oriented 036/41 SE - the upper part of the clast has moved down dip about 3 cm in the direction 132° (Figure 16). On the top surface of the unit (and the exposure) there is a little lens of clast-supported granules about 40 cm long and 0-3 cm thick lensing out at both ends. From an incision in its middle an orientation can be measured, 114/70 SW.

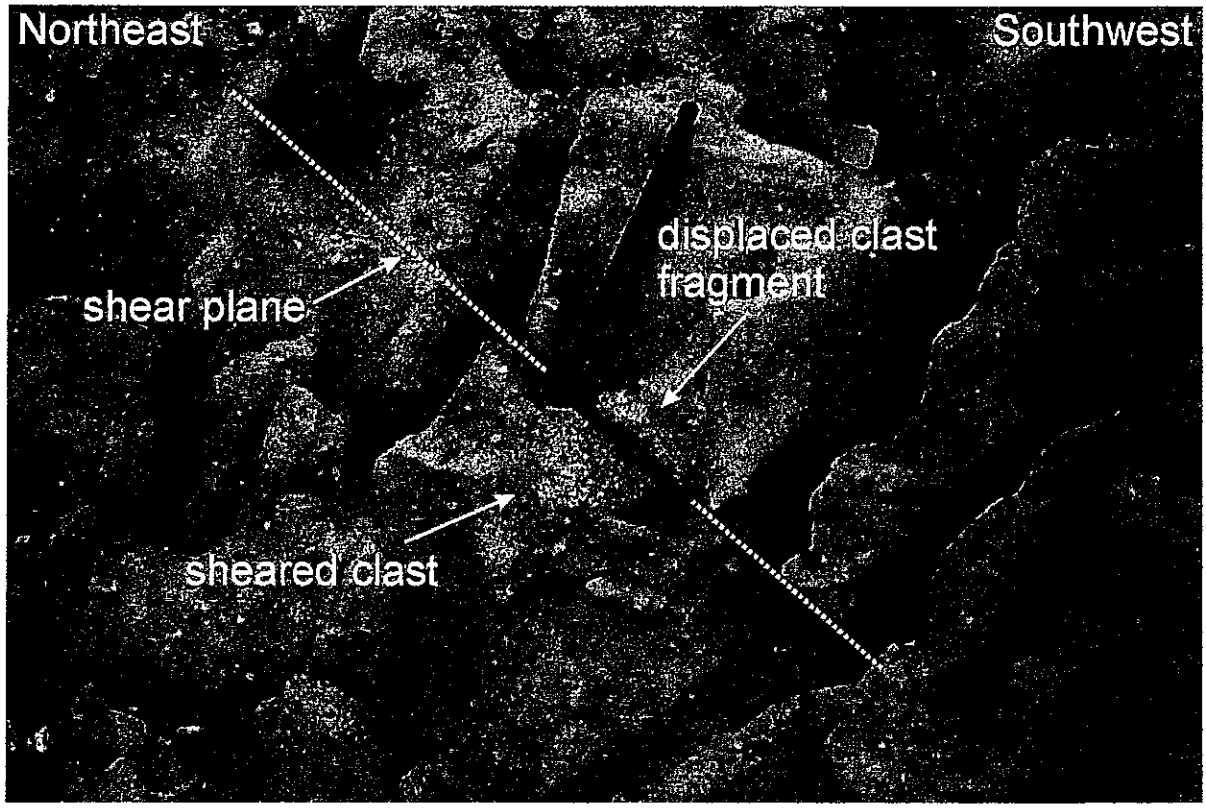


Figure 16. A sandstone (Feather Conglomerate) clast sheared in two pieces and displaced along a shear plane. Displacement direction is oblique and into the page from the left. Pencil for scale.

Measurements

Fabric:	30 clasts from 1-grey subunit of Unit 2, 30 clasts from Unit 3 (see Appendix 2)
Striae:	15 from Unit 2, 10 from Unit 3 (see Appendix 3)
Clast lee-ends:	4 from Unit 2, 3 from Unit 3 (see Appendix 4)
Structures:	10 from Unit 2, 7 from Unit 3 (see Appendix 5)

Samples	(see Appendix 6)
VUW37454	block of diamict from 1-grey subunit of Unit 2, 1.6 m above basal contact with Feather Conglomerate
VUW37455	pebbles from diamict from 1-grey subunit of Unit 2, 1.6 m above basal contact with Feather Conglomerate
VUW37458	block of diamict from 4-pink subunit of Unit 2, 8.3 m from basal contact with Feather Conglomerate
VUW37459	pebbles from 4-pink subunit of Unit 2, 8.3 m from basal contact with Feather Conglomerate
VUW37460	block of diamict from Unit 3
VUW37461	pebbles from Unit 3

Section 7

(Grid coordinates: N 441844 ± 1.9 m, E 427822 ± 1.9 m; MSL 1642 ± 4.8 m)

This outcrop is located on the east flank of a large gully cut into the eastern edge of the Triangle (Figure 17). The exposure is approximately 100 m long and has formed where slope erosion has produced a fairly regular and vertical face exposing sandstone and carbonaceous strata of the Weller Coal Measures overlain by Sirius Group diamictite. When seen from a distance of about 30 m grey, brown and pink colour bands approximately 1 m thick, can be seen in the diamictite, but at the outcrop face the colour banding is very faint and difficult to discern. Pink-tinted sediment drapes over portions of the lower half of the diamict where water has washed matrix from pink-tinted diamict down to partly obscure underlying diamict. Cliff height and stratigraphic thickness are greatest at the southern end of the exposure where much of the following description was done. There is a gap several metres wide in the midpart of the section which divides the exposure in two and provides good access to the middle stratigraphy. Immediately south of the exposure the slope is very irregular and gullied and the Sirius Group occurs only on, or near the top of, the cliff. At this transition in slope types an end-wall is formed which extends near-orthogonal from the exposure face.

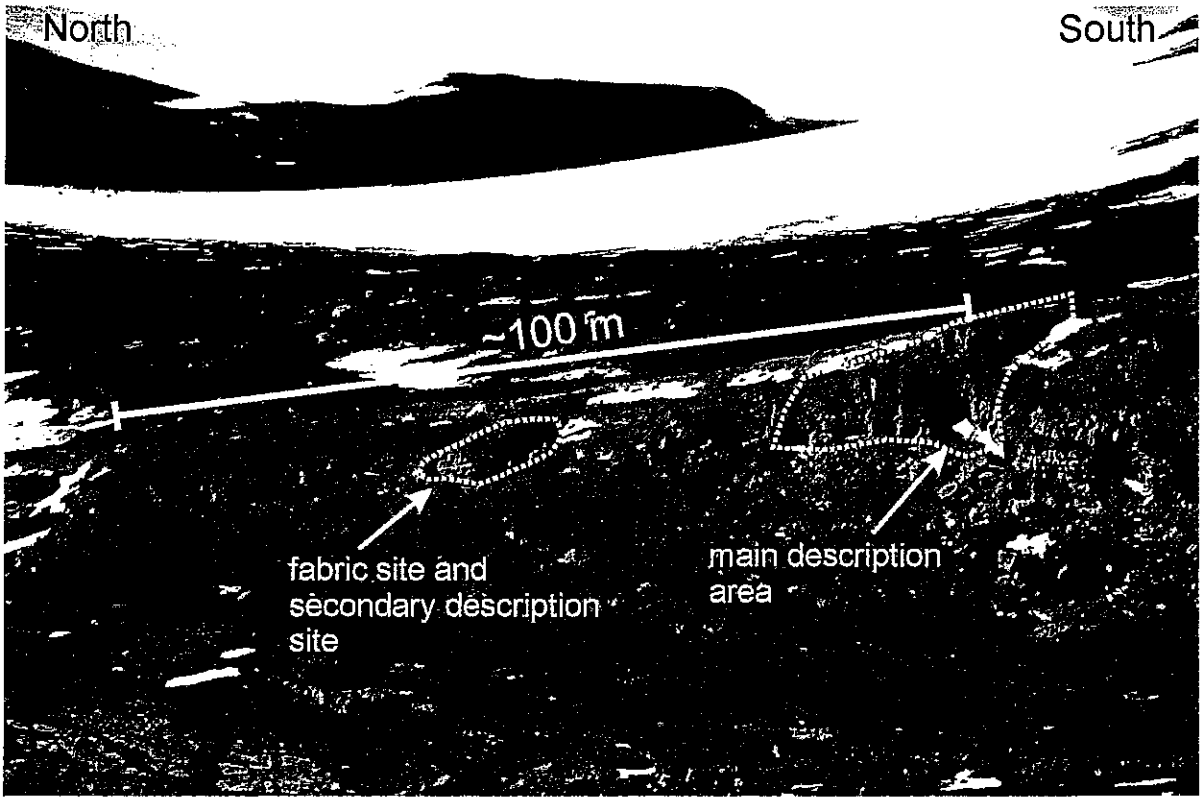


Figure 17. Section 7 showing description sites.

At the south end of the exposure a hollow eroded into the base of the cliff provides good access to the lower stratigraphy. Care was taken to constantly trace the stratigraphy across the exposure to check lateral variation and continuity. The hollow is about 3 m across at the base by about 4 m high and cuts about 2.5 m into a sandstone bed of the Weller Coal Measures. The floor of the hollow is a colluvial shale/siltstone gravel and slopes away from the face, oriented 201/21 NW.

Unit 1: This unit is a zone in which sandstone from the underlying Weller Coal Measures has been crushed and comminuted. The unit is grey and consists of about 40 cm of pulverised sandstone (in which bedding has been destroyed) overlain by up to 50 cm of brecciated sandstone. In some parts the unit consists of highly fractured but unbrecciated sandstone, presumably where shearing has been less intense. At the base of the unit (and most commonly in the southern quarter of the exposure), there are

many fractures, some injected with matrix, that extend downward into Weller Sandstone (Figure 18). The unit extends across most of the exposure and ranges in thickness from 0-1 m with an average thickness of about 40-50 cm, but is absent in the hollow at the south end of the exposure where it has been completely incised and replaced by Unit 2. At about 2 m away from the base of the exposure along the top of the end-wall the pulverised subunit is replaced laterally by the overlying sandstone breccia.

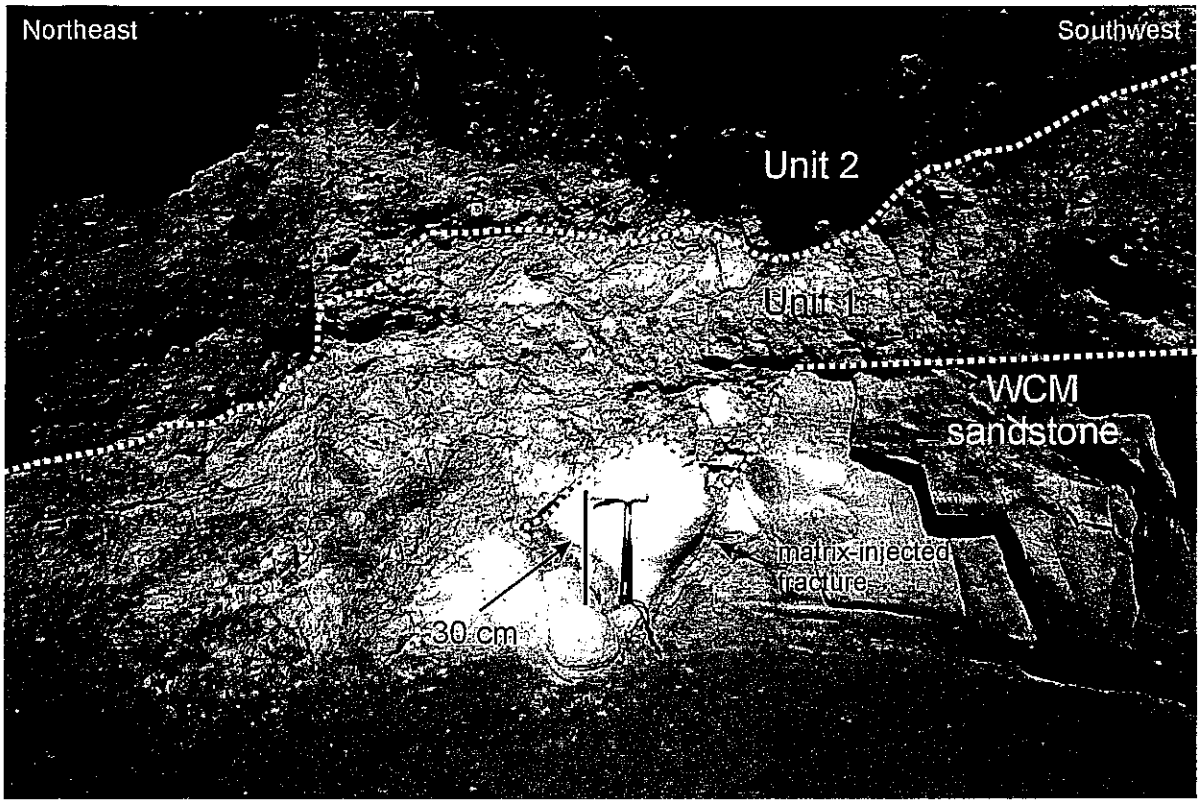


Figure 18. WCM sandstone, Unit 1 and Unit 2, showing matrix-injected fracture.

