LOGISTICS REPORT

K047: Dating Relict Ice in the Dry Valleys
ANTARCTICA NEW ZEALAND 2005/06

Event Personnel:

Dr Warren Dickinson	Victoria University Wellington
Mr Martin Schiller	Victoria University Wellington
Ms Gretchen Williams	Victoria University Wellington
Dr Ron Sletten	University of Washington

Name of compiler:___________________Signature of compiler:_______________________

*AIMS

The ongoing aim of this project is to understand the origin and paleoenvironmental significance of relict ice from glaciers and lakes, which now lies buried by surficial sediments in many parts of the Dry Valleys. This phase of the project focuses on relict ice, buried in Lower Victoria Valley, which will be used as an analogue for relict ice in Beacon Valley. Of particular value will be the independent dating of sediments covering the ice using a new method of atmospherically derived beryllium-10.

Studies have shown that the use of atmospheric Be-10 to date Antarctic soil profiles gives equivocal results, and an independent test is needed. This requires sampling of a soil profile in a deposit of a known age. Such a deposit was sampled near the Hart Glacier in the Wright Valley.

In this field season, we also sampled the modern environments and stratigraphically recent ice deposits in Lower Victoria Valley as well as the modern and buried ice deposits in Beacon Valley. The main aim will be to analyse the ice for percentages of O_2, N_2 and Ar in the occluded gas bubbles. Ratios of these gases can be used to distinguish glacial and lake ice. The gas analyses will be used in conjunction with standard chemical (6 cations and 3 anions) and stable isotopic analyses to help characterize the ice. Results from this study will not only help with interpreting the origin of the buried ice but also test Hall's (2002) lake model for Victoria Valley.

*PERSONNEL

Name	Designation	Organisation	Departed Chch	Returned Chch
Warren Dickinson	Event PI	VUW	7 Nov	14 Dec
Ron Sletten	Colleague USA	Univ Washington	21 Nov	14 Dec
Gretchen Williams	Student	VUW	7 Nov	17 Dec
Martin Schiller	Student	VUW	7 Nov	22 Dec

*PLANNING

- *Application process*

The application process was organised in a professional and efficient manner. While the review process of the Antarctic Research Committee is rigorous and unbiased, the ranking/grading system lacks accountability, as the ranking results are not provided to the applicant. This also leaves the applicant without a clear understanding for several months of whether or not his/her event will have logistical support for the coming season.

- *Communications with Antarctica New Zealand staff*

Generally good

- *Provision of maps and aerial photographs*

Need for additional LIDAR data

- *Pre-season information*

Generally good

- *Medicals, documentation and flights to Antarctica*

Excellent

- *Environmental Advice*

- *Other comments*

*PREPARATIONS FOR THE FIELD

- *Reception and planning for your event*

- *Availability and condition of equipment received*

All equipment needs to be thoroughly checked out by event personel before leaving for the field. There should now be enough resources in the HFC to allow event personel to select from a variety of equipment.

- *Field training*

For those with previous Antarctic field experience, the AFT refresher is a reminder (in case people have short memories) of Antarctic conditions. However, Antarctica NZ should consider whether AFT is a beneficial and an efficient use of funds for personnel with continuous Antarctic field experience. As I understand, AFT was set up in 1995 for event personnel who had no Antarctic field experience within the last 5 years. It is not clear why this has changed to one of mandatory AFT every 3 years.

- *Field party equipment 'shakedown' journey*

All equipment was functional.

- *Delays at Scott Base, whatever the cause*

Weather

- *Safety and Risk Management processes*

I have considerable concern regarding the 'new' safety and risk management processes. It is not clear how these procedures contribute to improved safety in the field, which essentially relies on the equipment and judgment of event personnel in the field. These new proceedures should take into account previous experiences of the field party. Implementing these proceedures contributes to a substantial increase in the work load of both the science and base personel without, in my view, clear advances in field safety.

General comments about Scott Base

Scott Base staff were generally up to the usual high standards of 'can-do' and help that I have received in previous years.

Other comments

Comments such at those found on the BM report (11 Dec. 2005) were unwarrented.

*Event Diary

Date	Main Activities and Location	Other Comments
6 NOV	Arrive in ChCh, WD, GW, MS kit-up	
7 Mon	Depart for SB at 8:45pm C-17, ariv McM 2:10 dinner at SB; Base/AFT briefs	
8 Tue	SB; WD, AFT refresh & SB paper; GW, MS - AFT	Helo wts needed
9 Wed	SB; GW, MS -AFT continued; WD weighs helio loads	
10 Thu	SB; WD, MS, & GW pack field equipment	beautiful walk on the sea ice
11 Fri	SB, re-weigh field equipment, repacking of food boxes	
12 Sat	SB; Snow Day stand-by helio day	!
13 Sun	SB; Sleep in, rec-day	Wx clearing
14 Mon	SB to Victoria Valley Dunes 9:30am, WD, GW & MS: set up camp; Packard ice	Tour vly, late finish in eve
15 Tue	VV, Sampling ice near VLG	

16 Wed	VV, Sampling ice near VLG; plenty of snow drifts to stor spls	New ice drill works great
17 Thu	VV, Sampling dune & soils for OSL	
18 Fri	VV, Walk to L. Vida, examine/spl granites and gelifluction lobes	3hr walk dunes–central Vida
19 Sat	VV, Envi audit; spl packard ice and relict dunes	Envi audit needs practicality
20 Sun	VV, petro drill broken, hand cored dune spls	Helo w/ Blake; cuts storge cave
21 Mon	WV, move to WV Meserve Gl camp 10a; set up; recon to Hart ash outcrop;	Camp needs clean up
22 Tue	WV, found Hart ash, dug 2 pits.	Early dinner 7pm
23 Wed	WV, dug 2 more pits in Hart ash	
24 Thu	WV, walk 4hr to Prospect Mesa to examine sedimets, GW spl granites	Lg dust devel near Bull pass
25 Fri	BV, move to BV 10a, RS joins event; set up camp; recon to met sta	Beaut lt wind day
26 Sat	BV, WD & GW transect counts of clasts; MS & RS met sta & find polygon to spl	MS,GW sew guy loops on tent
27 Sun	BV, all walk 3hr to lower met sta. Clast profiles and examine Taylor ice front	Blowing 20-30kts all day
28 Mon	BV, WD, MS spl polygon at met sta. GW clast counts	RS repairs mst sta
29 Tue	BV, MS, RS & WD discuss 10Be sampling; GW clast counts	RS & WD find bad GPS bolt UV
30 Wed	BV walk to Mullens lake; RS measures 8 GPS positions	Snowing 4:30
1 Dec	BV, GW & MS clast counts Beacon Hts; WD & RS to B-10 met sta	Windy!
2 Fri	BV, MS & WD collect 10Be polygon spls on Mullins BV04, BV06; GW clast counts	Windy/snowy
3 Sat	KV, 2p move to Kennar Vly with photo tour of Beacon and Turnabout; set up camp	No wind, beaut day
4 Sun	KV, spl Metschel tillite; walk around pinnacle ridge 10hr walk; views awsome	Beaut day (no wind)
5 Mon	KV, Wallk to finger mtn 10hr return along Taylor Gl;	Beaut day, again no wind
6 Tue	KV, WD & RS spl soil pits cntral KV; MS & GW search for Metschel	Morn visit by Eric
7 Wed	KV, break camp early; move to SB not poss, too windy/snowy;	Winds gusting 40 kts
8 Thu	SB, Rob makes it in 9a; pack helo and av SB by 10:45	Winds gusting 20 kts
9 Fri	SB, clean equip; Andrill fam to Royds no herc from ChCh; K047 shout bar	1 Herc broke, 1 makes it down
10 Sat	SB, cleaning, sorting & packing of field equipment; GW to WV with K064	Beaker Babble talk not attended
11 Sun	SB, WD,& MS subsample VVice at HFC, used 18C rm	Ob Hill
12 Mon	SB, WD, & MS finish subsample ice	Bag drag WD & RS
13 Tue	SB. WD RS & MS tired of SB	RNZAF herc makes it
14 Wed	SB, Northbound Herc off 8:30a, hot cramped flt; no water!	In Welly by 9:30p

SB=Scott Base; VV=Victoria Valley; VLG = Victoria Lower Glacier; WV= Wright Valley, BV=Beacon Valley; KV= Kennar Valley
WD = Warren Dickinson; GW = Gretchen Williams; MS = Martin Schiller; RS = Ron Sletten

WEATHER

Generally good for field work in the Dry Valleys

*ACCIDENTS, INCIDENTS OR HAZARDS

None to report.

FIELD EQUIPMENT

- *Quality, suitability and performance of field clothing*

All new parkas and wind jackets should be a bright colour (yellow). Black, blue and green simply do not show up in the Dry Valley landscapes.

- *Performance and design of field equipment such as tents, technical climbing equipment, kitchen gear, primus boxes, sleep kits and sledges*

Lots of new gear coming on line, but proceed with caution. The old stuff works well and is tried and tested. Field parties were given choices on the new gear which is a good way to proceed. The new Macpac dome tents should not have been taken into the field without the modified flys.

- *20 person day ration box system*

OK for some uses but generally need to be repacked in to breakfeast, lunch and dinner for longer duration events; Field support people need to be flexible on this; Rationing of certain foods for field parties does not seem appropriate in some cases.

RADIO COMMUNICATIONS

- *Other comments*

Iridium is cheap comms for areas that cannot get VHF; Suggest HF be used as backup. However, the new HF radios are good.

ADDITIONAL EQUIPMENT TAKEN TO SCOTT BASE

Numerous items have purchased by K047 over the years, but this past season there were 2 issues; 1) A solar panel kit for charging computers in the field was promised by Antarctica NZ, and this piece of kit never arrived. Prudently, I brought my own solar panel charging kit, but this added 40 lbs of cargo to SB. 2) Because of past experience in trying to cram 4 people into a Scott tent for cooking and evening discussion, I purchased an Arctic Oven (AO) tent, which has been used sucessfully for winter camping on the north slope of Alaska. The tent has about the same floor space as an Endura but is half the weight and much easier to set up. Modifications were made to the AO tent to make it more wind resistant, but the tent was deemed to be unsafe for Dry Valley conditions. I was faced with not using the AO and taking an Endura, a situation which would put us over the allowable helio weight. A compromise was reached in that a Scott tent, which just put us under allowable weight, would be used as a backup. The AO tent weathered 40-50kt gusts in Beacon and Kennar valleys without problems.

- *Other comments*

*ENVIRONMENTAL IMPACT

*Sites Visited (please fill in a box for each site visited)

Site name	Victoria Valley
Site location (coordinates/description)	Central to lower Victoria Valley
Dates occupied	14.11.05-20.11.05
Total days (or hours) at site	6 days
Maximum number of people at site (your event)	3
Total person-days (or person-hours) at site	6 days
Main activity undertaken	Granite sampling, ice sampling
Cumulative impacts observed	no

Site name	Central Victoria Valley
Site location (coordinates/description)	At 77.37824773°S, 162.21840204°E. Polygon in Victoria Valley.
Dates occupied	20.11.05
Total days (or hours) at site	4 hours
Maximum number of people at site (your event)	3
Total person-days (or person-hours) at site	1 day
Main activity undertaken	Soil profile sampling
Cumulative impacts observed	no

Site name	Wright Valley
Site location (coordinates/description)	Central to lower Wright Valley
Dates occupied	20.11.05-25.11.05
Total days (or hours) at site	5 days
Maximum number of people at site (your event)	3
Total person-days (or person-hours) at site	5 days
Main activity undertaken	Granite sampling
Cumulative impacts observed	no

Site name	Hart Ash
Site location (coordinates/description)	Around 77.49694956°S and 162.37238330°E, located between Hart Glacier and Goodspeed Glacier in Wright Valley. About 100 m^2 of ash occurrence.
Dates occupied	22.11.05-23.11.05
Total days (or hours) at site	16
Maximum number of people at site (your event)	3
Total person-days (or person-hours) at site	4 days
Main activity undertaken	Soil profile sampling
Cumulative impacts observed	minor surface disturbance

Site name	Central Beacon Valley
Site location (coordinates/description)	77.84823127°S 160.60356494°E, a polygon in central Beacon Valley close to the MetStation
Dates occupied	28.11.05-29.11.05
Total days (or hours) at site	2 days
Maximum number of people at site (your event)	4
Total person-days (or person-hours) at site	3 days
Main activity undertaken	Soil profile sampling
Cumulative impacts observed	minor surface disturbation

Site name	Mullins Glacier
Site location (coordinates/description)	Around 77.88421663°S, 160.54304995°E, debris covered glacier in Beacon Valley
Dates occupied	30.11.05-2.12.05
Total days (or hours) at site	12 hours
Maximum number of people at site (your event)	2
Total person-days (or person-hours) at site	2.5 days
Main activity undertaken	Soil profile sampling, bulk soil sampling
Cumulative impacts observed	no

Site name	Beacon Valley
Site location (coordinates/description)	(77.86343143°S, 160.59164261°E); whole Beacon V.
Dates occupied	25.11.05-2.12.05
Total days (or hours) at site	7 days
Maximum number of people at site (your event)	2
Total person-days (or person-hours) at site	7 days
Main activity undertaken	Granite sampling
Cumulative impacts observed	no

Site name	Kennar Valley
Site location (coordinates/description)	Kennar Valley
Dates occupied	3.12.05-7.11.05
Total days (or hours) at site	2 days
Maximum number of people at site (your event)	4
Total person-days (or person-hours) at site	3 days
Main activity undertaken	Granite sampling
Cumulative impacts observed	no

Geological Material

Location (coordinates if available)				weight
	Hart Ash	77.49694956S	162.3723833E	4
	Hart Ash	77.49596251S	162.37243778E	3
	Hart Ash	77.49624859S	162.37364142E	2
	Hart Ash	77.49582731S	162.37311353E	3.6
	Beacon V.	77.90286116S	160.59456361E	0.5
	Beacon V.	77.89881815S	160.58747311E	0.5
	Beacon V.	77.89552281S	160.58025009E	0.5
	Beacon V.	77.89235939S	160.57461745E	0.5
	Beacon V.	77.89052702S	160.57097208E	0.5
	Beacon V.	77.88660337S	160.56343926E	0.5
	Beacon V.	77.88344541S	160.5584449E	1.5
	Beacon V.	77.8864333S	160.55063331E	0.5
	Beacon V.	77.88421663S	160.54304995E	0.5
	Beacon V.	77.84823127S	160.60356494E	3.5
	Victoria V.	77.37824773S	162.21840204E	1.5
	Victoria V.	-	-	5
	Beacon V.	-	-	25
	Kennar V.	-	-	5
	Wright V.	-	-	5
Specimen type	Soil, rocks			
Quantity (kg)	68.1 kg			

Disturbance to ice-free areas

Location (coordinates if available)			
	Hart Ash	77.49694956S	162.37238330E
	Hart Ash	77.49596251S	162.37243778E
	Hart Ash	77.49624859S	162.37364142E
	Hart Ash	77.49582731S	162.37311353E
	Beacon V.	77.84823127S	160.60356494E
	Victoria V.	77.37824773S	162.21840204E
Nature of disturbance	Soil pit (one each site)		
Approximate area of disturbance (m^2)	12 m^2 (12 / 6 sites = 2 m^2 each site)		
Evidence of previous site use	no		

Antarctica New Zealand

IMMEDIATE SCIENCE REPORT

K047: Dating Relict Ice in the Dry Valleys
ANTARCTICA NEW ZEALAND 2005/06

Event Personnel:

Dr Warren Dickinson	Victoria University Wellington
Mr Martin Schiller	Victoria University Wellington
Ms Gretchen Williams	Victoria University Wellington
Dr Ron Sletten	University of Washington

1 Scientific Programme

a. Context of research

The 8 Ma relict ground ice in Beacon Valley, Antarctica has been the topic of much debate since Sugden and others reported it in 1995 (Sugden et al. 1995). There is little debate about the age of the volcanic ash, which dates the ice, but the emplacement of this ash and origin of the ice continues to be a matter of contention. The occurrence of relict ice is not unique to Beacon Valley, with a range of occurrences now reported throughout the Dry Valleys (Dickinson et al. 2003a). Such ice is likely to be much older than even the oldest ice in the present ice sheet, making it important because of the paleoenvironmental and paleobiological record it may contain. The ice also represents a terrestrial analogue for ice that is thought to exist on Mars. Thus, the overall aim of this ongoing project is to understand all aspects of relict ice in the Dry Valleys and the information that it can provide. The specific aim of this proposal is to obtain observations and materials for establishing the setting of these ice bodies and dating the length of time they have been in their present situation. The latter can be achieved by a new method that is based on the undisturbed accumulation of ^{10}Be in the rock debris overlying the ice.

In addition to Beacon Valley, relict ice has now been confirmed to exist in Pearse, Columnar, Kennar, and Victoria Valleys, and is thought to be widespread throughout the Dry Valleys (Fig. 1). Studies associated with this project suggest that relict ground ice in the Dry Valleys can originate from either stranded remnants of glaciers (Marchant et al. 2002; Sugden et al. 1995) or buried glacial lakes (Hall et al. 2002; Kelly et al. 2002). Ground ice that is not relict may also result from a variety of *in situ* processes (Dickinson et al. 2003a; Dickinson and Rosen 1999; Dickinson and Rosen 2003). Relict ground ice appears to have been stranded in valley bottoms and is found as a continuum between two end-members: 1) massive clear ice with bubbles and trace amounts of debris to 2) highly deformed, debris-rich ice. The massive ice may derive from lake ice or ice cored moraines of wet-based glaciers pre-dating the present valley floors or ice cored moraines from the margins of the more recent cold-based glaciers. Highly deformed debris-rich ice may result from accumulated strain of multiple advances and retreats of cold-based glaciers (Fitzsimons et al. 1999). Clues to these origins may be determined from the chemistry and stable isotopic ratios of the ice as well as gas analysis of its bubbles. Such studies will need to be complemented with descriptions and analyses of the surrounding glacial sediments.

The age of the relict ice is critical to its value as a record of past climate. The difficulties in dating it are best exemplified by the numerous and conflicting ages, which range from 0.5 to 8Ma, published for Beacon Valley ice (Schafer et al. 2000; Stone et al. 2002; Sugden et al. 1995; Tschudi 2000; Ng et al. 2005). We have collected samples of relict ice and its overlying sediment for use in a new and evolving dating technique that involves the use of atmospherically-derived ^{10}Be. This technique has been used with limited success for over a decade in dating soils from temperate areas. Recently, it has been applied to Antarctic soils (Graham et al. 1995; Graham et al. 2002) and sediments

(Dickinson et al. 2003b) where it has produced logical and reasonable dates. However, the method needs further development and testing against a surface of known age. For this we have collected samples of Hart Ash between the Meserve and Hart glaciers in the Wright Valley. This ash has a radiometric date of 3.9 Ma.

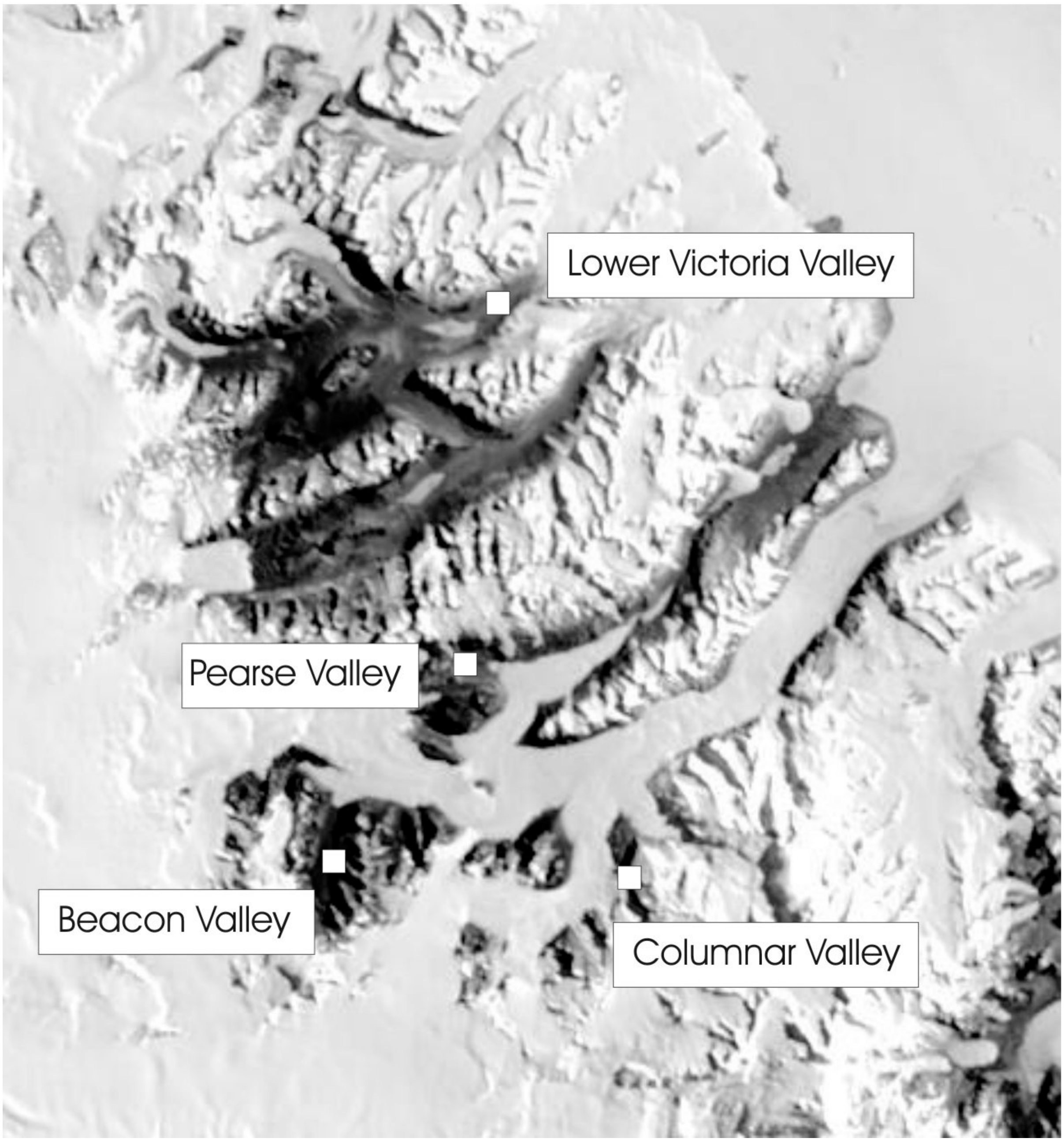

Figure 1. Locations of valleys known to contain ancient ice.

Our approach to dating the surface of the relict ice uses ^{10}Be produced in the upper atmosphere, which in Antarctica, accumulates in the salt components of the soil surface through snowmelt and evaporation (see method section for more detail). Atmospherically-derived ^{10}Be differs in concentration by 1-2 orders of magnitude from the ^{10}Be produced *in situ* that is used for surface exposure dating. In soils and sediments from three other areas in Antarctica (Dickinson et al. 2003b; Graham et al. 1995; Graham et al. 2002), we have assumed a closed system of 10Be accumulation. We also assume the $^{9}Be/^{10}Be$ ratio is fixed at the surface, and we think it is locked into clays and salts. We found that the $^{10}Be/^{9}Be$ ratio of the fines decreased systematically with depth to yield a decay age for the soil and sediment. The decay with depth suggests that Be is somehow infiltrating into the ground, by a process we do not fully understand. Nevertheless, the decay ages that we have obtained are reasonable for the soils and sediment analysed. We believe that this method should be applicable to dating the soils and ice-cemented sediments that overlie relict ice in the Dry Valleys, and indeed other parts of the Transantarctic Mountains.

b. Objectives

Lower Victoria Valley (14 – 21 Nov)

1) Sample ice in modern glacial and lake environments at snout of Lower Victoria Glacier. Sample buried ice and ice cemented sediment down valley (stream) from Lower Victoria Glacier.