Unit 2: This unit is a stony diamictite with a silty sand matrix that is dark to medium grey and weathers a tan brown colour. The diamictite has a gradational lower contact and is matrix-supported, but contains pockets which are clast-supported. Clasts within the diamictite can be divided into two roundness groupings: clasts of the same sandstone and siltstone lithology as the underlying coal measures are angular and range in size from granules to large cobbles; the second group consists of mainly subangular to rounded clasts from small pebbles (generally subangular) to boulders (generally more rounded). This second grouping contains dolerite, red amygdaloidal basalt, quartzite and sandstone. There are striated clasts in the hollow at the south end of the exposure, but they are all stuck into the headwall of the cave and are very difficult to measure - careful visual observation did not reveal a trend. In a second hollow 25 m north from the south end of the exposure the unit is somewhat chaotically interbedded muddy coarse sand with pebbles and sandy diamictite (Figure 19). In some places there are pockets <20 cm long of bedded sand, some foreset. In general, the pebbly sand beds also have muddy laminae that wind-winnowing has enhanced. Unit 2 is common across most of the entire length of the exposure, but it generally does not contain a lot of comminuted sandstone. The more common stratigraphy is for a comminution zone (Unit 1) to overlie in situ sandstone and be overlain by the unsorted sandy diamict with flow features in it. At the end-wall the combined unit is about 2 m thick. The unit is present across most of the exposure and has a more variable thickness than Unit 1 (ranging from 0 – about 1.5 m thick), but is absent in the hollow at the south end of the outcrop. Where it is thickest it is interbedded with overlying diamictite.

Where the end-wall meets the face of the exposure the contact between the unaltered sandstone and Unit 2 dips into the face at about 25° for about 1.5 m and then dips steeper at about 50° for about 1.2

m before again becoming a horizontal contact in the face of the cave head wall. There are many flow features within this unit and many wind-winnowed muddy laminae which are most commonly oriented in approximately the same plane that forms the upward sloping roof of the cave. A very general orientation for the laminae in the roof of the hollow is 041/32 SE, but there are also well over one hundred little irregular laminae oriented every which way, some of which are cm long while others run through fractures for about 2 m. On the southwest side of the hollow, at the 50° dipping contact between the Weller and the diamict, some of the Weller sandstone has been entrained and muddy laminae can be seen in the 7 cm thick portion of diamict that lies between the underside of the entrained piece and the in situ sandstone below (Figure 20). In general the unit is very unsorted and has a fluvial feel to it - likely a subglacial sediment flow of some kind.

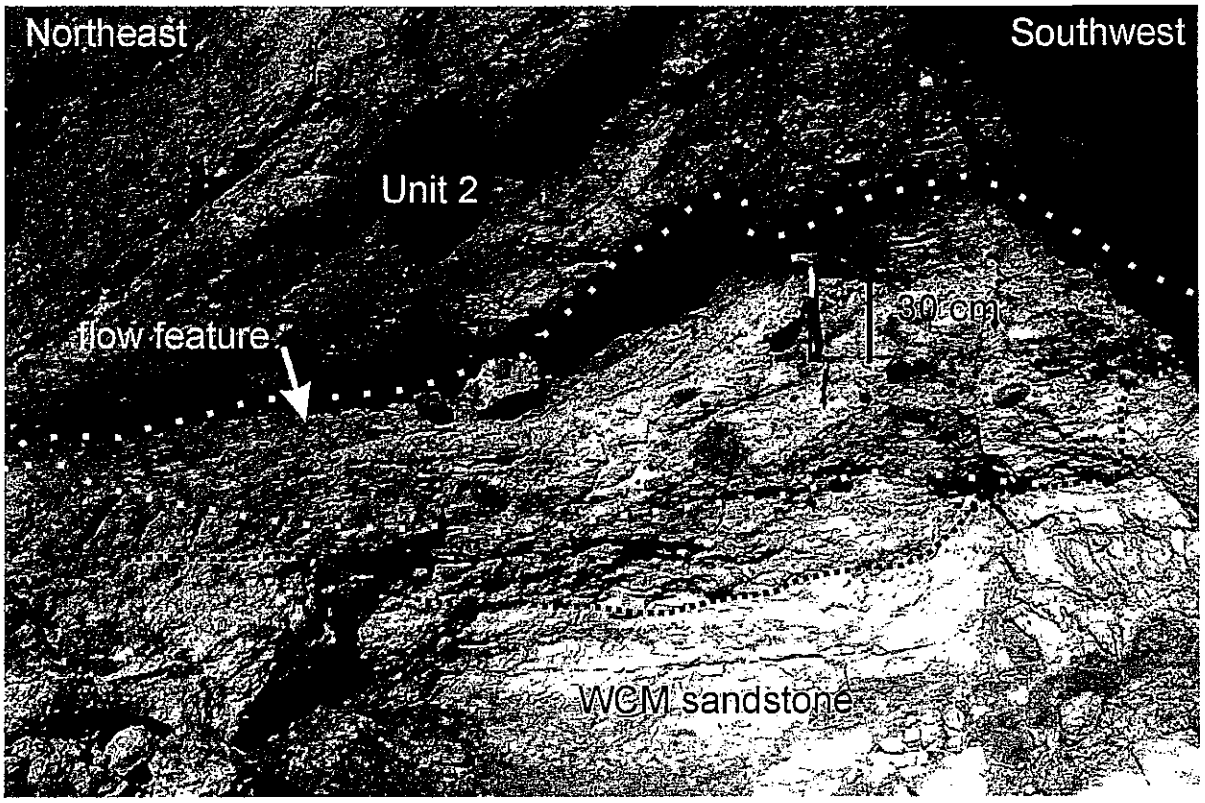


Figure 19. Flow feature in Unit 2.

Unit 3: This unit is a well-compacted, slightly greenish grey diamictite (weathering a light brown) overlain by medium grey diamictite - the diamictites are identical except for colour. Over most of the exposure the unit is draped with mud from overlying deposits so this description was done at an exposure on the north face of the main gap in the section (Figure 21) and in a hollow 25 m north of the south end of the section. The diamictite is not very stony (<10%) and has a muddy sand matrix. The unit's basal contact is not exposed. Clasts range from granules to cobbles locally but it is evident that boulders up to 1.5 m long have fallen out of the face nearby. Clasts are subangular to well-rounded except coal clasts which are generally angular to subangular. There are many fractures in the diamict; these occur generally as linear cracks 1-2 mm wide and clefts and ledges. No flow structures are apparent here except in the lower part of the unit where there is a gradational contact in some places with Unit 2. In a hollow 25 m north from the south end of the exposure the underlying brown-weathered subunit is 2.4 m thick and the overlying grey coloured subunit is about 1.8 m thick - a similar thickness is assumed across the rest of the outcrop. The 'contact' between brown and grey layers of the unit is abrupt and regular in the hollow becoming abrupt and irregular in the southern part of the section. There is a distinct fragmentation plume and halo around a big boulder of Mawson B.

Unit 4: This unit is a stony diamict with a slightly muddy sand matrix and a basal contact that is gradational over 8 cm. It has a slightly muddy sand matrix and contains clasts from granules to

cobbles locally. Clast-content is continuous upward through a weathered brown band about 0.8-1 m thick and then gradually decreases towards the top of the unit. Clasts are angular to rounded, but most are subangular to subrounded. No folding, deformation or fissility were seen; the latter may possibly be due to the high sand content in the matrix. The unit is approximately 1.2 m thick with a pink band about 40 cm thick at its base. Unit thickness is difficult to estimate because the draping of pink mud down the exposure is misleading and access to this unit is very limited. The unit thickens gradually southward and forms the top of the exposure except at the extreme south end above the hollow where a diamict (Unit 5) several metres thick overlies.

About 30 m south of the described exposure there is a small, isolated outcrop where Unit 2 is 4-5 m thick and the pink band in Unit 4 is associated with a stonier diamict.

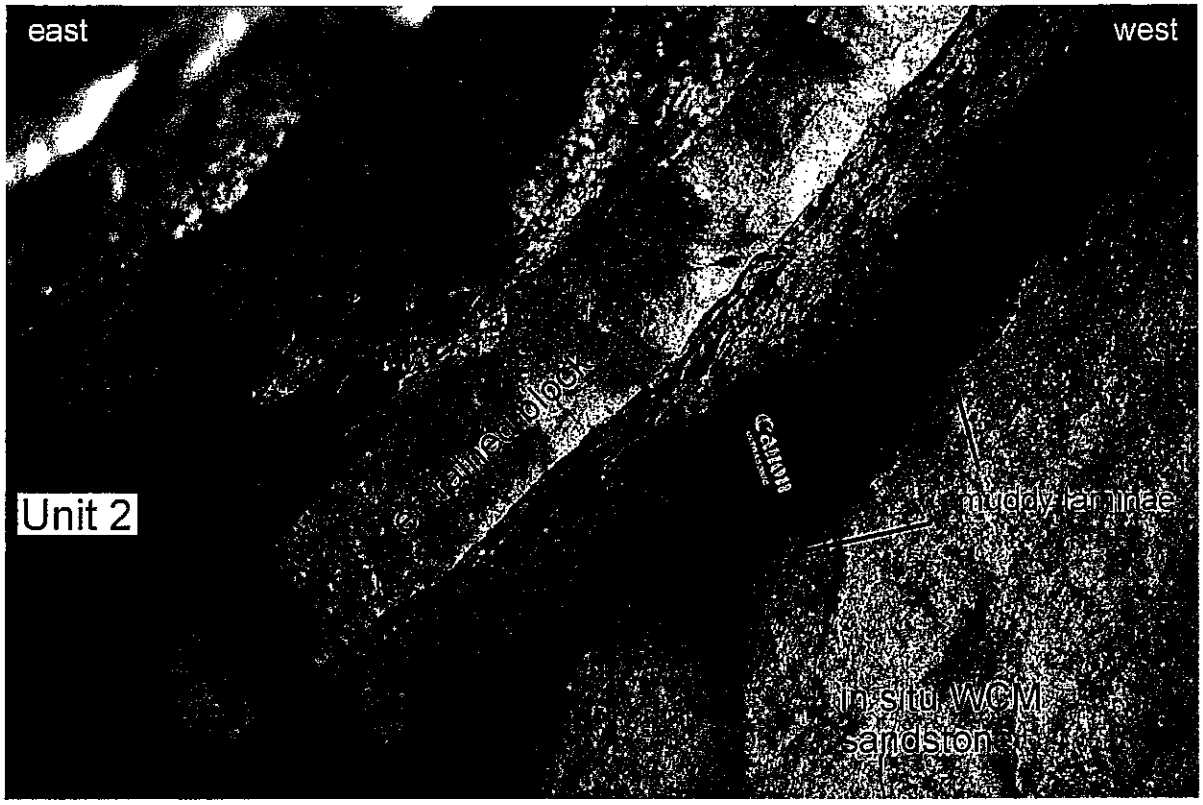


Figure 20. Elongate block of sandstone which has been entrained. Note muddy laminae in space separating block from in situ sandstone.

Unit 5: This unit is 2.9 m thick and consists of diamict with a slightly muddy sand matrix that is grey (medium to dark) when fresh (Figure 22). The diamictite is moderately stony at its base becoming less stony towards the top with angular to rounded clasts from granules to boulders. Although not initially apparent, the diamictite is very fissile, with the platelets oriented in the plane of the exposure face. No folding or deformation was seen.