2) Sample several soil profiles for atmospheric Be-10 on top of buried ice, down valley from Lower Vic Glacier.

3) Sample inflationary sand soils on the interfluves of lateral melt water channels. These sands will be dated by OSL to get an accumulation rate and approximate age of interfluve surface.

4) Collecting samples of granite plutons for Pb-Pb isotopic fingerprinting. This information will be used to identify sources of granitic clasts in glacial tills.

Wright Valley – Meserve Glacier (21 – 25 Nov)

1) Sample several soil profiles, which are associated with the Hart Ash, for Atm Be-10. The Hart Ash has a K-Ar date of 3.9Ma and this will allow an independent test of the Be-10 method of dating.

2) Observe Miocene-Pliocene sediments at Prospect Mesa to understand the context of the Hart Ash.

Beacon Valley (25 Nov – 3 Dec)

1) Sample several soil profiles for Atm Be-10 to understand relative rates of processes which occur in on top of the buried ice to .

2) Collection and mapping of granite clasts in till deposits in and around Beacon Valley. These data will be used to fingerprint the granites to help understand their source in the tills.

Kennar Valley (3 – 8 Dec)

1) Collection of granite clasts from the Metschel Tillite. These samples will be ananlyed for Pb-Pb isotopic fingerprinting to understand their source and determine if they could contribute to tills in Beacon Valley.

2) Reconnaissance of buried ice in the valley. If ice is present, then to understand its context with buried ice in Beacon Valley.

c. **Methodology**

Sampling sites were selected for the occurrence of massive relict ice. At each site, a 1.5 square metre pit was dug into the ice free soil or sediment above the relict ice. In some areas ice cemented sediment was above the relict ice. This was sampled by means of a small gasoline powered hammer drill with a diamond or carbide core bit. Once into the relatively sediment-free relict ice, a sipre auger with carbide cutters was used to core to a depth of about one metre.

Ian Graham and co-workers at GNS, Lower Hutt, will carry out the dating method using atmospheric ^{10}Be. The procedure will be similar to that used in previous studies (Dickinson et al. 2003b; Graham et al. 1995; Graham et al. 2002). To streamline the method, we will only process the >62 micron fraction of sediment which we believe contains most of the Be.

Samples of granite used for fingerprinting will be cut (1-2 cm^2 slabs) and rough polished. These will be placed in a laser ablate chamber attached to a multi-collector mass spectrometer. Lead isotopes 204,206 and 207 will be measured in the feldspars of each sample. Plots of $^{207}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ will show areas of feldspar genesis which are unique to the magma bodies where granitic rocks crystallize. The Lead isotopic composition of feldspars are incorporated at the time of crystallization and form distinctive signatures which can be used for tracing the origin of the feldspar.

d. Results and discussions

Three members of the event spent 7 days in Lower Victoria Valley from 14 - 21 Nov and 4 days near the Meserve Glacier in the Wright Valley from 21 - 25 Nov. Ron Sletten joined the event in for 8 days in Beacon Valley (25 Nov – 3 Dec) and 5 days (3 - 8 Dec) in Kennar Valley. All totalled we collected 35 kg of surface sediments and about 40kg of granite. Preliminary mapping of granite clasts in Beacon Valley show they are concentrated in the northeastern part of the valley. There appears to be about 5 different types of granites which can be identified in hand sample. Further results will have to wait for laboratory analysis.

e. How this research fits in with future work being planned

Future research by this investigator will centre on the geochemistry and dating of relict ice and permafrosted sediments obtained from shallow cores. Based on the outcome of the proposed work, the intention for the 2007/08 season will be to core areas of relict ice. Experience has shown that two drilling areas per season are logistically and scientifically the most productive use of resources and time. However, a season between coring seasons for analysis of samples is necessary.

In two years, we hope to have funds available to drill Beacon Valley in a joint project (Chris McKay) with NASA. Beacon Valley contains an undertermined thickenss of debris-laden ice. The present shallow coring system provides the technical development and expertise that will be necessary to drill Beacon Valley, but the system will need to be scaled up in size. The McKay proposal calls for the development of a ‘smart’ drill head that is capable of obtaining aseptic samples and has sensors to determine the presence of organic material and conduct microbiological assays through non-destructive methods.

f. Contributions from visiting foreign scientists

This past season, is part of an on-going project that utilises shallow drilling technology in the Dry Valleys to study permafrost and relict ice. The project has numerous collaborations and linkages but one collaboration occurred for this season. Ron Sletten of the University of Washington provided expertise in the Beacon and kennar valleys and he will provide chemical and stable isotopic analyses of the relict ice samples.

2 Publications

A paper on landscape modification by meltwater from the Packard Glacier has been submitted to Boreas in Dec 2005. Results from OSL sampling of Victoria Valley sediments will be published as a paper in Holocene in May 2005. Results from the ^{10}Be anaysis will first be published as an MSc thesis at Victoria University in 2006. Results from granite fingerprinting will be first published as an Hons Thesis at VUW. Copies of these will be sent to Antarctica NZ.

Further publications of the scientific results will be published in international peer-reviewed scientific journals. Copies of this work will also be sent, when available, to Antarctica NZ.

3 Acknowledgments

Thanks to the following:
Prof Peter Barrett, (Director, Antarctic Research Centre, VUW)
Dean Peterson, Paul Woodgate and Steve Brown (Antarctica NZ)
All of the Scott Base personnel (Nov-Dec 2005)
Websters Drilling, for equipment preparation and cargo handling

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Antarctica New Zealand; University Grants Committee, VUW; Foundation of Research and Technology, NZ

K049
2005/06

LOGISTICS REPORT

K049 NZ – ITASE: Holocene Climate Variability along the Victoria Land Coast
ANTARCTICA NEW ZEALAND 2005/06

Event Personnel:

Dr Nancy Bertler	Antarctic Research Centre, Victoria University of Wellington
Mr Alex Pyne	Antarctic Research Centre, Victoria University of Wellington
Mr Mark Morrison	Antarctica New Zealand

Name of compiler: Nancy Bertler Signature of compiler:____________________

*AIMS

Seven key locations were identified for the NZ ITASE (International Transantarctic Scientific Expedition) programme. The analyses on the ice core from the first site, Victoria Lower Glacier in the McMurdo Dry Valleys, have been completed. During the 2003/04 field season we carried out a detailed reconnaissance of sites 2 and 3: Evans Piedmont Glacier (EPG) and Mt Erebus Saddle (MES) and determined the most suitable locations of the ice core recovery. During the 2004/05 field season we recovered to intermediate length ice cores (180m and 200m, respectively) from these locations and conduct further in-situ measurements, such as borehole temperature and light penetration characteristics, snow density and stratigraphy and its geographical variability. Furthermore, we installed a weather station and mass balance devices at EPG and cased the borehole at MES for future measurements. During the 2005/06 field season we re-visited VLG and EPG to conduct GPS measurements of the submerge velocity devices and to sample shallow snow pits. Furthermore, we retrieved the meteorological data and carried out maintenance work on the automatic weather station at EPG. Lastly we deployed 6m snow stakes at the high accumulation site at Mt Erebus Saddle.

The NZ ITASE programme has five objectives:

1. ITASE-Objective
   The focus of the New Zealand ITASE group is to provide information from the climate sensitive, low altitude, coastal sites. This will capture the climate signature of the troposphere, which represents a regional account on the Ross Sea climate. The ice core data are expected to provide a record of air temperature, snow accumulation, precipitation source, atmospheric circulation strength, storm frequency, sea ice variation, ocean productivity, and anthropogenic influences. The results will help to decide whether the Ross Sea region is currently cooling or warming with a longer-term prospective, taking low frequency climate variability (100 to 1000 year cycles) into account. Furthermore, proposed tele-connections such as the Amundsen Low-ENSO correlation [Bertler et al. 2004; Meyerson et al. 2002] or the Southern Hemisphere Annual Mode [Thompson and Solomon 2002] can be further constrained.

2. Latitudinal Gradient Project Objective
   The project is expected to contribute substantially to the Latitudinal Gradient Project, as it can provide a history of temperature, humidity, sea ice cover, precipitation source, atmospheric circulation, and ocean productivity along the Victoria Coast for the last 200 to 10,000 years. Furthermore, the timing and velocity of the Ross Ice Shelf retreat some 9 to 5ka years ago is still discussed controversially [Hall and Denton 2000; Steig et al. 1998; Steig et al. 2000].

3. ANDRILL Objective
   The ice core locations 2 and 3 (Evans Piedmont Glacier and Mt. Erebus Saddle) are in the vicinity of planned ANDRILL coring locations (Granite Harbour and Windless Bight). The ice core records will provide a high resolution climate dataset, which serves as a reference for the younger part of marine record recovered through ANDRILL.

4. Longer-Term Mass Balance Objective
   During the 1999/2000 season mass balance measurement devices (submergence velocity method [Hamilton and Whillans 2000; Hamilton et al. 1998]) have been deployed at Victoria Lower Glacier. The device has since been revisited during season 2000/2001 and 2001/2002. The measurements show that the glacier has a slightly negative mass balance, losing around

12cm thickness per year. A continuation of the measurements will allow monitoring changes in the ablation intensity of the McMurdo Dry Valleys.

5. The Antarctic – New Zealand Connection Objective
New Zealand's future economic and social development, environmental sustainability, and infrastructural planning critically relies upon the accurate assessment of the impact of "global warming" in our sector of the planet. Future climate change is a result of both natural variability and anthropogenic influence. A joint programme between IGNS, University of Maine, Victoria University is investigating ice core records from New Zealand (Tasman Glacier and Mt. Ruapehu ice field). The comparison between our NZ and Antarctic ice core records will provide much needed data for the development of realistic regional climate models to predict NZ climate in the 21th Century [Mullan et al. 2001].

*PERSONNEL

Name	Designation	Organisation	Departed Chch	Returned Chch
Nancy Bertler	PI	Antarctic Research Centre, Victoria University	24 Nov 05	06 Dec 05
Alex Pyne	Engineer	Antarctic Research Centre, Victoria University	16 Nov 05 (K001)	06 Dec 05
Mark Morrison	Field Safety	Antarctica New Zealand	NA	NA

*PLANNING

- *Application process*

  The application process was organised in a professional and efficient manner. While we feel that the review process of the Antarctic Research Committee is rigorous and unbiased, the ranking/grading system lacks accountability, as the ranking results are not provided to the applicant. This also prevents the applicant to improve future applications.

- *Communications with Antarctica New Zealand staff*

  Communication with Antarctica New Zealand staff was professional, timely, and effective.

- *Provision of maps and aerial photographs*

  N.A.

- *Pre-season information*

  In late May 2005 we were informed that our planned work at Cape Hallett (GPR and drilling of 200m ice core) could not be supported due to Antarctica New Zealand logistics constraints. For this reason our programme was condensed to our long-term mass balance monitoring at Victoria Lower Glacier and the maintenance work on the automatic weather station at Evans Piedmont Glacier. Furthermore, Antarctica New Zealand accommodated an additional visit to Mt Erebus Saddle to deploy snow stakes for mass balance measurements.

- *Medicals, documentation and flights to Antarctica*

  The information received was timely and valuable

- *Environmental Advice*

  The information received was timely and valuable

- *Other comments*

  In our experience over the last years, Antarctica New Zealand excelled through practical, innovative approaches and reasonable flexibility to evolving situations and opportunities. In contrast, we feel that last season, communication and discussions on the practical execution of fieldwork preparations were noticeable bureaucratic and lacked some of the flexibility that has made the New Zealand programme so successful. While growing demands and challenges may necessitate the organisation to streamline, we would hope that the practical and innovative spirit of the New Zealand programme will be retained and not exchanged for a bureaucratic and removed administration.

*PREPARATIONS FOR THE FIELD

- *Reception and planning for your event*

  The reception was well organised, friendly and efficient. The main issues of the event were promptly discussed and organised.

- *Availability and condition of equipment received*

  The equipment requested from Scott Base was supplied in good condition.

- *Field training*

  The re-fresher AFT for Pyne and Bertler was helpful and appreciated. The frequency of full AFT requirements for experienced people should be reviewed to take account of personal experience and regular Antarctic activity that includes fieldwork. The current 3-year frequency is too short and has changed from the 5-year frequency implemented by Rex Hendry.

- *Field party equipment 'shakedown' journey*

  N.A.

- *Delays at Scott Base, whatever the cause*

  Unsuitable weather conditions at the start of our schedule delayed the deployment of mass balance snow stakes at Mt Erebus Saddle until the end of our field deployment. Good weather conditions and a smooth flight plan permitted all other moves to be carried out according to schedule.

- *Safety and Risk Management processes*

  Safety and risk management is a difficult task and benefited from the personal experience of the Antarctica New Zealand coordinator. However, the established process does not take into account local knowledge and/or experience of the field party. To allow a realistic evaluation we recommend to establish a process that includes a memory of previous seasons. This will not only benefit the evaluated group and Scott Bases resources but represents a useful data base for groups going for the first time to locations that have been visited previously by other groups.

- *General comments about Scott Base*

  Scott Base staff created a friendly, professional, and supportive environment. We are grateful for the enthusiastic and helpful support we received. The new HFC is an excellent facility to test field and science equipment, to pack helicopter loads and to prepare cargo shipment. The use of the elevator in the HFC should be open to science groups moving polar tents and other field equipment between floors. It is difficult to understand why it requires currently a Scott Base operator to do this for the field groups.

- *Other comments*

  Overall, we experienced a significant increase in paper work. The requirement for each field party member to fill out a Scott Base Clearance Form seems excessive and impractical.

FIELD TRANSPORT

- *Vehicles*

  N.A.

- *Aircraft Operations*
- All aircraft operations were performed professionally. We are also particular grateful for the reliable and experienced support of HNO.

- *Ship Operations*

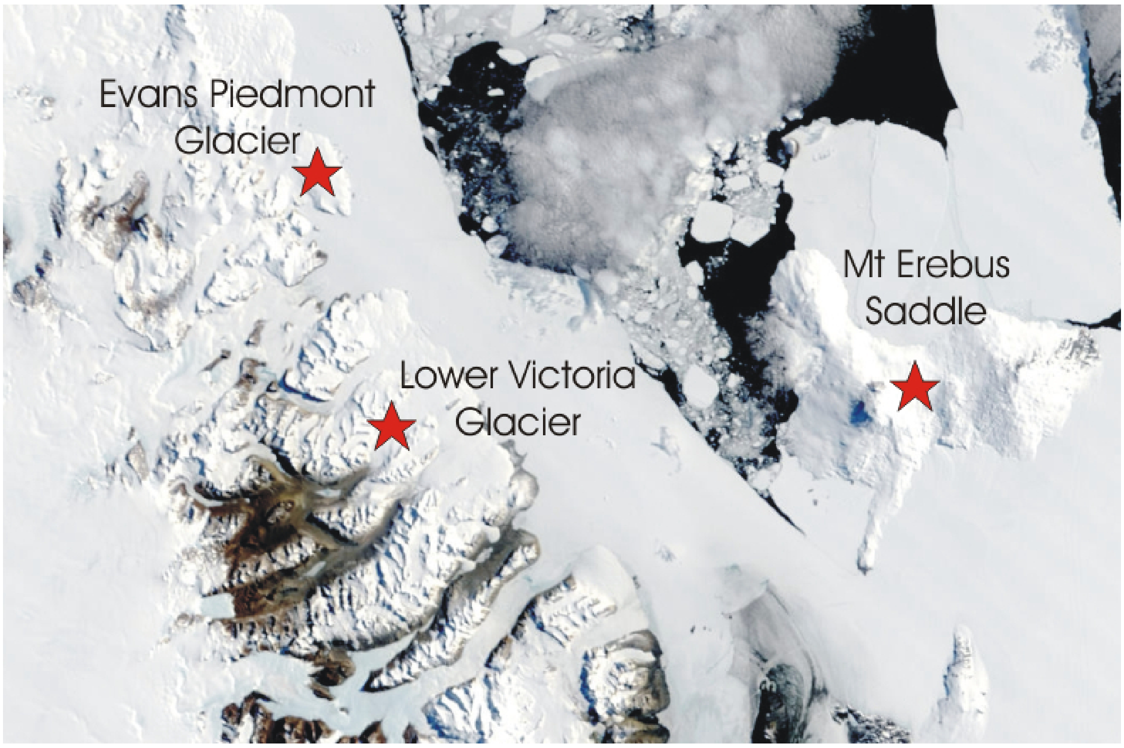
  N.A.

*EVENT DIARY

Date	Main Activities and Location	Other Comments
24/11/05	Arrival at Scott Base	
25/11/05	AFT re-fresher for Bertler	
25/11/05	Bad weather prohibits input to Mt Erebus Saddle (MES) for deployment of mass balance snow stakes	
28/11/05	Bertler, Pyne, Morrison deploy to Evans Piedmont Glacier (EPG) with HNO (1shuttle). Field camp set-u and initiation of GPS mass balance measurement	
29/11/05	Sampling of multiple, 1m deep snow pits for high resolution analysis updating the record derived from EPG deep core in 2004. Investigation of	

	snow pits for geographical variability in snow stratigraphy. Continuation of GPS measurements for submergence velocity devices. Data retrieval from automatic weather station. The weather station was raised 30cm but remained at the original sites. General maintenance and repair of three sensors (pressure, wind direction and wind speed) were carried out.	
30/11/05	Completion of snow pits sampling for high resolution analysis. Investigation of snow pits for geographical variability in snow stratigraphy. Completion of GPS measurements for submergence velocity devices. Completion of maintenance work on automatic weather station.	
01/12/05	Bertler, Pyne, Morrison deploy to Victoria Lower Glacier (VLG), with HNO (1shuttle). Field camp set-up. Ski to Staeffler Ridge to set-up GPS base station. Initiate base station and rover GPS measurements for submergence velocity devices at VLG I.	
02/12/05	Initiation of rover GPS measurements for submergence velocity devices at VLG II. Sampling of multiple, 1m deep snow pits at VLG I for high resolution analysis updating the record derived from VLG 180m deep core in 2002. Investigation of snow pits for geographical variability in snow stratigraphy. Continuation of base station and rover GPS measurements for submergence velocity devices.	
03/12/05	Check on base station at Staeffler Ridge, base station and rover GPS measurements for submergence velocity devices, and high resolution snow pit sampling. Completion of measurements at VLG II and retrieval of submergence velocity device.	
04/12/05	Completion of base station and rover GPS measurements for submergence velocity devices. Dissembling and retrieval of base station.	
05/12/05	Bertler, Pyne, Morrison return to Scott Base with HNO (1shuttle) Bertler, Pyne, Morrison deploy for 1.5 hours to MES for installation of 6m snow stakes.	

EVENT MAP


Evans Piedmont
Glacier
Lower Victoria
Glacier
Mt Erebus
Saddle

*WEATHER

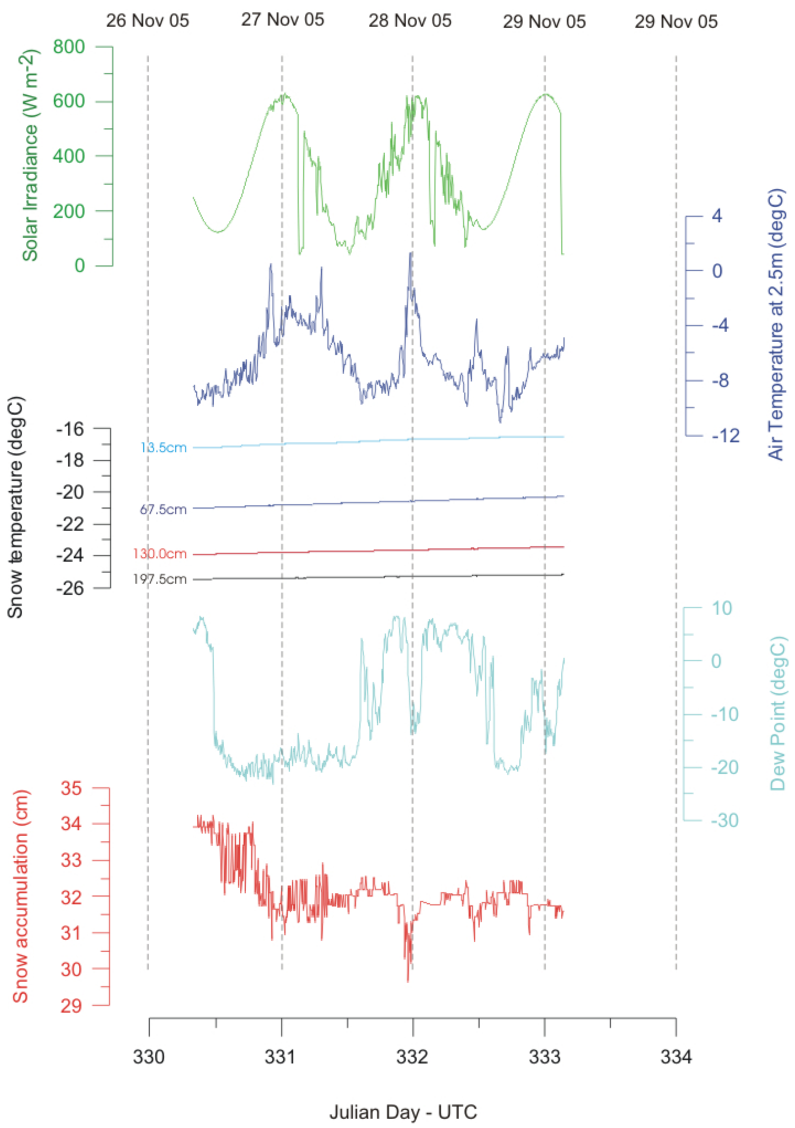


Fig. 1: Most recent weather data from the automatic weather station at Evans Piedmont Glacier

*ACCIDENTS, INCIDENTS OR HAZARDS

N.A.

FIELD EQUIPMENT

- *Quality, suitability and performance of field clothing*

  The issued field clothing was of suitable for the warm, calm weather conditions we encountered. However, we would like to reinforce our recommendation from last year that Antarctica NZ should investigate active field clothing that is warmer than the standard ECW's, less bulky, sheds snow and is semi waterproof for some filed parties working in cold glacial locations.

- *Performance and design of field equipment such as tents, technical climbing equipment, kitchen gear, primus boxes, sleep kits and sledges*

New Macpac Dome Tents

The new macpac tents represent a good, light-weight alternative to polar tents in warm, calm conditions for short field deployments. The tent is easy and fast to pitch and is spacious for two people. However, the tent is like the Olympus model very temperature sensitive. As seen in Fig.2 during our field deployment, the temperature in the Olympus tent changed by as much as 12ºC within a couple of hours, while air temperature only showed moderate changes and remained below 0ºC. These fluctuations, caused by solar heating or cooling during cloudy periods impact on the sleep quality as a sleeping person will be either too cold or too warm over the course of the night. Moreover, the outer cover of the tent is of light quality and only suitable for calm conditions to moderate winds (<30knots). In addition, the lack of snow flaps prevented secure pitching.