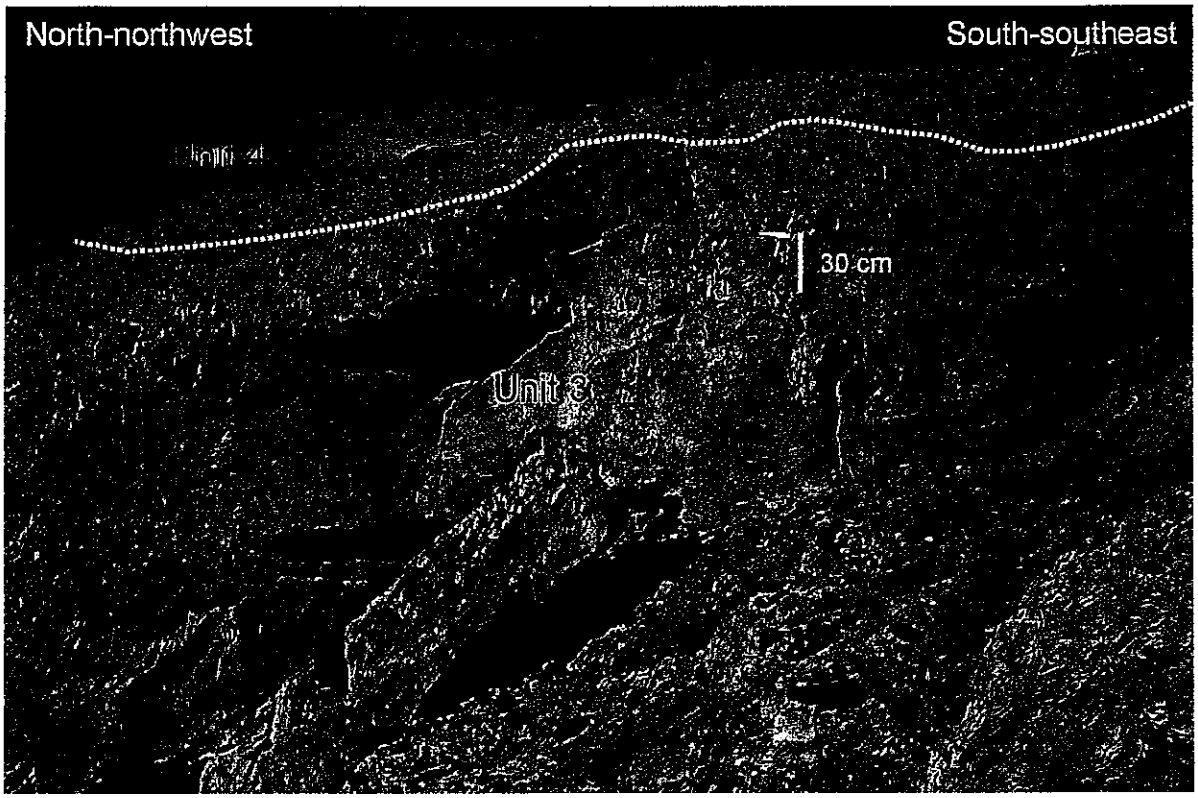


Figure 21. Description and fabric site for Unit 3.

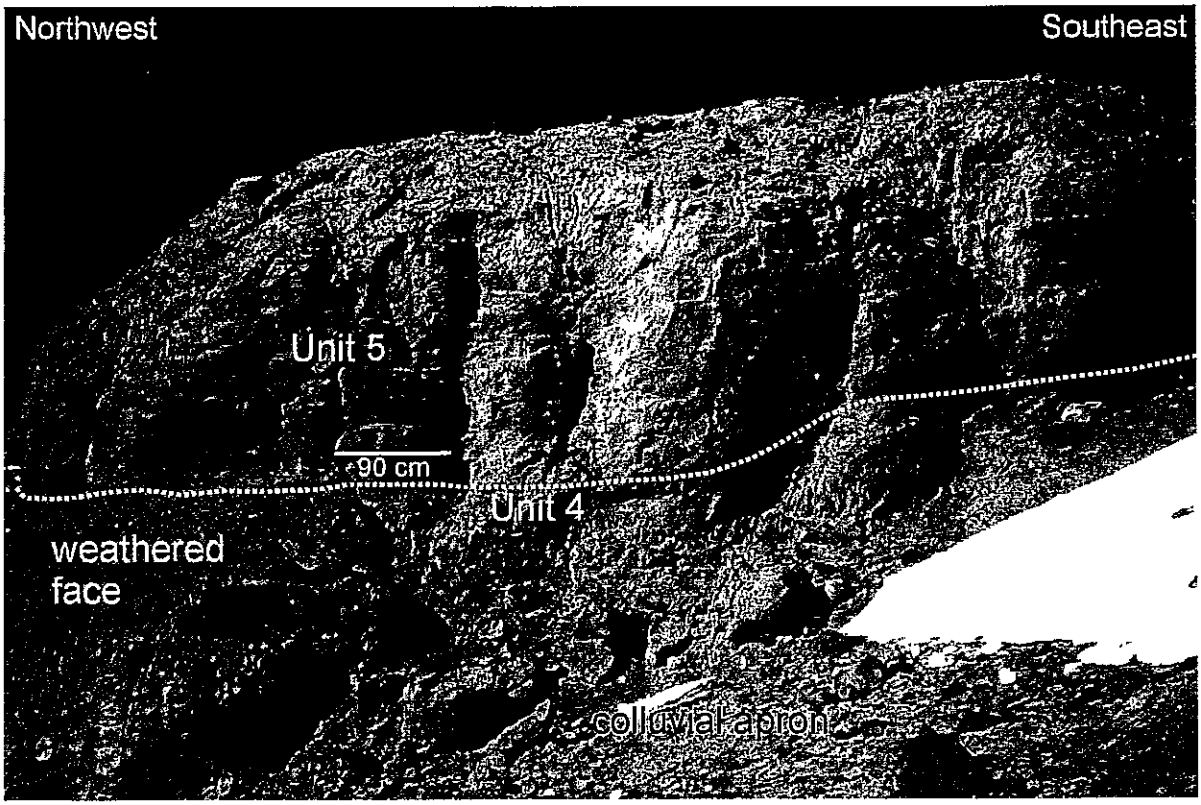


Figure 22. Section 7 Unit 5 fabric site.

Measurements	
Fabric:	36 clasts from Unit 3, 30 clasts from Unit 5 (see Appendix 2)
Striae:	13 from Unit 5 (see Appendix 3)
Lee-ends:	6 from Unit 3, 5 from Unit 5 (see Appendix 4)
Structures:	1 from Unit 2, 4 from Unit 3, 8 from Unit 5 (see Appendix 5)

Samples	(see Appendix 6)
VUW37465	block of diamictite from Unit 3
VUW37466	pebbles from Unit 3
VUW37456	block of diamict from Unit 5
VUW37457	pebbles from Unit 5

Section 8

(Grid coordinates: N 441945 m, E 429415 m)

This outcrop is an exposure of brown diamictite that forms a crude ledge or step along the north slope of Trudge Valley, running westward from a point about 100 m west of the blue ice tongue of the Odell. The Sirius Group here forms a mostly continuous outcrop (or significant break in slope) for 120 m across the slope, with the best (thickest and most vertical) exposure occurring in the western third of this. The exposure along this 120 m length ranges from 0-2 m thickness of near-vertical face. The following description is in the immediate vicinity of a gap about 5 m wide in the continuity of the ridge, where the exposure is most vertical (Figure 23). Sirius Group is present in the floor of the gap, but it has a slope the same as that of the general slope. The outcrop here is 3.2 m high and consists of a diamict overlain by a more stony diamict.

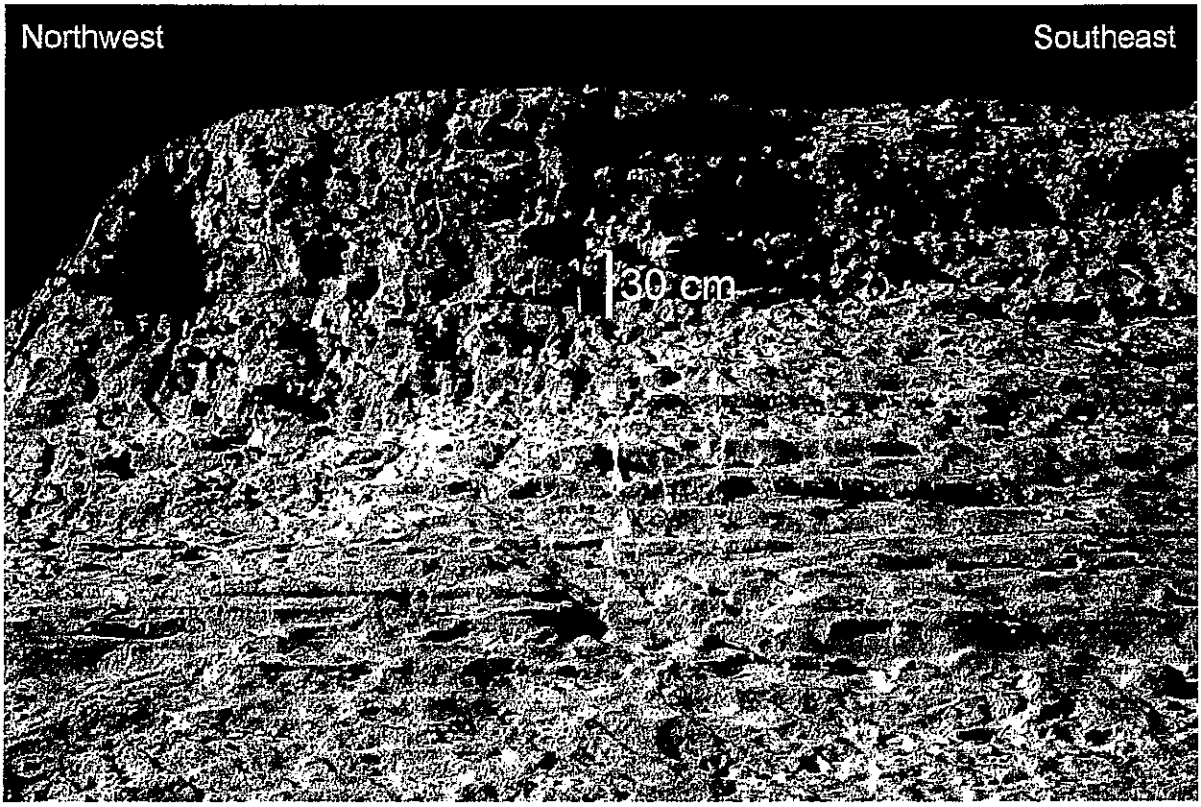


Figure 23. Section 8 description site.

Unit 1: This unit is a diamict with a yellowy tan brown matrix of granular, medium to coarse sand. The basal contact is not exposed because the unit continues downslope from the outcrop to form the slope surface. Clast content is about 10% and clasts range from (abundant) granules up to large pebbles, and are subangular to well-rounded. The unit is quite fractured and is stratified with about 15 inclined planes that cut across the exposure. In the exposure face these beds form positive features where the wind has winnowed out intervening material to leave steps with the beds forming the vertical faces of the steps. They are made of the same material as the rest of the diamict and are likely shear planes or planar failures of some kind. One step had a vertically oriented friable sandy 'bed' where the vertical backwall meets the horizontal step, very likely weathering due to surface water migrating down there. There is a dark grey, granular bed that coincides with one of the beds running across the face of the exposure. It is about 1-2 cm thick and is texturally similar to the rest of the diamict except that it is more stony. Contacts with it are regular and abrupt, top and bottom. Another one is about 1-2 mm thick and contains a dark grey mud. The trace of this lamination across the portion that has been exposed (about 50 cm) is irregular and appears to have been faulted with offsets of up to 2 cm throw. A branch of the lamination descends vertically in an irregular manner for about

15 cm down this fresh face. High winds during the description have winnowed material away from the exposed face to reveal a fracture 3-4 cm wide and 25 cm long, containing granules that are clast-supported. It appears that water has flowed down this fracture and washed away the matrix.

Unit 2: This diamict has a lower contact that is gradational over 25 cm and best seen when standing back a few metres from the face. The upper, vertical part of the unit is the most easily described. The diamict is light grey-brown sand and is quite cemented (or indurated); it is as cemented and compacted as the upper diamict at Section 7. Clasts range from granules to cobbles and are angular to subrounded; dominant lithologies are dolerite and basalt. The diamict is unstratified but fractured - no deformation features seen. No clasts of Mawson B seen.

Measurements

Fabric:	30 clasts measured in Unit 1 (see Appendix 2)
Striae:	22 from Unit 1 (see Appendix 3)
Clast lee-ends:	3 from Unit 1 (see Appendix 4)
Structures:	4 from Unit 1, four from Unit 2 (see Appendix 5)

Samples (see Appendix 6)

VUW37462	block of diamict from Unit 1
VUW37463	pebbles from Unit 1
VUW37467	block of diamict from Unit 2

Section 9

(Grid coordinates: N442071 m, E427074 m)

This exposure is located on the west side of the lower half of the triangle in central Allan Hills. The outcrop is approximately 40 m wide and 15 m high and occurs on a slight promontory, providing about a 50-80° difference of perspective from the flank to the nose of the promontory (Figure 24). General stratigraphy consists of 8-10 m of occasionally fractured sandstone and thin carbonaceous beds of the WCM (below the outcrop proper), overlain by a few metres of more fractured WCM (of similar lithologies to that below) – there is diamict injected down into some of these fractures. Overlying, there is a zone very rich in sandstone blocks, cobbles, pebbles and matrix. The unit is approximately 1-1.5 m thick and is a zone where the underlying WCM is being comminuted and entrained. This is overlain by 2-3 m of slightly greenish grey brown diamictite that contains Mawson B clasts and much dolerite and basalt.

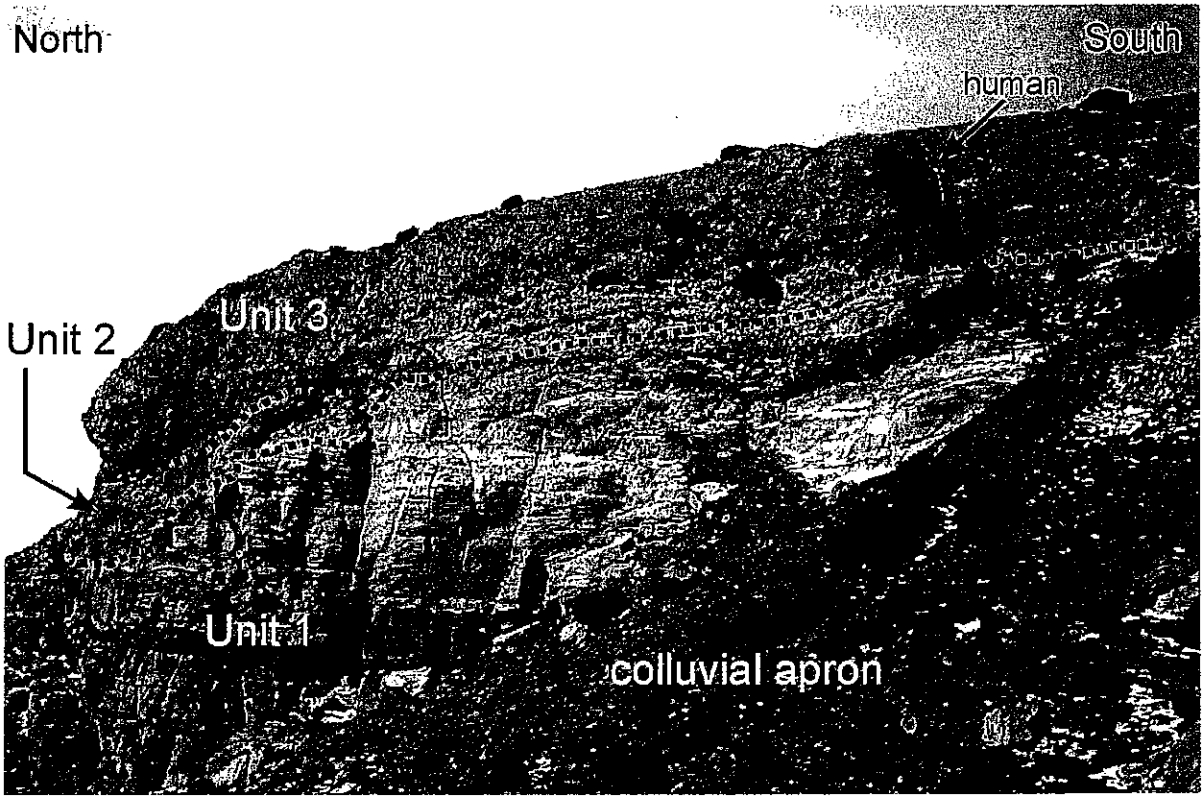


Figure 24. Section 9 with human for scale.

Unit 1: This unit consists of fractured sandstone beds of the Weller Coal Measures. Near the top of the unit at about 1 m below the contact with Unit 2 there is a series of carbonaceous laminae about 10-20 cm thick in total. The deformed beds are cross-bedded, medium to coarse sand with many granules. Some fractures in the WCM sandstone have been injected with diamict and mud. A diamict- and mud-filled fracture extends down from the series of carbonaceous laminae mentioned above to a few more carbonaceous laminae below (Figure 25). The fracture is about 80 cm long, tapering from about 12 cm wide at its upper part to 2-3 cm at its lower end where it enters the lower set of laminae. The fracture is infilled with some diamict and some sand, and many mud laminae (<1 cm thick) are present. In the upper 30 cm of the fracture the laminae etc. are largely replaced by subangular pebbles (up to 6 cm) of sandstone of the same lithology as the surrounding rock which look to be material comminuted from the WCM. On the south side of the promontory that forms the outcrop there is a large diamict-filled fracture that extends down from the diamictite (Figure 26). The fracture width is uniform and 8-10 cm and its length is 1.6 m.

Unit 2: This unit is a blocky, bouldery unit consisting of crushed and entrained sandstone of the Feather Conglomerate. The lower contact is abrupt, erosional and regular. There are some muddy-sand laminae present in flat-lying fractures. The unit exists in only the northern part of the exposure; diamictite directly overlies the Beacon Supergroup in the southern part. The unit halts abruptly in the southern part of the exposure and the fractured sandstone of Unit 1 replaces it laterally.

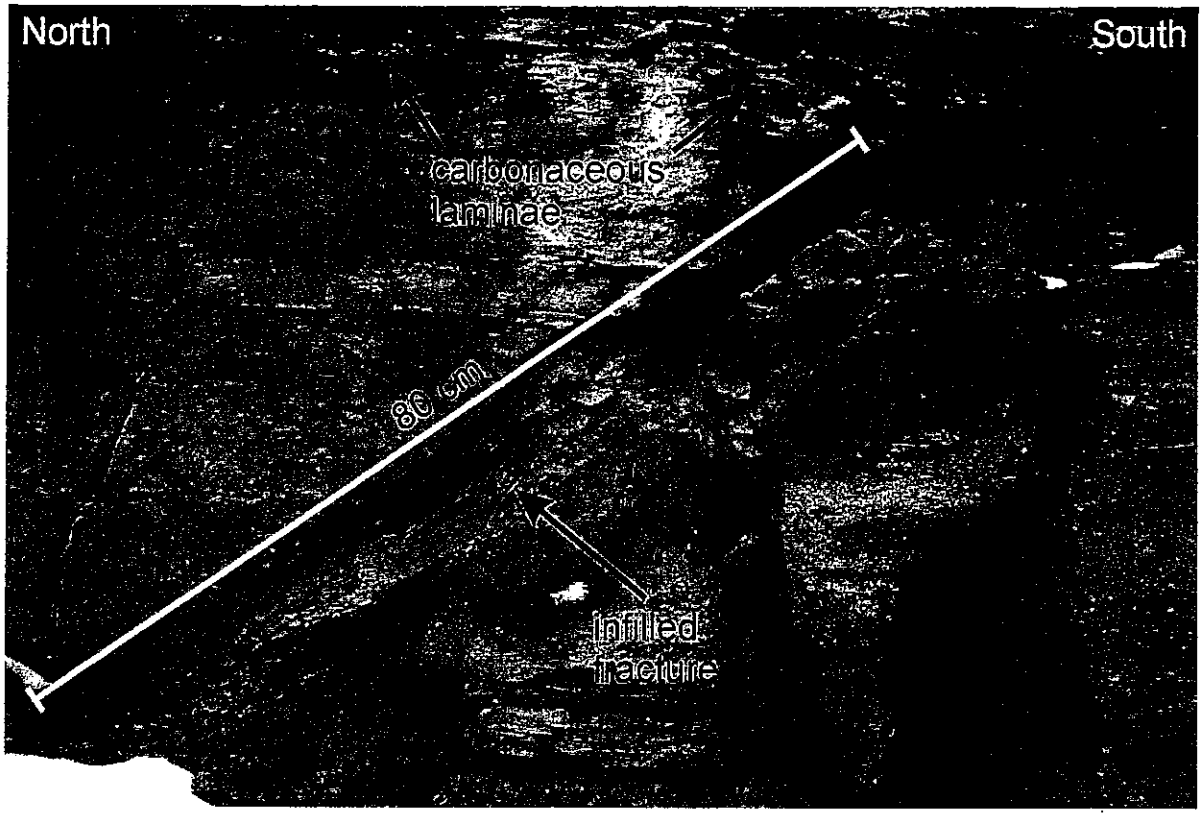


Figure 25. Diamict- and mud-filled fracture in fractured sandstone.

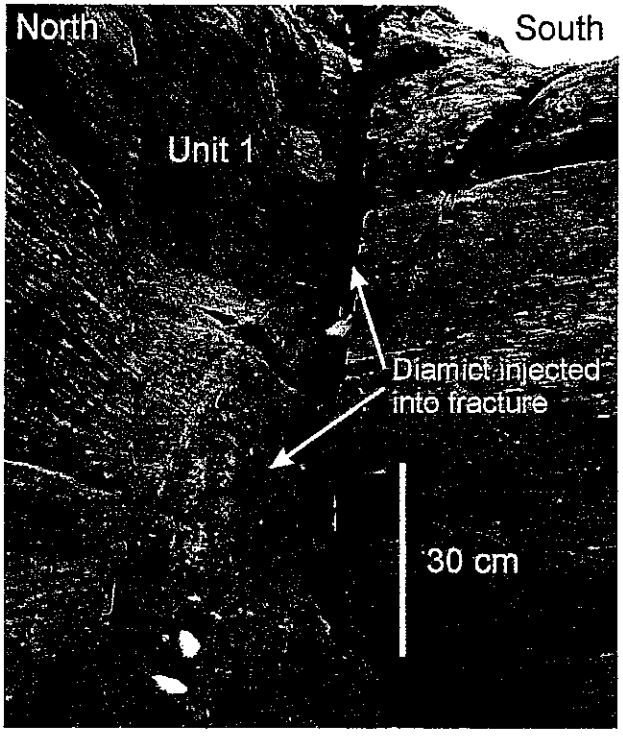


Figure 26. Large diamict-filled fracture in fractured sandstone.

Unit 3: Overlying Unit 2 is brownish grey diamictite with an erosional, irregular and abrupt basal contact. The diamictite has a coarse sand matrix and is moderately stony (15%) in places but less so (10%) in others. Many of these stonier zones appear to be where larger clasts are disaggregating; most notably where Mawson B clasts have been disintegrating and given the matrix a brownish hue. Clasts range in size from granules to boulders 80 cm long, and are rounded to subangular although some small pebble-size fragments are angular. There are some poorly defined flow structures in the deposit, but no clearly defined glaciotectonic structures. The unit ranges in thickness from about 3-5 m. When seen from a distance there appears to be a brown diamict unit forming the lower half metre or so of Unit 3 but this feature is not continuous across the exposure.