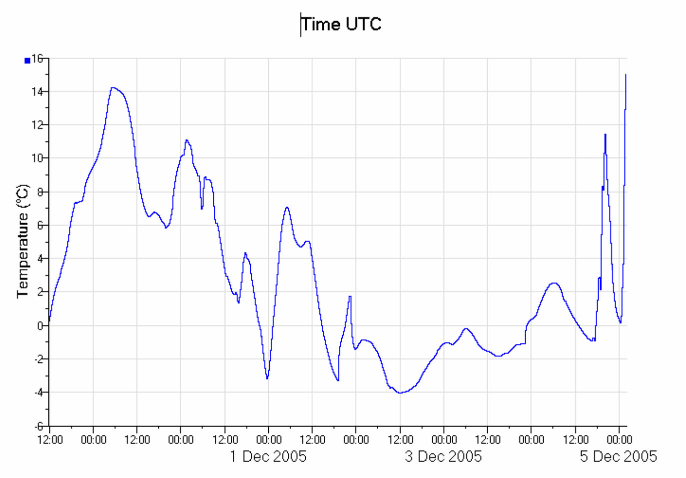


Fig. 2: a) Temperature inside the olympus tent as measured during field deployment, b) new macpac dome tent on Victoria Lower Glacier

Skis, Skins and Pulk

We used skis and a manhaul pulk to move equipment (~100lb) between sites at both Evans and Victoria Lower Glacier. As in previous years, the pulk performed very well and can be used on snowy and icy surfaces alike (Fig.3). The Mukluk-Skis showed signs of fatigue, especially the bindings, which broke or fell apart. Furthermore, there was a lack of skins. The use of cord tight around the skis is less efficient and makes pulling a heavy sledge uphill very difficult. We recommend that Antarctica New Zealand invests in new skies and skins to be pre-allocated to field parties undertaking glaciological traverses.

Fig.3: Manhauling equipment between sites at Victoria Lower Glacier

- *20 person day ration box system*

  The new food boxes (or bags) were well packed in terms of quantity and nutrition and were favourably received by all members. The addition of savoury snack food and new innovative extras, such as bagged tuna and couscous was very much appreciated.

RADIO COMMUNICATIONS

- *Suitability and effectiveness of the radio equipment*

  A high gain aerial was required at EPG and MES locations. We noted the radio batteries were more difficult to charge than in previous years. While all batteries were charged in the comfort of HFC before heading into the field, even unused batteries discharged within 24hours in moderate temperatures.

  Moreover, the solar panel charger for the radio batteries has two disadvantages: The batteries are cold during the charging process and in moderate winds the solar panel cannot be securely anchored to e.g. a tent. We suggest providing a black plastic box with clear lid to store the batteries and charger during charging. In sunny conditions solar heating will significantly rise battery temperature and hence charging capacity. A simple and inexpensive thermistor mechanism could be used prevent overheating through regulating air circulation within the box. A couple karabiners glued to the solar panel will assist greatly in charging batteries in windy locations.

- *Reception/transmission conditions and suitability of radio schedule timing*

  As last year, we noted that communications at EPG on channel 3 and 5 were poorer than the previous season at a very similar location when a hand held without high gain aerial was reliable.

- *Scott Base's general efficiency during radio schedule*

  Radio communication was efficient, professional, and appreciated. The timing of the radio schedule convenient.

COMPUTER FACILITIES

- *Assistance the science technicians gave with computer / IT issues*

  N.A.

- *Issues concerning public computer facilities in the Hatherton Laboratory*

  The computer network met our needs satisfactorily. A possibility to connect laptops to the Scott Base external net connection would be highly appreciated, especially during prolonged delays at Scott Base.

- *Other comments*

*ENVIRONMENTAL IMPACT

*Sites Visited (please fill in a box for each site visited)

Site name	Evans Piedmont Glacier
Site location (coordinates/description)	76º 435335S; 162º 35.2940 E, 314m asl, glacier surface
Dates occupied	28 Nov 05 to 01 Dec 05
Total days (or hours) at site	4
Maximum number of people at site (your event)	3
Total person-days (or person-hours) at site	12
Main activity undertaken	High resolution snow pit sampling, maintenance and data retrieval of automatic weather station, GPS measurements for submergence velocity devices
Cumulative impacts observed	Transitory and less than minor

Site name	Victoria Lower Glacier I
Site location (coordinates/description)	77º 19.8053S; 162º 31.9252 E, 626m asl, glacier surface
Dates occupied	01 Dec 05 to 05 Dec 06
Total days (or hours) at site	5
Maximum number of people at site (your event)	3
Total person-days (or person-hours) at site	15
Main activity undertaken	High resolution snow pit sampling, GPS measurements for submergence velocity devices
Cumulative impacts observed	Transitory and less than minor

Site name	Victoria Lower Glacier II
Site location (coordinates/description)	77º 20.81846S; 162º 29.5371 E, 527m asl, glacier surface
Dates occupied	02 Dec 05 and 03 Dec 05
Total days (or hours) at site	6 hours
Maximum number of people at site (your event)	3
Total person-days (or person-hours) at site	18 hours
Main activity undertaken	Completion of GPS measurement for submergence velocity device. Complete retrieval of the device.
Cumulative impacts observed	Transitory and less than minor

Site name	Mt Erebus Saddle
Site location (coordinates/description)	77º30.90S; 167º 40.59 E, 1600m asl, glacier surface
Dates occupied	05 Dec 05
Total days (or hours) at site	1 hour
Maximum number of people at site (your event)	3
Total person-days (or person-hours) at site	3 hours
Main activity undertaken	Deployment of three 6m high snow stakes for mass balance measurement
Cumulative impacts observed	Transitory and less than minor

Geological Material

Location (coordinates if available)	76º 435335S; 162º 35.2940 E, 314m asl
Specimen type	Snow samples
Quantity (kg)	30 kg

Location (coordinates if available)	77º 19.8053S; 162º 31.9252 E, 626m asl
Specimen type	Snow samples
Quantity (kg)	35 kg

Equipment installed/left in field

Type of equipment/marker installed	Three snow stakes
Location of installation left in field	77º30.90S; 167º 40.59 E, ~1600m
Size of items left in field (Dimension in metres: H, W, L)	6m high snow stakes (2m below and 4m above ground), with an average diameter of 2.5cm
Number of items left in field	3
Estimated retrieval date	Dec 2007

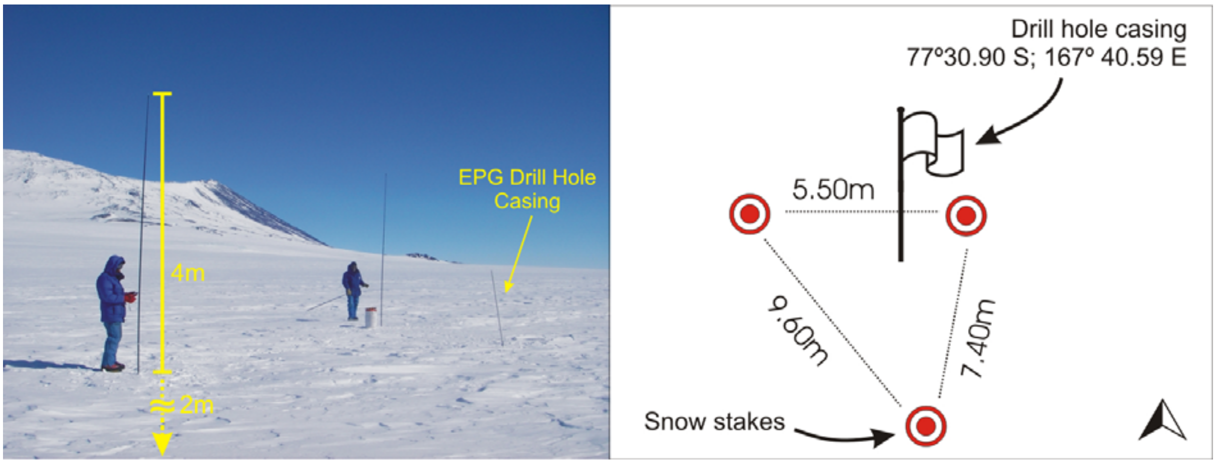


Fig.4: Three snow stakes placed in the vicinity of the 2004/05 drill hole casing maker at Mt Erebus Saddle

*Differences from original Preliminary Environmental Evaluation (PEE)

We completed the mass balance measurement at VLG II. The submergence velocity device (77º 20.81846S; 162º 29.5371 E, Fig. 5) was completely removed.

Fig.5: GPS measurement at the VLG II submergence velocity device before its complete removal

ANTARCTIC SPECIALLY PROTECTED AND MANAGED AREAS

Note that all event leaders who hold permits for entry to an ASPA need to complete a Visit Report for each ASPA entered. Please contact Rebecca Roper-Gee, the Environmental Advisor for report forms.

- *New ASPA or ASMA designation to be considered:*

N.A.

CITED REFERENCES

Bertler, N. A. N., Barrett, P. J., Mayewski, P. A., Fogt, R. L., Kreutz, K. J., and Shulmeister, J., 2004, El Niño suppresses Antarctic warming: Geophysical Research Letters, v. 31.

Hall, B. L., and Denton, G. H., 2000, Extent and chronology of the Ross Sea ice sheet and the Wilson Piedmont Glacier along the Scott Coast at and since the Last Glacial Maximum: Geografiska Annaler, v. 82A, p. 337-363.

Hamilton, G. S., and Whillans, I. M., 2000, Point measurements of mass balance of Greenland Ice Sheet using precision vertical Global Positioning System (GPS) surveys: Journal of Geophysical Research, v. 105, p. 16,295-16,301.

Hamilton, G. S., Whillans, I. M., and Morgan, P. J., 1998, First point measurements of ice-sheet thickness change in Antarctica: Annals of Glaciology, v. 27, p. 125-129.

Meyerson, E. A., Mayewski, P. A., Kreutz, K. J., Meeker, L. D., Whitlow, S. I., and Twickler, M. S., 2002, The polar expression of ENSO and sea-ice variability as recorded in a South Pole ice core: Annals of Glaciology, v. 35, p. 430-436.

Mullan, B. A., Wratt, D. S., and Renwick, J. A., 2001, Transient model scenarios of climate change for New Zealand: Weather and Climate, v. 21, p. 3-34.

Steig, E. J., Hart, C. P., White, J. W. C., Cunningham, W. L., Davis, M. D., and Saltzman, E. S., 1998, Changes in climate, ocean and ice-sheet conditions in the Ross embayment, Antarctica, at 6ka: Annals of Glaciology, v. 27, p. 305-310.
Steig, E. J., Morse, D. L., Waddington, E. D., Stuiver, M., Grootes, P. M., Mayewski, P. A., Twickler, M. S., and Whitlow, S. I., 2000, Wisconsian and Holocene climate history from an ice core at Taylor Dome, Western Ross Embayment, Antarctica: Geografiska Annaler, v. 82A, p. 213-235.
Thompson, D. W. J., and Solomon, S., 2002, Interpretation of recent Southern Hemisphere climate change: Science, v. 296, p. 895-899.

K049
2005/06

IMMEDIATE SCIENCE REPORT

K049 NZ – ITASE: Holocene Climate Variability along the Victoria Land Coast
ANTARCTICA NEW ZEALAND 2005/06

Event Personnel:

Dr Nancy Bertler	Antarctic Research Centre, Victoria University of Wellington
Mr Alex Pyne	Antarctic Research Centre, Victoria University of Wellington
Mr Mark Morrison	Antarctica New Zealand

1 Scientific Programme

Seven key locations were identified for the NZ ITASE (International Transantarctic Scientific Expedition) programme. The analyses on the ice core from the first site, Victoria Lower Glacier in the McMurdo Dry Valleys, have been completed. During the 2003/04 field season we carried out a detailed reconnaissance of sites 2 and 3: Evans Piedmont Glacier (EPG) and Mt Erebus Saddle (MES) and determined the most suitable locations for the ice core recovery. During the 2004/05 field season we recovered to intermediate length ice cores (180m and 200m, respectively) from these locations and conduct further in-situ measurements, such as borehole temperature and light penetration characteristics, snow density and stratigraphy and its geographical variability. Furthermore, we installed a weather station and mass balance devices at EPG and cased the borehole at MES for future measurements. For the 2005/06 field season proposed to identify a drilling location and recover an intermediate length ice core from Whitehall Glacier in the vicinity of Cape Hallett. Due to logistical constraints of Antarctica New Zealand this was part of our programme was postponed and our field programme condensed accordingly. During the 2005/06 field season we re-visited VLG and EPG to conduct GPS measurements of the submerge velocity devices and to sample shallow snow pits. Furthermore, we retrieved the meteorological data and carried out maintenance work on the automatic weather station at EPG. Lastly we deployed 6m snow stakes at the high accumulation site at MES.

a. Context of the research

Unprecedented changes are occurring in the Earth's climate. The 1990's were the warmest decade in the last 2000 years and average global temperature is projected to rise between 1.4ºC and 5.8ºC by 2100 [IPCC 2001]. Although the scientific evidence of global warming is now widely regarded as incontrovertible, predicting regional impacts is proving more problematic. Especially, conclusions of the Southern Hemisphere record are limited by the sparseness of available proxy data at present [Mann and Jones 2003].