Measurements

Fabric:	30 clasts from Unit 3 (see Appendix 2)
Striae:	4 from Unit 3 (see Appendix 3)
Clast lee-ends:	4 from Unit 3 (see Appendix 4)

Samples (see Appendix 6)

VUW37484	block of diamictite from Unit 3
VUW37485	pebbles from Unit 3

Section 10

(Grid coordinates: N442127 m, E427647 m)

This outcrop lies on the northeast edge of the Triangle in the northwest part of Echo gully. The portion of the outcrop described here as Section 10 is about 3.5 - 5 m high (thinning northward) and is about 20 m across (Figure 27). The outcrop consists largely of sheared and deformed sandstone and coal beds of the WCM overlain by diamictite.

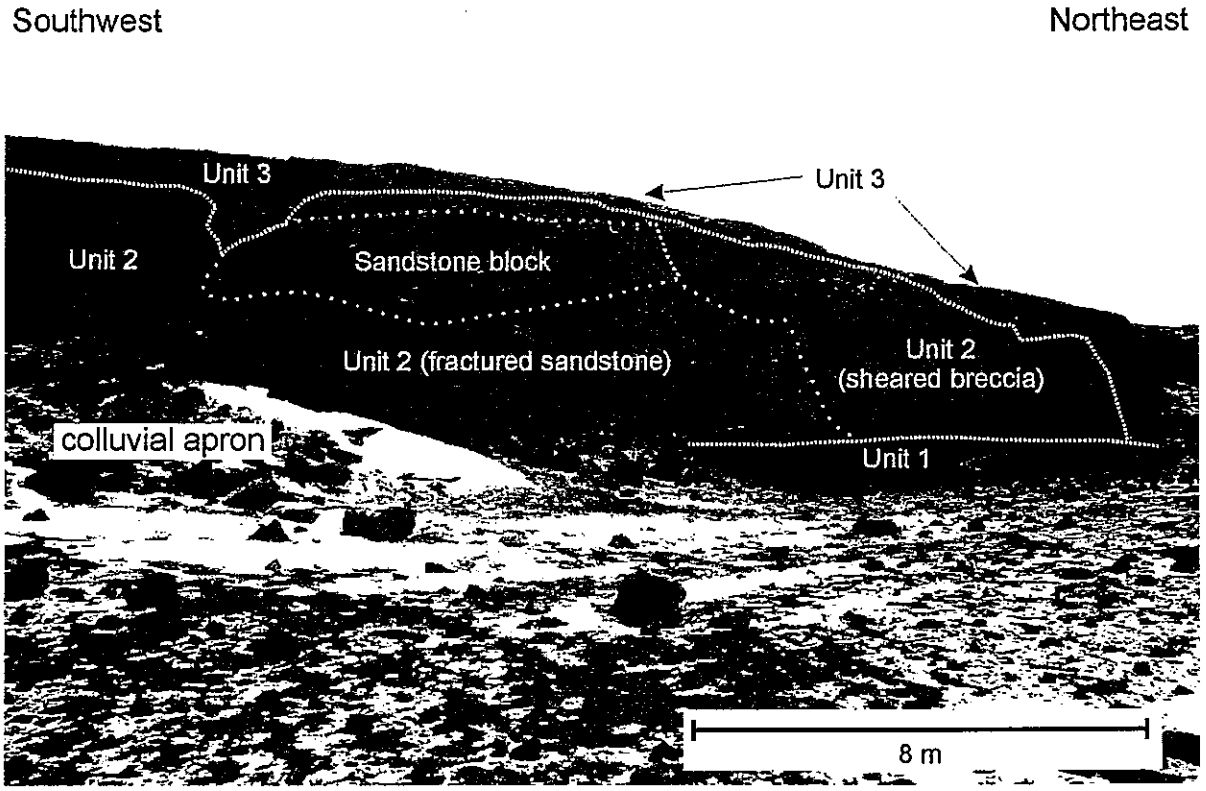


Figure 27. Section 10 showing stratigraphy.

Unit 1: The basal unit exposed in the outcrop is a Weller coal bed. This is exposed across 6 m of the northern part of the exposure and is obscured by debris to the south. The unit is 50-65 cm thick and moderately fractured over most of its length, becoming brecciated over the northern-most metre.

Unit 2: Overlying this is a shear zone about 2.5 m thick with a regular and abrupt basal contact. The shear zone can be roughly divided into two parts laterally. The southern two thirds is sheared sandstone with many gently dipping shear planes running across it. There is a large 1.5 x 8 m block of dark sandstone occupying the upper part of this portion of the unit. At the south end of the block there is a fracture about 45 cm wide which is filled with material injected down from the overlying unit. The injected material is comprised of diamict, large angular pebbles of sandstone that have been pulled down, and also muddy laminae which suggest that this fracture acted as a water escape conduit as did several other fractures which also have muddy laminae. The injected material at the base of the fracture is mixed with a very jumbled and sheared breccia of clasts ranging from granules to cobbles often with diamictic matrix (grey sand) in the interstices. This wedge of heavily sheared rock is 2 m long x 90 cm thick lensing out to the northeast. In the northern third of the unit the sheared sandstone of the southern portion is replaced laterally at an abrupt, near vertical contact by a heavily brecciated shear zone with clasts ranging from granules to boulders 2 m long (Figure 28; Figure 29). There are muddy laminae at the contact (that follow its curve) which suggests that it was used as a water-escape structure. There are curvilinear concentrations of coal-rich diamict from Unit 3 which have some

sandstone from the WCM in them and appear to be distinct zones of dry or brittle shear. There are muddy laminae in one of them.

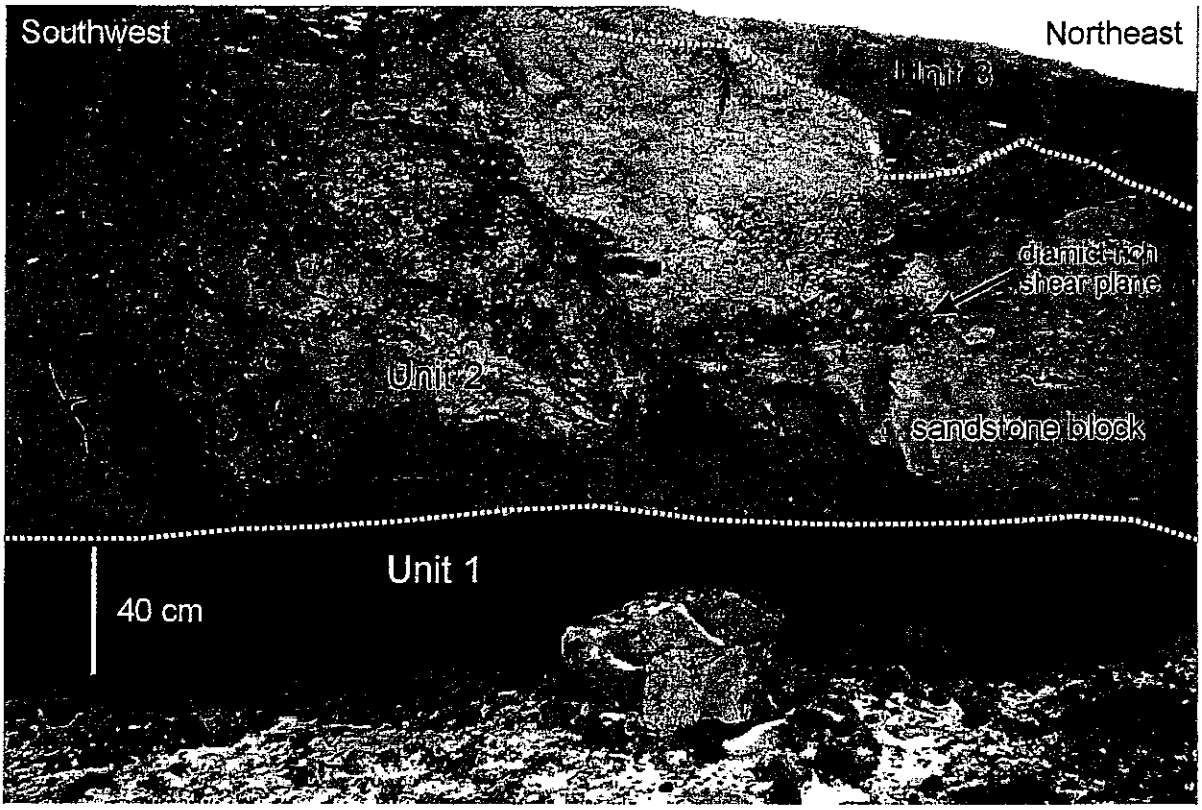


Figure 28. Northern third of Unit 2.

Unit 3: Capping the section is diamictite which thickens northward from 50 cm – 1.4 m. The diamict is sandy with grey and brown patches and is moderately stony with clasts ranging from granules to cobbles 15 cm long locally. Clasts are subangular to subrounded. Clast lithologies include: dolerite, red basalt, coal fragments (many), quartz-rich coarse sandstone (grey/white), brown sandstone, Mawson B. This diamict is stonier than the banded diamict at Section 6, but less stony than the upper there. At the top of the outcrop there is a basalt boulder 40 cm long on the diamictite walking-surface at the top of the outcrop. There are fresh crude striae oriented 170° - this orientation is supported by plucked surfaces on top of the boulder that suggest ice flow from the 359° to 028°. These have very likely been done by the Manhaul (post-Sirius Group) advance. There are many other, finer striae on the boulder that range in orientation from 152-332° to 354-174°. These finer striae are <1 mm wide and many are hairthin – all the fine striae are weathered red like the rest of the surface of the rock, only the crude striae are fresh (unweathered). There are fractures in the diamictite but they are inaccessible at the top of the exposure.

Measurements

Fabric:	30 clasts from Unit 3 (see Appendix 2)
Striae:	6 from Unit 3 (see Appendix 3)
Lee-ends:	7 from Unit 3 (see Appendix 4)
Structures:	10 from Unit 2 (see Appendix 5)

Samples	(see Appendix 6)
VUW37486	block of diamictite from Unit 3
VUW37487	pebbles from Unit 3

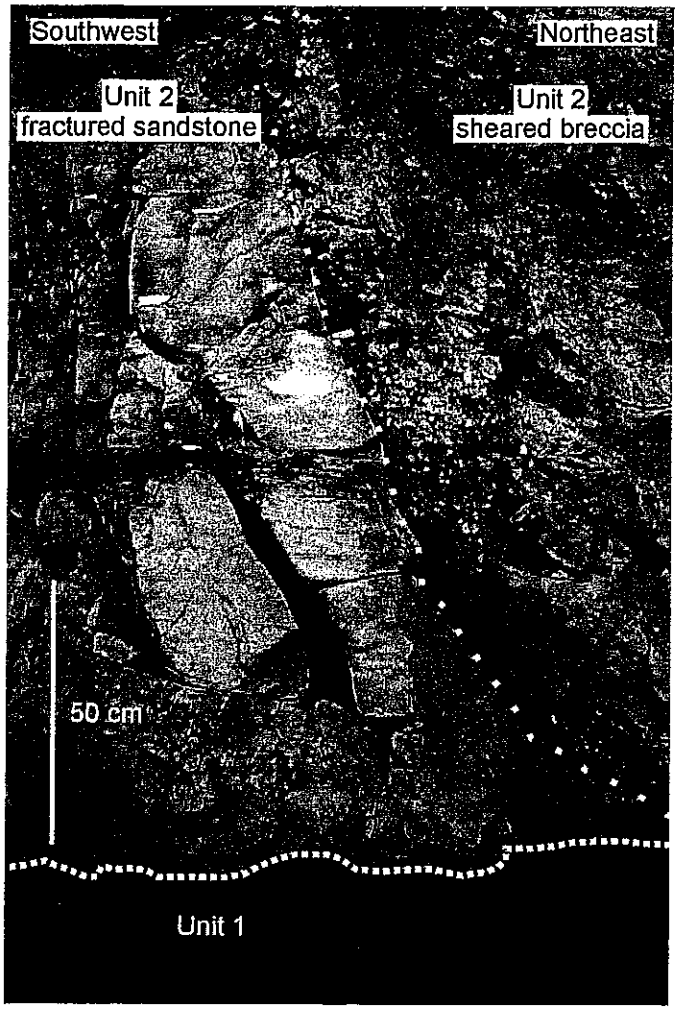


Figure 29. Abrupt, near vertical contact within the shear zone.

Other Significant Outcrops:

About 10 m north of the central dyke and maybe 100-200 m east of Section 3 there is a small ridge or elongate mound (about 1.5-3 m high and 25-30 m long) consisting of Weller Coal Measures with about 2 m of sandstone overlying a coal bed that is at least 1 m thick. The ridge is oriented with its long axis running northeast/southwest. The south half of the ridge is mostly jumbled up debris while the north half is still intact. There is a thin series of thin coal beds / laminae that extends along the ridge about 1 m below the top of the sandstone (within the sandstone). This packet of beds is about 10 cm thick and is horizontal in the northern half of the ridge but forms a sinewave with an amplitude of about 30 cm and a wave-length of about 2.5 m in the southern half where the ridge material has been crushed. Initially it appears that all the debris was pushed along the top of the ridge to fall on the lee (south) side, but the sinuous, continuous bed indicates that the ridge was compressed, crushed and some beds folded. It appears that the whole sandstone bed was pushed a short distance southward by glacial ice advancing from the north, along the sandstone-coal bed contact until it ran into the central dyke. The advancing ice compressed the ridge against the dyke, crushing the southern-most end and folding some beds (the thin set of coal beds/laminae) while leaving the northern end displaced but effectively intact. There is no evidence of any brecciation of the underlying coal bed.

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Lloyd-Davies, M. L., and van der Meer, J.J.M., 2001,

APPENDIX 1 - EVENTS LOG FOR P.HOLME

Day	Date	Location	Activity
01	20/11/99	camp	insertion and camp setup
02	21/11/99	camp	camp setup
03	22/11/99	Triangle	recce south to the Triangle area
04	23/11/99	Northwest Platform	recce west across Northwest Platform and up onto west edge of Allan Hills. Found section with good stratigraphic contacts
05	24/11/99	Boulder Ridge	recce east to Boulder Ridge
06	25/11/99	Echo Gully	looked for Hiemstra's sections and found excellent outcrop
07	26/11/99		helped Mark look for Hiemstra's sections
08	27/11/99		did write-up summary of preceding events
09	28/11/99	Sec 01	worked on Section 01
10	29/11/99	Sec 01	worked on Section 01
11	30/11/99	Sec 01	worked on Section 01
12	01/12/99	Manhaul snout to northeast platform	recce along Manhaul snout and out to northeast platform
13	02/12/99	just south of the Northwest Platform	recce – found potential section
14	03/12/99	Northwest Platform	recce, outcrop investigation
15	04/12/99	camp	sore knee – did paperwork
16	05/12/99	Northwest Platform	section 03
17	06/12/99	Northwest Platform	section 03
18	07/12/99	Northwest Platform	recce
19	08/12/99	Triangle, Boulder Ridge	recce
20	09/12/99	?	recce
21	10/12/99	?	recce
22	11/12/99	Lake valley, Trudge valley	recce
23	12/12/99	south to the Rim	recce – looking for Sirius Group
24	13/12/99	camp	paperwork
25	14/12/99	along Manhaul snout to Lake valley	recce
26	15/12/99	central Allan Hills south of the central dyke	GPS measurements of the southern limit of the Beacon butter
27	16/12/99	Echo gully, Trudge valley	recce and GPS measurements of outcrops and striated surfaces
28	17/12/99	South limb	recce, looking for Sirius Group deposits
29	18/12/99	camp	rest
30	19/12/99	Camp valley	section 03
31	20/12/99	Camp valley	section 03
32	21/12/99	Camp valley	section 03
33	22/12/99	Camp valley	section 03
34	23/12/99	Camp valley	section 03
35	24/12/99	Camp valley and contra ridge	recce
36	25/12/99	camp	Christmas
37	26/12/99	camp	Christmas
38	27/12/99	Northwest Platform, Camp valley, contra ridge	outcrop tour
39	28/12/99	contra ridge	recce

40	29/12/99	contra ridge	section 04
41	30/12/99	central and southern Allan Hills (north of the Rim)	recce and sampling
42	31/12/99	contra ridge	section 04
43	01/01/00	camp	New Year's Day
44	02/01/00	contra ridge	section 05
45	03/01/00	contra ridge	outcrop investigation
46	04/01/00	Trudge valley	Beta camp setup
47	05/01/00	north flank of Trudge valley	mapping
48	06/01/00	Beta camp	rest
49	07/01/00	floor and south ridge of Trudge valley	recce
50	08/01/00	south ridge of Trudge valley	recce
51	09/01/00	south ridge of Trudge valley	recce
52	10/01/00	south rim of gully (SE gully) in southeast corner of Trudge valley	section 06
53	11/01/00	gully (Echo gully) in southwest corner of Trudge valley	section 07, outcrop investigation
54	12/01/00	Echo gully	section 07, outcrop investigation
55	13/01/00	Echo gully	section 07, outcrop investigation
56	14/01/00	SE gully	section 06, outcrop investigation
57	15/01/00	north flank of Trudge valley	recce and section 08 outcrop investigation
58	16/01/00		
59	17/01/00	north flank of Trudge valley	mapping and section 08 outcrop description
60	18/01/00	north flank of Trudge valley	mapping and section 08 outcrop description
61	19/01/00		
62	20/01/00	Echo gully/Beta camp	section 07 and breakdown/pullout of Beta camp
63	21/03/00	camp/Scott Base	pullout of Alpha camp and return to Scott Base

APPENDIX 2 - FABRIC DATA

Data presented in table format below as: azimuth trend, plunge, plunge direction.

Section 1 - Unit 2

059	11	NE		229	14	SW		008	26	NE
231	01	SW		281	25	NW		055	00	NE/SW
039	58	NE		029	32	NE		295	18	NW
083	23	E		259	27	W		267	06	W
223	18	SW		251	00	SW		265	01	W
219	53	SW		051	26	NE		087	23	E
227	16	SW		359	02	N		169	43	S
203	11	SW		093	41	E		193	10	SW
309	13	NW		056	06	NE		321	22	NW
079	32	E		193	28	SW		297	72	NW

Section 2 - Unit 3

023	02	NE		191	21	SSW		306	03	NW
337	05	NNW		325	16	NW		287	03	NW
160	08	SE		091	08	E		147	00	-
171	42	S		015	13	NE		006	20	N
187	10	SW		090	20	E		023	06	NE
359	14	N		190	16	SSW		194	08	SW
143	15	SE		081	06	E		071	16	NE
081	18	E		012	20	NNE		185	12	S
197	45	SSW		109	06	ESE		175	22	S
144	57	SE		006	12	NNE		235	13	SW
240	33	SW								

Section 3 - taken at 59 m north of the south end of the section in Unit 5

058	26	NE		182	66	S		350	07	N
161	11	SE		053	40	NE		155	28	SE
213	26	SW		134	10	SE		134	11	SE
046	13	NE		360	32	N		110	15	SE
178	55	S		150	41	SE		194	11	SW
081	23	E		142	38	SE		130	16	SE
041	10	NE		294	43	NW		092	25	E
187	11	S		194	07	SW		130	13	SE
262	08	W		326	13	NW		191	01	SW
140	76	SE		150	16	SE		007	40	N

Section 4 - Unit 3

015	34	NE		314	27	NW		202	14	SW
038	08	NE		070	13	NE		179	02	S
353	21	N		338	78	NW		231	18	SW
025	59	NE		086	24	E		246	05	SW
231	50	SW		106	34	SE		058	50	NE
050	19	NE		072	10	NE		042	18	NE
250	31	SW		036	24	NE		054	13	NE
050	31	NE		272	46	W		258	04	SW
217	36	SW		258	18	SW		332	12	NW
239	16	SW		028	80	NE		166	14	SE

Section 5a - Unit 2

122	04	SE		059	20	NE		014	02	NE
028	25	NE		331	07	NW		216	25	SW
012	27	NE		031	22	NE		202	14	SW
172	14	S		208	16	SW		225	29	SW
233	22	SW		008	17	N		123	02	SE
030	61	NE		220	64	SW		284	22	NW
346	04	NW		033	27	NE		241	04	SW
060	10	NE		248	56	SW		092	27	E
082	05	E		237	02	SW		228	05	SW
177	16	S		022	06	NE		231	60	SW

Section 6 - 1-grey subunit of Unit 2

132	08	SE		160	33	SE		262	10	W
180	26	S		111	14	SE		298	08	NW
085	12	E		300	10	NW		084	10	E
080	08	E		290	05	NW		146	02	SE
248	10	SW		252	14	SW		217	17	SW
124	22	SE		063	25	NE		256	06	W
099	04	S		076	17	NE		271	02	W
188	31	S		071	38	NE		136	42	SE
104	07	SE		038	18	NE		265	01	W
122	04	SE		258	16	SW		260	02	W

Section 6 - Unit 3

284	58	NW		031	30	NE		086	16	E
064	07	NE		307	48	NW		278	09	W
140	07	SE		065	06	NE		130	18	SE
266	19	W		068	63	NE		093	03	E
200	29	SW		104	02	SE		066	68	NE
259	13	SW		036	17	NE		212	05	SW
077	01	NE		052	11	NE		257	19	SW
236	18	SW		262	07	W		250	29	SW
262	08	W		248	23	SW		242	19	SW
240	18	SW		303	07	NW		351	05	N

Section 7 - Unit 3

088	12	E		310	15	NW		210	15	SW
046	07	NE		311	02	NW		110	14	SE
122	18	SE		005	02	N		142	47	SE
032	22	NE		129	10	SE		136	19	SE
138	07	SE		146	10	SE		127	10	SE
310	02	NW		132	05	SE		294	01	NW
171	09	S		328	10	NW		126	25	SE
126	15	SE		170	16	S		130	27	SE
159	23	SE		138	04	SE		059	25	NE
130	12	SE		150	03	SE		130	12	SE
140	13	SE		322	08	NW		298	02	NW
131	22	SE		313	04	NW		137	04	SE

Section 7 - Unit 5

165	10	SE		139	02	SE		148	21	SE
246	06	SW		270	24	W		144	23	SE
098	06	E		163	22	SE		337	28	NW
011	15	NE		151	05	SE		013	50	NE
055	47	NE		096	06	S		341	11	NW
160	14	SE		159	02	SE		346	32	NW
022	08	NE		334	08	NW		294	09	NW
014	31	NE		145	13	SE		062	52	NE
353	03	N		017	10	NE		270	02	W
352	18	N		073	18	NE		051	52	NE

Section 8 - Unit 1

150	01	SE		000	17	N		283	09	NW
188	29	S		201	09	SW		316	13	NW
145	07	SE		339	02	NW		048	08	NE
135	05	SE		170	08	S		140	01	SE
122	28	SE		325	08	NW		278	26	W
060	50	NE		135	06	SE		146	20	SE
158	03	SE		152	12	SE		337	05	NW
141	14	SE		132	23	SE		323	48	NW
323	04	NW		334	32	NW		157	18	SE
158	34	SE		141	60	SE		214	12	SW

Section 9 - Unit 3

035	13	NE		046	00	NE		042	30	NE
030	78	NE		247	04	SW		239	80	SW
049	06	NE		182	12	S		221	30	SW
024	17	NE		049	10	NE		004	10	N
190	34	S		174	10	S		023	01	NE
086	32	E		170	29	S		092	20	E
176	02	S		036	08	NE		032	25	NE
186	12	S		024	40	NE		212	32	SW
289	05	NW		013	79	NE		234	10	SW
055	00	NE		000	10	N		194	20	SW

Section 10 - Unit 3

095	45	E		184	17	S		346	38	NW
095	25	E		154	14	SE		104	33	SE
110	20	SE		134	08	SE		141	42	SE
056	27	NE		179	20	S		222	08	SW
179	10	S		114	23	SE		108	46	SE
174	15	S		060	32	NE		205	02	SW
192	30	SW		347	29	NW		064	25	NE
148	12	SE		124	28	SE		334	27	NW
104	80	SE		151	07	SE		085	10	E
064	46	NE		359	55	N		078	25	E

APPENDIX 3 - STRIAE DATA

(Note: two numbers indicate a bidirectional striation while a single number indicates a unidirectional striation.)