While meteorological records from instrumental and remote sensing data display the large intercontinental climate variability, they series are insufficient to infer trends or to understand the forcing, which renders prediction difficult [Jones et al. 1999; Mann and Jones 2003]. The long ice core records from the Antarctic interior and Greenland revolutionised our understanding of global climate and showed for the first time the occurrence of RCE (Rapid Climate Change Events) (for review e.g. Mayweski and White [2002]). To understand the drivers and consequences of climate change on timescales important to humans, a new focus of ice core work is now moving towards the acquisition of 'local' ice cores that overlap with and extend the instrumental records of the last 40 years back over the last several thousand years.

This has been a key motivation behind the US-led International Transantarctic Scientific Expedition (ITASE) of which New Zealand is a member. The NZ ITASE objective is to recover a series of ice cores from glaciers along a 14 degree latitudinal transect of the climatically sensitive Victoria Land coastline to establish the drivers and feedback mechanism of the Ross Sea climate variability [Bertler and 54 others 2005; Bertler et al. 2004a; Bertler et al. 2005a; Bertler et al. 2004b; Bertler et al. 2005b; Patterson et al. 2005]. Furthermore, the ice core records will provide a baseline for climate change in the region that will contribute to the NZ-led multinational Latitudinal Gradient Project as well as providing a reference record for the NZ-led ANDRILL objective to obtain a high-resolution sedimentary archive of Ross Ice Shelf stability.

b. Objectives

Our 2005/60 field season comprises 4 objectives.

Automatic weather station maintenance and data retrieval

In 2004/05 we deployed an automatic weather station on Evans Piedmont Glacier. We anticipate to collect data from the site for at least two years. The data permit the calculation of transfer functions between ice core proxies and meteorological parameters, such as temperature, precipitation, meso-scale atmospheric circulation pattern, katabatic winds, and seasonality of snow accumulation. In addition a new snow accumulation sensor and high precision snow temperature probes allow us to monitor snow accumulation rates, the potential influence of snow loss through sublimation, wind erosion or melt, and the quality of preservation of the meteorological signal in the snow. Furthermore, the data allow us to estimate the uncertainty of re-analysis data (NCEP/NCAR and ERA-40 data) in the region.

Submergence Velocity Measurements at Victoria Lower and Evans Piedmont Glacier

The response time of a glacier to changes in accumulation or ablation is dependent on the size and thickness of the ice mass. In general, the response time of cold-based glaciers is positively correlated with the size of its ice mass, leading to long response times in Antarctica. For glaciers in the McMurdo Dry Valleys, with lengths on average of 5-10km and flow rates of 1 to 3 m/a, the response times are thought to range from 1,500a to 15,000a [Chinn 1987; Chinn 1998]. Consequently, annual variations in surface elevation may only reflect changes in loss rates. As a result surface measurements of mass balance are difficult to interpret in terms of long-term mass balance [Hamilton and Whillans 2000]. This is especially the case in places like the McMurdo Dry Valleys where mass loss is thought to be predominately due to sublimation at ice cliffs and glacier surface caused by wind and solar radiation [Chinn 1987; Chinn 1998]. For Victoria Lower Glacier, two mass balance measurements are available in the literature for 1983 and 1991 based on ice cliff characteristics and the motion of the glacier snout [Chinn 1998]. The measurements indicate that VLG was advancing 1.24m/a into Victoria Valley during this time period. However, the small number of observations (2) and the cliff's sensitivity to sublimation (contemporary surface ablation) result in a high uncertainty of longer term mass balance. To determine the longer-term mass balance of the glaciers, unaffected by annual surface variations, three 'coffee-can' or 'submergence velocity' devices [Hamilton and Whillans 2000; Hamilton et al. 1998] were deployed at Victoria Lower Glacier in 1999/2000 and two at Evans Piedmont Glacier in 2004/05.

High resolution snow pit sampling at Victoria Lower and Evans Piedmont Glacier

Intermediate length cores were recovered from Victoria Lower Glacier and Evans Piedmont Glacier in 2001/02 and 2004/05, respectively. High resolution samples from shallow snow pits are used to update the records and to investigate post-depositional changes in the snow signal, such as isotopic diffusion or nitrate loss. Furthermore, meteorological data recorded at Evans Piedmont Glacier and re-analysis data are used to calculate transfer functions and establish seasonality in the ice core record. In order to estimate the influence of small-scale local influences such as sastrugi features, we investigate spatial variability by studying physical properties of multiple snow pits at each location.

Snow Accumulation at Mt Erebus Saddle

We have recovered a 200m deep ice core from the slopes of Mt Erebus Saddle during the 2004/05 Antarctic field season. The site topography promotes strong winds leading to significant compaction of the surface snow (~0.45 gcm^{-3}). Furthermore, average snow accumulation lies in the range of 72 – 150 cm yr^{-1} water equivalent. This is more than one order of magnitude higher than the regional average [Bertler et al. 2004a; Bertler et al. 2004b; Bromwich 1988; Bromwich et al. 1998] and provides ideal characteristics for a high resolution ice core gas record. To measure the accumulation rate at the drill site we deployed three snow stakes, which we hope will endure the high wind velocities and snow accumulation.

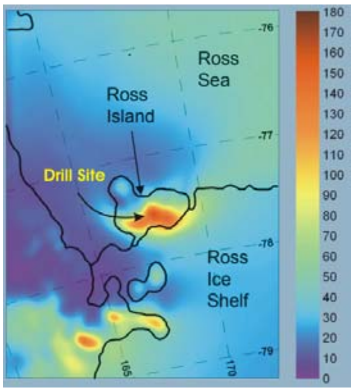


Fig.1: Snow accumulation (cm) in the Southern McMurdo Sound region

c. Methodology

Automatic Weather Station at Evans Piedmont Glacier

An automatic weather station has been established near the 2004/2005 ice coring site that records several parameters to help characterise the meteorology and snow accumulation regime of the area (Fig.2).

Fig.2: Automatic weather station and submergence velocity devices at Evans Piedmont Glacier

Parameters measured as of 15 November 2004 are:

- Air Temperature at 2.5 height
- Snow accumulation, and air temperature at 1.5 m height
- Dew point temperature at 2.5 m height
- Solar radiation (incoming) at 2.5 m height
- Snow temperatures (thermistor resistance) from 0.135 to 2.085 m depth in at 13.5 cm intervals

To these were added as of 01 December 2005

- Barometric pressure
- Wind speed (ultrasonic)
- Wind direction (ultrasonic)

Submergence Velocity Measurements at Victoria Lower and Evans Piedmont Glacier

During the 1999/2000 season three submergence velocity devices [Hamilton and Whillans 2000] for mass balance measurements in the McMurdo Dry Valleys were installed (Fig.3). During the 2004/2005 season two submergence velocity devices have also been installed at EPG (Fig.3). This method is used to determine mass balance by comparing vertical velocity of a marker in firn or ice with long-term, average snow accumulation rates. The movement of the marker is the result of three motions: firn compaction, gravitational glacial flow, and changes in mass balance.

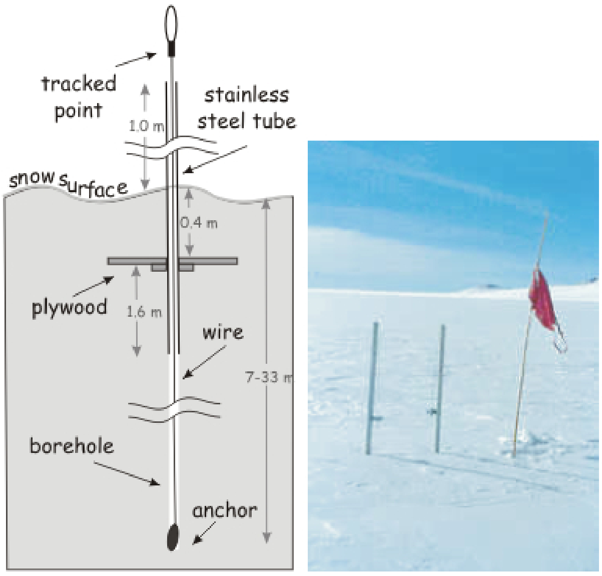


Fig.3 a) Cartoon of the 'coffee can' submergence mass balance device. The device consists of a low-stretch, stainless steel wire attached to a metal anchor (initially a coffee can, hence the name) that is heated and placed into the drilling hole drilled in firn. The anchor is melted with the bottom of the ice and freezes in. The wire is stretched tight and guided by a stainless steel tube. The tube is held in place using plywood that was buried ~40cm into the snow to avoid melt around the darker wood surface. The top end of the wire has a loop and permanent marker, the tracking point (modified after Hamilton and Whillans 2000). b) picture of coffee can device deployed at Victoria Lower Glacier.

High precision GPS measurements are used to determine absolute position of the tracking point during subsequent years. Trimble 5700 base station and rover unit were used to measure the absolute position of the tracking point of the mass balance devices. At Victoria Lower Glacier, the base station was deployed on a rocky platform at Staeffler Ridge <3km away from all mass balance sites. The proximity of the base station to the rover allowed the tracking points to be measured with a horizontal precision of <1mm and a vertical precision of <5mm. At Evans Piedmont Glacier base station data from the Cape Roberts permanent GPS/GLONASS and tide gauge observatory will be used. All GPS measurements are post-processed using precise orbits, which are published on-line at "http://igscb.jpl.nasa.gov/components/prods_cb.html". These data are corrected using GIPSY-OASIS II software and provide precise point positions by taking into account satellite orbit, Earth orientation, and clock solution from NASA Jet Propulsion Laboratory's independent analysis of globally distributed GPS receivers.

Fig.4: a) submergence velocity device at VLG II (glacier tongue), b) temporary GPS base station at Staeffler Ridge, c) submergence velocity devices at EPG.

The rate of thickness change H, can then be calculated using [Hamilton et al. 1998]:

$$\dot{H} = \frac{\dot{b}_m}{\rho} + \dot{z} + \vec{\alpha} \bullet \vec{u}$$

where:

H	= rate of thickness change (myr^{-1})
b_m	= accumulation rate ($Mgm^{-2}yr^{-1}$)
ρ	= density at marker depth to account for densification processes (Mgm^{-3})
z	= vertical component of ice velocity (upward is positive, myr^{-1})
α	= surface slope (radians)
u	= horizontal velocity (myr^{-1} with azimuth)

High resolution snow pit sampling at VLG and EPG

At EPG and VLG I, 1m deep snow sequences were sampled with 1cm resolution for analysis on snow chemistry (Na, Ca, K, Mg, Cl, NO_3, SO_4, MS, Al, Fe, Si, Sr, Tr, Zn), isotopic composition (δ18O and δD), dust content and mineralogy. The snow sampling surface was cleaned with a pre-cleaned plastic spade, and subsequently with a sterile scalpel, at least 20cm horizontally into the snow to prevent sampling of contaminated snow. All tools, sampling equipment, and bottles were rinsed and soaked with ultra pure 18MΩ Millipore® water and dried in a class 100 clean room facility prior to fieldwork. A scalpel was used to collect 1cm thick samples. Sample were collected into sterile Nasco whirl-paks®. Tyvek® clean suits and dust free polyethylene gloves prevent sample contamination from personnel.