Section 1, a ridge nearby the outcrop

Striae dir^{n}	bi / uni	Comment
061	bi	from dolerite boulder exposed on top surface of Sirius Group diamictite
051	bi	same as above
002	bi	same as above
011	bi	same as above
056	bi	same as above
025	bi	same as above
081	bi	same as above
080	bi	same as above
075	bi	same as above
096	bi	same as above
166	bi	same as above
035	bi	same as above
281	uni	same as above
249	bi	same as above
002	bi	same as above
174	bi	same as above
289	bi	same as above
090	bi	same as above
196	bi	same as above
327	bi	same as above

Section 2, Unit 3

Striae dir^{n}	bi / uni	Comment
144	bi	a set of 10-15 fine striae on a clast
009	bi	
026	bi	
015	bi	
359	bi	

Section 3, Unit 5 between 38-66 m

Striae dir[n]	bi / uni	Comment
017	uni	nailhead on bullet boulder
035	bi	striation from bullet boulder
014	bi	striation from bullet boulder
017	bi	striation from bullet boulder
049	bi	striation from bullet boulder
008	uni	nailhead from bullet boulder
030	bi	striation from bullet boulder
022	bi	set of 5-10 striae from underside of bullet boulder
066	bi	set of 5-10 striae from underside of bullet boulder
117	bi	set of 5-10 striae from underside of bullet boulder
013	bi	set of 5-10 striae from underside of bullet boulder
056	bi	set of many tiny abrasion marks 3-4 mm long on a boulder 1 m long - they modify all but one set of striae
012	bi	striation not modified by set of tiny abrasion marks on 1 m boulder
013	bi	striation not modified by set of tiny abrasion marks on 1 m boulder
016	bi	striation not modified by set of tiny abrasion marks on 1 m boulder
030	bi	striation not modified by set of tiny abrasion marks on 1 m boulder
015	bi	hair-thin striation on lee-end of a 1.3 m long boulder
360	bi	hair-thin striation on lee-end of a 1.3 m long boulder
022	bi	hair-thin striation on lee-end of a 1.3 m long boulder

Section 3, Unit 5 north of 66 m

Striae dir[n]	bi / uni	Comment
299	uni	nailhead on cobble
131	bi	hair-thin striation <1 cm long on cobble
108	bi	hair-thin striation <1 cm long on cobble
126	bi	hair-thin striation <1 cm long on cobble

Section 4, Unit 3

Striae dir[n]	bi / uni	Comment
060	bi	
057	uni	nailhead
068	bi	
062	bi	
046	bi	
044	bi	
036	bi	
224	uni	rat-tail on the lower, north end of a clast oriented 050-230
027	uni	

Section 5a, Unit 2

Striae dir[n]	bi / uni	Comment
048	bi	
060	uni	nailhead
058	bi	
180	uni	nailhead on the lee-end underside of a clast
078	bi	
078	bi	
068	bi	
071	bi	
123	bi	
088	bi	
079	bi	
082	bi	

Section 6, Unit 2

Striae dir[n]	bi / uni	Comment
072	bi	1-pink band - many rat-tails on a cobble fall within this range
060	bi	3-grey band - two weathered striae on a basalt cobble
063-068	bi	2-grey band - 20 striae within this range from a 4 cm pebble
080	bi	1-grey band - set of 12 striae on a pebble
063	bi	1-grey band
074	uni	1-grey band - rat-tail
074	uni	1-grey band - rat-tail
080	uni	1-grey band - rat-tail
081	uni	1-grey band - rat-tail
087-094	bi	1-grey band - range of a set of about 100 fine striae on a boulder
076	bi	4-pink band
076	bi	4-pink band
083	bi	4-pink band
083	bi	4-pink band
063	bi	4-pink band

Section 6, Unit 3

Striae dir[n]	bi / uni	Comment
077	bi	large scratch on a boulder
266	bi	
191	bi	
057	bi	
093	bi	
098	bi	first set of 30-50 striae on a boulder
108	bi	second set of 30-50 striae on the boulder
138	bi	third set of 30-50 striae on the boulder
108	uni	nailhead
096	uni	three rat-tails

Section 7, Unit 5

Striae dir^{n}	bi / uni	Comment
165	bi	
353	bi	
353	bi	
139	bi	
226	bi	
239	bi	
163	bi	
154	bi	
147	bi	
144	bi	
133	bi	
141	bi	
136	bi	
341	bi	striae on underside of pebble

Section 8, Unit 1

Striae dir^{n}	bi / uni	Comment
149	bi	range of 13 rat-tails on a clast
158	bi	
150	bi	
146	bi	
152-156	bi	range for a set of 20 striae
149	uni	rat-tail
132	bi	
149	bi	set of 15 striae
136	bi	
158	bi	

Section 8, Unit 2

Striae dir^{n}	bi / uni	Comment
092	uni	set of about 50 rat-tails all with same orientation

Section 9, Unit 3

Striae dir^{n}	bi / uni	Comment
233	bi	
191	uni	faint striae on top of stone
247	uni	striae on bottom of stone
004	bi	very faint striae on top and bottom

Section 10, Unit 3

Striae dir^{n}	bi / uni	Comment
260	bi	from the upper surface of a striated cobble
222	bi	
170	uni	fresh, crude striae on a 40 cm boulder exposed on top surface of the unit
152-174	bi	fine, (<1 mm) weathered striae on the 40 cm boulder
090	bi	striae on a cobble
122	bi	striae on a cobble

APPENDIX 4 - LEE-END DATA

Section 2, Unit 3

Lee-end	Comment
227	
193	
230	bullet
047	
057	
074	
240	

Section 3, Unit 5 between 38-66 m

Lee-end	Comment
022	bulleted boulder
040	1.3 m boulder

Section 3, Unit 5 north of 66 m

Lee-end	Comment
209	cobble lee-end

Section 4, Unit 3

Lee-end
072
051
078
041
071
036
000
046
032
026

Section 5a, Unit 2

Lee-end
028
352
346
060
058
031
071
194
036
022
104

Section 6, Unit 2

Lee-end	Comment
256	in 1-grey band
264	in 1-grey band
080	in 1-grey band
099	1-grey band - lee-feature on boulder

Section 6, Unit 3

Lee-end	Comment
277	
098	
126	shear direction of top part of clast

Section 7, Unit 3

Lee-end
046
310
185
309
133
110
126

Section 7, Unit 5

Lee-end
353
139
163
325
013

Section 8, Unit 1

Lee-end
136
145
143

Section 9, Unit 3

Lee-end	Comment
191	
002	reworked
041	
092	

Section 10, Unit 3

Lee-ends	Comment
134	
179	
104	
042	
154	
359-028	plucked features on 40 cm boulder exposed at top of unit
090	cobble

APPENDIX 5 - STRUCTURAL DATA

Section 1, Unit 1

Strike/Dip/Dir	Comment
129/09/NE	shallowly dipping plane that cuts through the top part of an injection of diamict (Unit 2) into the underlying coal breccia (Unit 1)

Section 1, Unit 2

Strike/Dip/Dir	Comment
141/42/NE	shear plane of large diamictite wedge
282/61/NE	steeply dipping fracture which cuts down through the diamict wedge

Section 3, Unit 3

Strike/Dip/Dir	Comments
268-088	30 m north of south end of exposure - fold axis of large sheared fold
168/75/SW	at 30 m north - shear plane
273-093	at 30 m north - fold axis of large sheared fold
337/08/NE	between 50-65 m - gently dipping diamictite-filled shear plane
341/46/NE	between 50-65 m - diamictite wedge intersecting the shear plane listed above

Section 3, Unit 4

Strike/Dip/Dir	Comment
064/20/SE	north of 66 m - shear planes with imbricated clasts
066/20/SE	north of 66 m - shear planes with imbricated clasts
035/23/SE	north of 66 m - shear planes with imbricated clasts
214/11/SE	north of 66 m - axial plane of a series of recumbent folds underlying the lowest of the three above shear planes

Section 3, Unit 5

Strike/Dip/Dir	Comment
254/42/N	average orientation of bedded sand in the lower part of a diamictite wedge
131/56/NE	30 m north - fracture near the large sheared fold
320/43/NE	30 m north - fracture near the large sheared fold
342/43/NE	30 m north - fracture near the large sheared fold
093/38/S	59 m north - fracture
270/89/N	north of 66 m - fracture
134/08/SW	65 m north - shear plane where a thin extension of coal has been pulled out of a pocket
093/17/S	north of 88 m - 3 shear planes 1 m long and 4 cm thick
100/10/SW	between 38-66 m - coal-laden shear plane
026/30/SW	between 38-66 m - fracture
054/73/SE	between 66-94 m - fracture
264/42/N	north of 66 m - 2 m long fracture extending down from top of diamictite into coal breccia below
072/84/SE	north of 66 m - mud-filled fracture 2 m long

Section 4, Unit 1

Strike/Dip/Dir	Comment
278/82/N	diamict-filled fracture 1.3 m long

Section 4, Unit 2

Strike/Dip/Dir	Comment
264/17/N	orientation of interstratified beds
357/52/E	1 cm thick sand-filled fracture

Section 4, Unit 3

Strike/Dip/Dir	Comment
117/08/SW	shear plane
202/24/NW	shear plane
170/78/W	fracture that runs down into the basal sandstone unit

Section 5a, Unit 1

Strike/Dip/Dir	Comment
200/07/NW	10 cm thick coal-dominated shear
200/07/NW	a sand and coal dominated shear
320/42/NE	thin (2 cm) fracture extending from the diamictite down to the coal shear
250/66/NW	left branch of a diamict-filled fracture that intrudes down into the breccia from the overlying diamictite
138/84/SW	right branch of a diamict-filled fracture that intrudes down into the breccia from the overlying diamictite

Section 5a, Unit 2

Strike/Dip/Dir	Comment
289/13/NE	orientation of the unit's basal contact across most of the exposure
334/05/NE to 334/20/NE	orientation range of curvilinear beds in a fracture immediately above the unit's lower contact
335/18/NE	fracture
292/65/NE	fracture
015/63/SE	fracture
016/66/SE	fracture
113/08/SW	horizontal fracture 20 cm below the top of the exposure at its southeast end
050/74/SE	fracture at the southeast end of the exposure
302/80/NE	fracture at the southeast end of the exposure
346/90	fracture at the southeast end of the exposure
265/83/N	fracture at the southeast end of the exposure

Section 5b, Unit 2

Strike/Dip/Dir	Comment
055/34/SE	shear plane at the north end of the outcrop
321/28/NE	distinct shear plane in the lower part of the south end of the outcrop below which diamict like that above the shear plane has flow features
084/24/S	fracture

Section 6, Unit 1

Strike/Dip/Dir	Comment
063/46/SE	upper contact of comminution zone
326/68/NE	fracture
058/26/SE	shear

Section 6, Unit 2

Strike/Dip/Dir	Comment
088/85/S	4-pink band - fracture
016/51/SE	4-pink band - fracture
049/14/SE	1-pink band - orientation of 1-pink band
016/51/SE	1-pink band - fracture
015/36/SE	4-pink band - orientation of 4-pink band
257/76/NW	1-grey band - fracture
162/79/SW	2-grey band - fracture

Section 6, Unit 3

Strike/Dip/Dir	Comment
114/70/SW	40 cm long lens of clast-supported granules
020/67/SE	fracture
036/41/SE	fracture which has sheared a clast in two
180/52/W	
021/29/SE	
029/15/SE	
000/35/E	

Section 7, Unit 2

Strike/Dip/Dir	Comment
041/32/SE	general orientation of laminae in the roof of the hollow

Section 7, Unit 3

Strike/Dip/Dir	Comment
338/14/NE	fracture
334/49/NE	fracture
338/12/NE	
120/67/SW	fracture set

Section 7, Unit 5

Strike/Dip/Dir	Comment
306/35/NE	fracture
359/59/E	
014/67/SE	
140/26/SW	
145/27/SW	
105/28/SW	
130/28/SW	
357/35/E	

Section 8, Unit 1

Strike/Dip/Dir	Comment
101/10/SW	orientation of inclined beds in Unit 1
004/84/E	fracture
044/08/SE	fracture running down from the top of the exposure
006/78/E	25 cm long and 3-4 cm wide fracture filled with clast-supported granules

Section 8, Unit 2

Strike/Dip/Dir	Comment
090/17/S	fracture
112/54/SW	fracture
108/31/SW	fracture
108/35/SW	fracture
103/82/SW	sand-filled fracture 2 cm wide at the southwest end of the section