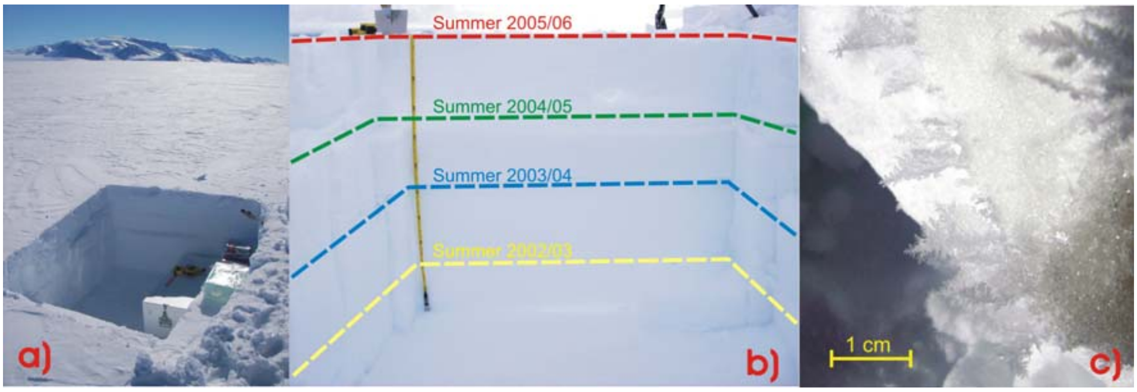


Fig.55: a) 1m deep snow pit at Evans Piedmont Glacier, b) stratigraphy of the snow pit, c) snow crystal growth during marine airmass intrusion.

Snow Accumulation at Mt Erebus Saddle

To accommodate high accumulation rates of about 2m snow/year, 6m snow stakes that are anchored 2m into the ground were deployed. The three snow stakes, made of epoxy/carbon fibre, have been chosen for their flexibility to withstand high wind velocities in excess of 100knts.

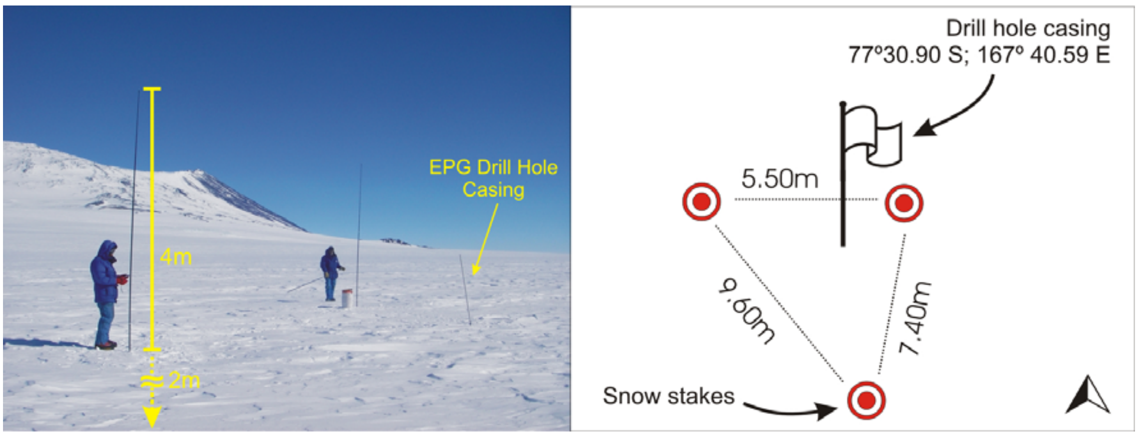
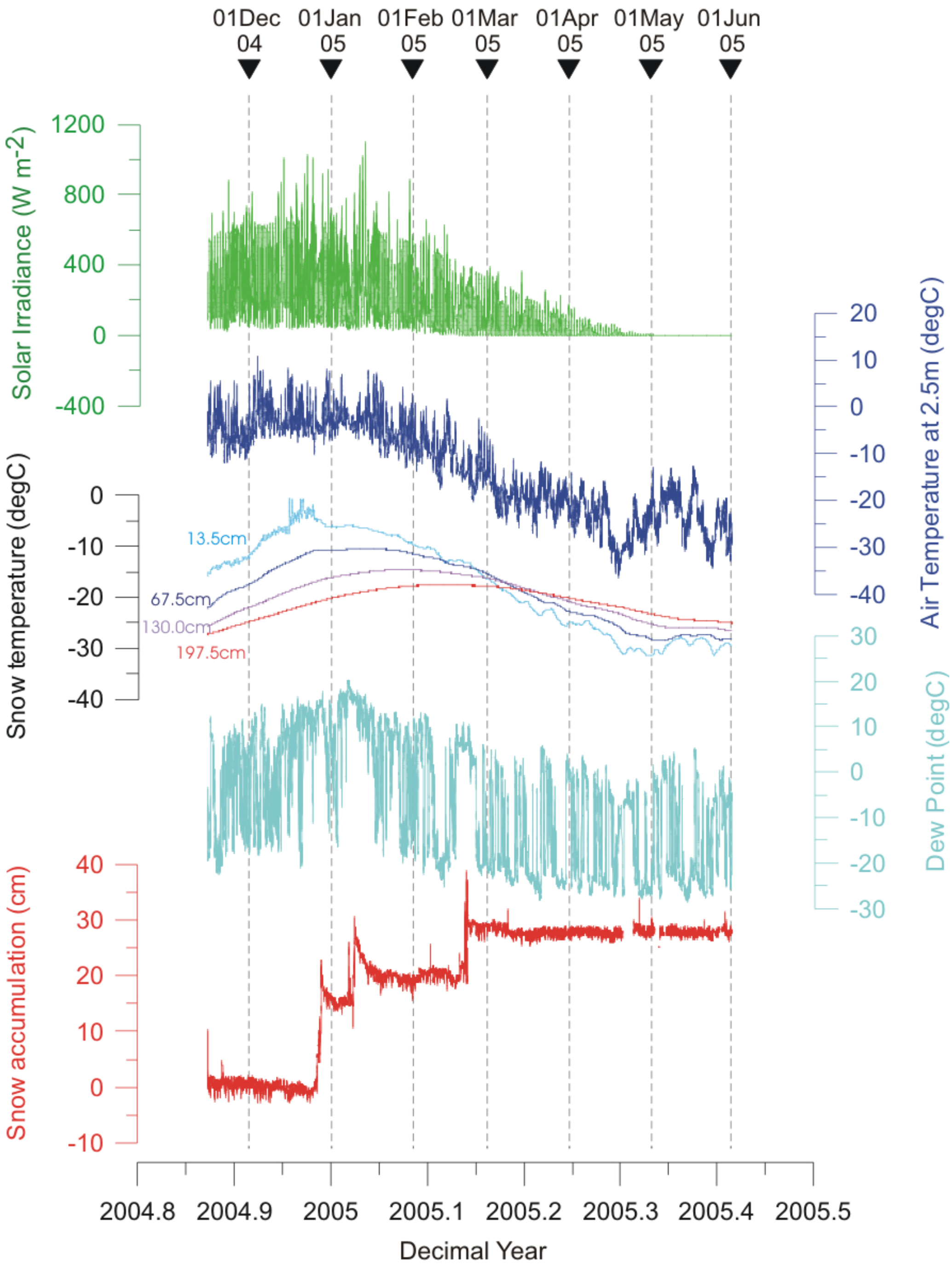


Fig.6: Three snow stakes placed in the vicinity of the 2004/05 drill hole casing at Mt Erebus Saddle

d. Results and discussions

The weather station has only recorded data from 15th Nov 2004 to 1st Jun 2005, when it stopped due to storage limitations but remained operating throughout the winter. The storage limitations have been addressed for future measurements. The recorded data for solar irradiation, air temperature, snow temperature, dew point, and snow accumulation are shown in below (Fig.7).



The time scale is in decimal years; months are indicated on top.

Fig.7: Meteorological data collected at Evans Piedmont Glacier.

As shown in Fig.7 the decrease in solar irradiance from January to mid April is accompanied by cooling temperatures. Interestingly the temperature increases again from mid April until mid May before cooling once again. A higher frequency temperature variability is superimposed on this trend from mid February onwards with positive temperature deviations on a 4-6 day periodicity with an amplitude of up to 20K. The cause of these warm events could be katabatic outflow from the McKay Glacier portal. Due to the lack of barometric and wind data caused by hardware failure, we will use data from existing weather stations (e.g. Scott Base, Lake Vida, Terra Nova) and satellite imagery to investigate this pattern further. Temperatures in the snow pack measured concurrently at 16 depth horizons from 0.135m to 2.085m show the decreasing influence of air temperature variability with depth. While the temperature in the upper most horizon (starting at 13.5cm arriving in June at 43.5cm) ranges from –2ºC to -30ºC, at the deepest sensor (starting at 197.5cm arriving in June at 227.5cm) ranges from –17ºC to -27ºC. The snow temperatures have yet to be corrected for their change in depth, which increased by 30cm as shown in the snow accumulation graph below. The snow accumulation record shows that most of the precipitation occurred during three event of 5 to 15cm snow accumulation. The data show also that are no prolonged time periods of snow loss, except in the first 2-5 days after the snow precipitation event which is partly due to snow compaction. After this time period the snow surface remains stable. Overall, the data confirm EPG as an excellent ice core site. The snow pit data and submergence velocity measurements from EPG and VLG have yet to be processed.

e. Integration into future work

Our preceding research – Holocene Climate History from Coastal Ice – has identified the value of the specific characteristics of ice core records from coastal, low altitude sites [Bertler and 54 others 2005; Bertler et al. 2004a; Bertler et al. 2005a; Bertler et al. 2004b; Bertler et al. 2005b; Mayewski et al. 2005; Patterson et al. 2005] and showed how tropical phenomena, such as ENSO have a significant influence on the Ross Sea Region. In contrast to Antarctica's interior, which is influenced by temperature inversion and climatic cooling of the stratosphere, the coastal sites are dominated by cyclonic activity, and hence by the climate of the lower troposphere [King and Turner 1997]. As a result, coastal sites are especially climate sensitive and show potential to archive local, rapid climate change events that are subdued or lost in the 'global' inland ice core records, such as Vostok. It is those rapid climate change events that are of greatest concern to human civilisation in the near future. The NZ ITASE programme contains five objectives that are scientifically inter-linked to the following programmes.

1. ITASE-Objective

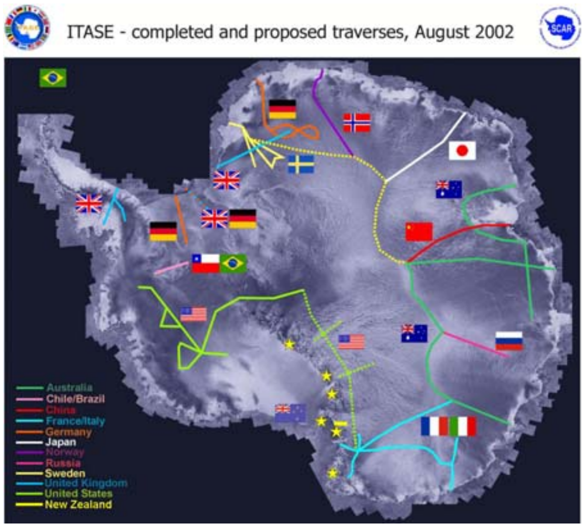


Fig.8: Overview of NZ ITASE proposed drilling sites (stars)
Source: http://www.ume.maine.edu/itase/nationals/map.html

The main objective of ITASE is to determine the spatial climate variability across Antarctica over the last 200 years, and where possible further back in time. The focus of the New Zealand ITASE group (this proposal) is to provide information from the climate sensitive, low altitude, coastal sites (Fig.8). This will capture the climate signature of the troposphere, which represents a regional account on the Ross Sea climate. Our preceding research showed that while the direct ENSO influence warms the eastern Ross Sea (oceanic forcing), the indirect ENSO influence dominated in the western Ross Sea, leading to the observed cooling in McMurdo Sound Region (atmospheric forcing) [Bertler et al. 2004a; Bertler et al. 2005b]. The comparison with data from other ITASE-nations will allow us to date relative phasing and signal migration velocities of these climate drivers across Antarctica.