Section 10, Unit 2

Strike/Dip/Dir	Comment
319/11/NE	Orientation of fracture that cuts under the dark sandstone block but it is curvilinear so only the strike is consistent
227/07/NW	another shear plane 30 cm that cuts across the southern half of the exposure
338/07/NE	measurement from different portion of previous shear plane.
349/76/NE	steeply dipping fracture in sandstone
331/73/NE	diamictite-injected fracture
322/26/NE	shear plane
329/58/NE	fracture in sandstone that is filled with muddy laminae and diamict that has flowed
329/58/NE	orientation of normal fault in a coal bed, has as throw of 4 cm and heave of 2 cm
322/78/NE	steeply dipping fracture in the sandstone
039	apparent extension direction of step-like normal faulting in carbonaceous beds

APPENDIX 6 - SAMPLES COLLECTED

Number	Sample Type	Location
VUW37429	Bulk diamict	Section 1, Unit 2 diamictite
VUW37430	Pebbles	Section 1, Unit 2 diamictite
VUW37431	Thin-section	Section 1, Mawson B boulder emplaced in Unit 2 diamictite nearby Section 1
VUW37432	Bulk diamict	Northwest Platform, P99120301
VUW37433	Pebbles	Northwest Platform, P99120301
VUW37434	Bulk diamict	Section 2, Unit 3 diamictite
VUW37435	Pebbles	Section 2, Unit 3 diamictite
VUW37436	Bulk diamict	Section 3, Unit 5 diamictite
VUW37437	Pebbles	Section 3, Unit 5 diamictite
VUW37438	Bulk diamict	Diamict intrusion near west side of contra ridge
VUW37439	Thin-section	P99123004, Mawson A, highland south of Camp Valley
VUW37440 ,41	Thin-section	P99123005, Mawson A, highland south of Camp Valley
VUW37442	Thin-section	P99123006, Mawson B, highland south of Camp Valley
VUW37443	Thin-section	P99123007, clastic dyke, highland south of Camp Valley
VUW37444	Bulk diamict	Section 4, Unit 3 - diamictite
VUW37445	Pebbles	Section 4, Unit 3 - diamictite
VUW37446	Bulk diamict	Section 5, Unit 2 - diamictite
VUW37447	Pebbles	Section 5, Unit 2 - diamictite
VUW37448	Bulk diamict	P00010501, diamictite patch on lower north flank of Trudge Valley near tent
VUW37449	Bulk diamict	P00010703 diamictite patch on lower south flank of Trudge Valley
VUW37450	Bulk diamict	P00010805, diamict in ice-cliff valley
VUW37451 ,52	Bulk diamict	P00010805, diamict in ice-cliff valley
VUW37453	Thin-section	P00010809, debris field beside ice-cliff
VUW37454	Bulk diamict	Section 6, Unit 2, 1-grey subunit 1.6 m above base of section
VUW37455	Pebbles	Section 6, Unit 2, 1-grey subunit 1.6 m above base of section
VUW37456	Bulk diamict	Section 7, Unit 5 diamictite
VUW37457	Pebbles	Section 7, Unit 5 diamictite
VUW37458	Bulk diamict	Section 6, Unit 2, 4-pink subunit 8.3 m above base of section
VUW37459	Pebbles	Section 6, Unit 2, 4-pink subunit 8.3 m above base of section
VUW37460	Bulk diamict	Section 6, Unit 3 diamictite
VUW37461	Pebbles	Section 6, Unit 3 diamictite
VUW37462	Bulk diamict	Section 8, Unit 1 diamictite
VUW37463	Pebbles	Section 8, Unit 1 diamictite
VUW37464	Bulk diamict	P00011909, diamictite lump on northwest side of cirque on south flank of Trudge Valley
VUW37465	Bulk diamict	Section 7, Unit 3 diamictite
VUW37466	Pebbles	Section 7, Unit 3 diamictite
VUW37467	Bulk diamict	Section 8, Unit 2 diamictite
VUW37484	Bulk diamict	Section 9, Unit 3 diamictite
VUW37485	Pebbles	Section 9, Unit 3 diamictite
VUW37486	Bulk diamict	Section 10, Unit 3 diamictite
VUW37487	Pebbles	Section 10, Unit 3 diamictite

APPENDIX 7 - GPS DATA

#	COMMENT	PDOP	# OF POSNS	LONG	LAT	NRTHIN (m)	EASTIN (m)	95% HPREC (m)	95% VPREC (m)	HAE (m)	MSL (m)
1	Trench dug in ridge on Triangle	4.5	516	159 39 51.4	76 42 27.3	442495.267	427218.972	1.965	3.92	1633	1686
2	Section 1	2.8	548	159 37 48.1	76 42 05.5	443128.308	426307.664	1.34	2.906	1607	1660
3		2.7	72	159 37 48.1	76 42 05.5	443128.035	426307.707	2.353	5.29	1607	1660
4	Striated Permian boulder in Beacon	6	505	159 39 50.8	76 42 03.3	443240.604	427178.789	1.785	4.1	1584	1637
5	Small outcrop of Sirius	4.5	562	159 40 53.3	76 42 36.9	442220.313	427674.34	1.455	4.436	1586	1639
7	Section JH1 - use this file	5.2	491	159 40 49.2	76 42 38.4	442171.468	427647.477	1.36	3.487	1591	1644
8	Striated Beacon surface	3.2	507	159 42 53.5	76 42 47.3	441939.71	428545.91	62.266	98.122	1550	1603
9	Old NZ fieldparty cache	5.1	532	159 45 14.9	76 43 04.7	441448.66	429577.59	62.392	98.32	1539	1592
15	Sirius patch Stop 1	5.1	503	159 45 31.2	76 42 54.5	441768.87	429679.52	63.074	99.395	1643	1696
16	Sirius patch N flank Stop 2	5.5	502	159 45 22.2	76 42 54.5	441765.84	429615.31	63.684	100.356	1561	1614
12	Sirius patch N flank Stop 3	3.7	402	159 45 18.7	76 42 54.3	441772.13	429590.03	0.819	1.7	1588	1641
18	Sirius patch N flank Stop 4	5.9	503	159 45 08.2	76 42 52.9	441809.80	429512.89	63.552	100.148	1555	1608
10	Sirius patch N flank Stop 5	5.4	234	159 44 58	76 42 50.5	441880.79	429437.31	1.268	3.188	1594	1647
21	Sir	2.5	12	159 44 55	76 42 48.1	441955.16	429412.15	97.77	154.069	1671	1725
22	JH9C	2.8	405	159 39 39.9	76 41 58.4	443386.429	427093.934	1.301	3.355	1588	1641
23	JH9A	5.2	389	159 39 27.5	76 42 04.5	443193.11	427014.644	2.174	6.41	1594	1647
24	JH6 A AND B (Section 5)	2.3	404	159 38 25.5	76 42 32.1	442317.023	426614.133	1.235	2.904	1642	1695
25	IHGNU	2.3	35	159 38 25.5	76 42 32.2	442316.162	426614.193	1.913	4.391	1643	1696
26	JH6 C (Section 4)	3.9	343	159 37 55.1	76 42 56.9	441539.42	426435.163	1.367	2.938	1669	1722
27	33 (Section 3)	3	403	159 37 12.6	76 42 18.4	442718.164	426074.286	1.43	3.729	1644	1697
28	JH7 D (Section 1)	4.6	401	159 37 47.6	76 42 05.5	443129.544	426303.573	1.687	5.761	1610	1663
29	JH10	4.3	395	159 37 50.5	76 42 11.7	442938.761	426334.332	1.545	3.92	1614	1667
30	P 3	3	519	159 36 58.3	76 42 27.9	442418.482	425986.984	1.014	2.564	1653	1706
31	Butter limit stop 2	5.9	535	159 37 19.3	76 42 33.6	442247.847	426145.16	1.514	5.067	1660	1713
32	Butter limit Stop 3	3.5	521	159 37 23.1	76 42 43.7	441937.048	426187.342	1.325	3.094	1674	1727
33	Butter on outcrop imm. west of Triangle	4.1	514	159 39 25.2	76 42 54.8	441635.178	427073.81	1.413	3.476	1692	1745
34	Boulder at top of Triangle	4.2	511	159 39 36.8	76 42 50.1	441786.276	427149.393	1.571	3.957	1698	1751
35	Section 7	5.7	501	159 41 11.5	76 42 49.3	441843.959	427822.224	1.875	4.842	1589	1642
36		4.3	145	159 38 46.7	76 41 51.8	443573.839	426704.15	2.442	8.005	1567	1620

Notes:

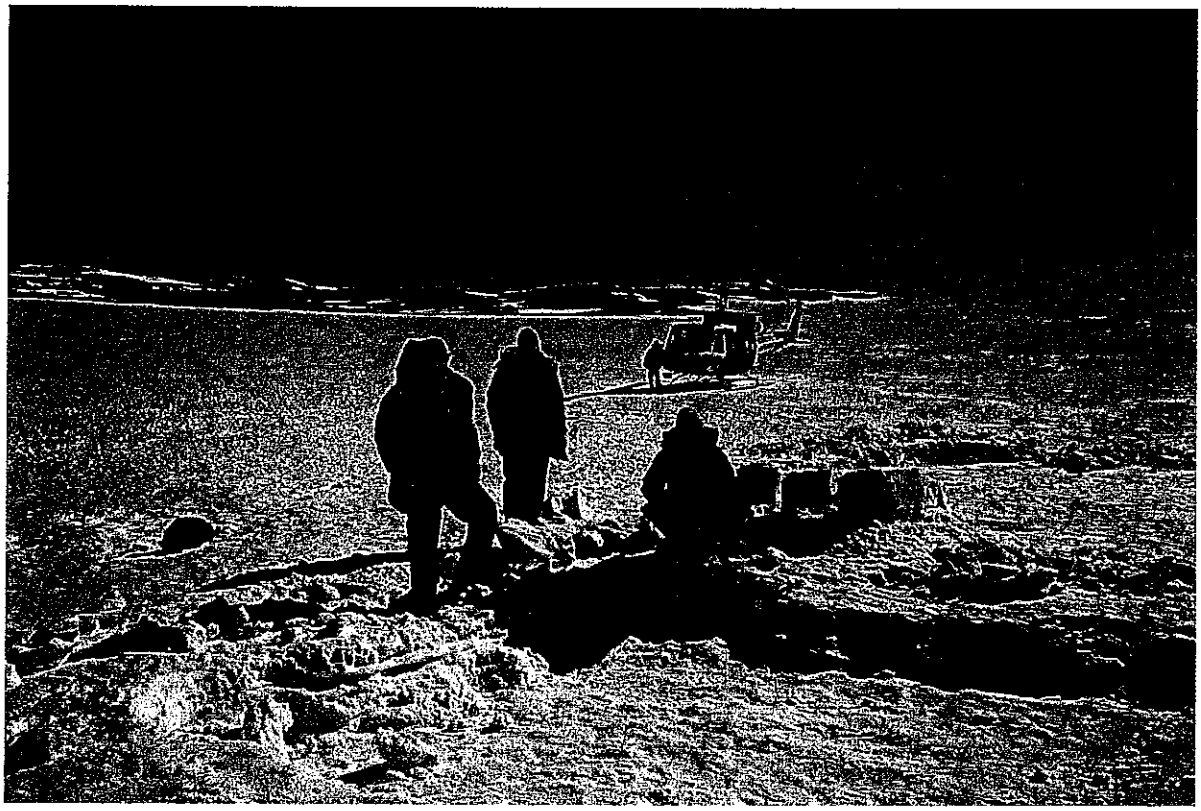
Those stations with an HPREC < 3 m have been differentially corrected.

Map grid references are generated based on the following data:

1st Standard Parallel:	76°40'00" S	Easting offset:	500 000 m
2nd Standard Parallel:	79°20'00" S	Northing offset:	300 000 m
origin of Latitude:	78°00'00" S	Ellipsoid:	WGS84
origin of Longitude:	162°30'00" E	Map projection:	Lambert Conformal Conic

List of abbreviations:

PDOP - Position Dilution of Precision, HPREC - Horizontal PRECision, VPREC - Vertical PRECision, HAE - Height Above Ellipsoid, MSL - height above Mean Sea Level.



Back cover: K042 Event members Mark Lloyd-Davies, Phil Holme and Jeremy Mitchell. Finished for the season and ready to head home - Jan 19, 2000.

Front cover: Looking northwest at Allan Hills from the top of Mount Brook, Convoy Range.