Furthermore, the gas record will allow us to determine the role of CO_2 and in rapid climate change events and the CO_2 and methane source/sink fluxes of the Ross Sea. The isotopic fractionation of biogenic (terrestrial) material is –with the exception of C4 plants – enriched in the lighter ^{13}C isotopes and carries therefore a different signature than ocean derived carbon, which shows no such enrichment [Indermühle et al. 1999; Sigman and Boyle 2000]. For this reason the change of isotopic ratio in CO_2 and CH_4 can be used to determine the change in sources of GHG concentration through time. This is particular important to determine the role of the oceans versus the atmosphere in rapid climate change [Broecker 2000; Broecker 2003; Ferretti et al. 2005; Schrag 2000; Stocker 1998; Stocker 2002; White 1993] and has the potential to detect influences of early human activities in the late Holocene [Ruddimann 2003].

In conjunction with the US-ITASE traverse of our collaboration partners altitude and continentality gradients across the Trans Antarctic Mountains (TAM) can be established. Temperature and humidity gradients across the TAM are amongst the most extreme on the continent and exceed the latitudinal gradients by more than one order of magnitude. The correlation between the US-ITASE polar plateau traverse (Fig.8) and our data will allow determining the climatic influence of the mountain range and also the position of the Antarctic Vortex, the geographical boundary of tropospheric and stratospheric influence.

2. Latitudinal Gradient Project Objective

Our project is expected to contribute an important data set to the Latitudinal Gradient Project, as it provides a history of temperature, humidity, sea ice cover, precipitation source, atmospheric circulation, and ocean productivity along the Victoria Coast for the last 1000 to 10,000 years depending on the site. This will help to determine whether the current ecological system found has evolved under prevailing climate, or how much time the ecological system had to adjust to potential climate change in the recent past. Furthermore, the timing and velocity of the Ross Ice Shelf retreat some 9 to 5ka years ago is still discussed controversially [Hall and Denton 2000;

Steig et al. 1998; Steig et al. 2000]. Coastal ice core records are very sensitive to the change from an ice shelf environment to seasonally open water, which manifests itself in a shift in the chemical signature of snow and aerosol precipitation [Legrand and Mayewski 1997]. By dating the occurrence of the characteristic chemistry shift in the proposed ice cores locations (Fig.8), average retreat velocity can be calculated and its dependency on air temperature tested. This will also add to our knowledge on the current Ross Ice Shelf stability.

3. ANDRILL Objective

Proposed ice core locations no. 2 and 3 (Evans Piedmont and Mt. Erebus) are in the immediate vicinity of planned ANDRILL coring locations (Granite Harbour and Windless Bight). The ice core records will provide a high-resolution climate dataset, which serves as a reference for the younger part of marine record recovered through ANDRILL. This will provide the unique opportunity to compare contemporary on- and off-shore records.

4. Longer-Term Mass Balance Objective

During the 1999/2000 season mass balance measurement devices (submerge velocity method [Hamilton and Whillans 2000; Hamilton et al. 1998]) have been deployed at Victoria Lower Glacier and at Evans Piedmont Glacier during 2004/05. The measurements at Victoria Lower Glacier show that the glacier has a slightly negative mass balance, losing around 12cm thickness per year. A continuation of the measurements will allow monitoring changes in the ablation intensity of the McMurdo Sound Region.

5. The Antarctic – New Zealand Connection Objective

New Zealand's future economic and social development, environmental sustainability, and infrastructural planning relies critically upon the accurate assessment of the impact of "global warming" in our sector of the planet. A joint programme between IGNS, University of Maine, and Victoria University is investigating ice core records from New Zealand (Tasman Glacier and Mt. Ruapehu ice field). The comparison between our NZ and Antarctic ice core records will provide much needed data for the development of realistic regional climate models to predict NZ climate in the 21th Century [Mullan et al. 2001].

2 Publications

Publications since the 2004/05 Antarctic field season include:

Bertler, N. A. N., Naish, T. R., Mayewski, P. A., and Barrett, P. J., 2006, Opposing oceanic and atmospheric ENSO influences on the Ross Sea Region, Antarctica: *Advances in Geosciences*, 6 (83-86), SRef-ID:1680-7359/adgeo/2006-6-83.

Bertler, N. A. N., and 54 others, 2005, Antarctic Snow Chemistry: *Annals of Glaciology, 41*

Bertler, N. A. N., Barrett, P. J., Mayewski, P. A., Fogt, R. L., Kreutz, K. J., and Shulmeister, J., 2005, Reply to comment by Doran et al. on "El Niño suppresses Antarctic warming": *Geophysical Research Letters*, 32 (L07707, doi:10.1029/2005GL022595).

Bertler, N. A. N., Barrett, P. J., Mayewski, P. A., Sneed, S. B., Naish, T. R., and Morgenstern, U., 2005, Solar forcing recorded by aerosol concentrations in coastal Antarctic glacier ice, McMurdo Dry Valleys: *Annals of Glaciology*, 41.

Mayewski, P. A., Frezzotti, M., Bertler, N. A. N., van Ommen, T., Hamilton, G. S., Jacka, T. H., Welch, B., and Frey, M., 2005, The International Trans-Antarctic Scientifc Expedition (ITASE) - An Overview: *Annals of Glaciology*.

Patterson, N. G., Bertler, N. A. N., Naish, T. R., Morgenstern, U., and Rogers, K., 2005, ENSO variability in the deuterium excess record of a coastal Antarctic ice core from the McMurdo Dry Valleys, Victoria Land: *Annals of Glaciology*, 41.

Bertler, N. A. N., Naish, T. R., Oerter, H., Kipfstuhl, S., Barrett, P. J., Mayewski, P. A., and Kreutz, K. J., in review, ENSO-driven temperature and snow accumulation variability in the McMurdo Dry Valleys, Antarctica: *Antarctic Science*.

Witherow, R. A., Lyons, W. B., Welch, K. A., Bertler, N. A. N., Mayewski, P. A., Sneed, S. B., Nylen, T., Handley, M. J., and Fountain, A., in review, The aeolian flux of calcium, chloride and nitrate to the McMurdo Dry Valleys Landscape: Evidence from snow pit analysis: *Antarctic Science*.

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4 Cited References

Bertler, N. A. N., and 54 others, 2005, Antarctic Snow Chemistry: Annals of Glaciology.

Bertler, N. A. N., Barrett, P. J., Mayewski, P. A., Fogt, R. L., Kreutz, K. J., and Shulmeister, J., 2004a, El Niño suppresses Antarctic warming: Geophysical Research Letters, v. 31.

Bertler, N. A. N., Barrett, P. J., Mayewski, P. A., Sneed, S. B., Naish, T. R., and Morgenstern, U., 2005a, Solar forcing recorded by aerosol concentrations in coastal Antarctic glacier ice, McMurdo Dry Valleys: Annals of Glaciology, v. 41.

Bertler, N. A. N., Mayewski, P. A., Barrett, P. J., Sneed, S. B., Handley, M. J., and Kreutz, K. J., 2004b, Monsoonal circulation of the McMurdo Dry Valleys -Signal from the snow chemistry: Annals of Glaciology, v. 39, p. 139-145.

Bertler, N. A. N., Naish, T. R., Mayewski, P. A., and Barrett, P. J., 2005b, Opposing oceanic and atmospheric ENSO influences on the Ross Sea Region, Antarctica: Advances in Geoscience, v. 6, p. 83-86, SRef-ID:1680-7359/adgeo/2006-6-83.

Broecker, W. S., 2000, Abrupt climate change: causal constraints provided by the paleoclimate record: Earth-Science Reviews, v. 51, p. 137-154.

—, 2003, Does the trigger for abrupt climate change reside in the ocean or in the atmosphere?: Science, v. 300, p. 1519-1522.

Bromwich, D. H., 1988, Snowfall in the high southern latitude: Reviews of Geophysics, v. 26, p. 149-168.

Bromwich, D. H., Cullather, R. I., and Van Woert, M. L., 1998, Antarctic precipitation and its contribution to the global sea-level budget: Annals of Glaciology, v. 27.

Chinn, T. J. H., 1987, Accelerated ablation at a glacier ice-cliff margin, Dry Valleys, Antarctica: Arctic and Alpine Research, v. 19, p. 71-80.

—, 1998, Recent fluctuations of the Dry Valley glaciers, McMurdo Sound, Antarctica: Annals of Glaciology, v. 27, p. 119-124.

Ferretti, D. F., Miller, J. B., White, J. W. C., Etheridge, D. M., Lassey, K. R., Lowe, D. C., MacFarling Meure, C. M., Dreier, M. F., Trudinger, C. M., van Ommen, T. D., and Langenfels, R. L., 2005, Unexpected changes to the global methane budget over the past 2000 years: Science, v. 309, p. 1717-1720.

Hall, B. L., and Denton, G. H., 2000, Extent and chronology of the Ross Sea ice sheet and the Wilson Piedmont Glacier along the Scott Coast at and since the Last Glacial Maximum: Geografiska Annaler, v. 82A, p. 337-363.

Hamilton, G. S., and Whillans, I. M., 2000, Point measurements of mass balance of Greenland Ice Sheet using precision vertical Global Positioning System (GPS) surveys: Journal of Geophysical Research, v. 105, p. 16,295-16,301.

Hamilton, G. S., Whillans, I. M., and Morgan, P. J., 1998, First point measurements of ice-sheet thickness change in Antarctica: Annals of Glaciology, v. 27, p. 125-129.

Indermühle, A., Stocker, T. F., Joos, F., Fischer, H., Smith, H. J., Wahlen, M., Deck, B., Mastroianni, D., Tschumi, J., Blunier, T., Meyer, R., and Stauffer, B., 1999, Holocene carbon-cycle dynamics based on CO2 trapped in ice at Taylor Dome, Antarctica: Nature, v. 398, p. 121-126.

IPCC, 2001, Climate Change 2001: The Science of Climate Change. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.: Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press, 881 p.

Jones, P. D., New, M., Parker, D. E., Martin, S., and Rigor, I. G., 1999, Surface air temperatures and its changes over the past 150 years: Reviews of Geophysics, v. 37, p. 172-199.

King, J. C., and Turner, J., 1997, Antarctic Meteorology and Climatology: Atmospheric and Space Science Series: Cambridge, University Press Cambridge, 409 p.

Legrand, M., and Mayewski, P. A., 1997, Glaciochemistry of polar ice cores: a review: Reviews of Geophysics, v. 35, p. 219-243.

Mann, M. E., and Jones, P. D., 2003, Global surface temperatures over the past two millennia: Geophysical Research Letters, v. 30.

Mayewski, P. A., Frezzotti, M., Bertler, N. A. N., van Ommen, T., Hamilton, G. S., Jacka, T. H., Welch, B., and Frey, M., 2005, The International Trans-Antarctic Scientifc Expedition (ITASE) - An Overview: Annals of Glaciology.

Mayewski, P. A., and White, F., 2002, The ice chronicles: Hanover, NH, University Press of New England, 233 p.

Mullan, B. A., Wratt, D. S., and Renwick, J. A., 2001, Transient model scenarios of climate change for New Zealand: Weather and Climate, v. 21, p. 3-34.

Patterson, N. G., Bertler, N. A. N., Naish, T. R., Morgenstern, U., and Rogers, K., 2005, ENSO variability in the deuterium excess record of a coastal Antarctic ice core from the McMurdo Dry Valleys, Victoria Land: Annals of Glaciology, v. 41.

Ruddimann, W. F., 2003, The anthropogenic greenhouse era began thousands of years ago: Climatic Change, v. 61, p. 261-293.

Schrag, D. P., 2000, Of ice and elephants: Nature, v. 404, p. 23-24.

Sigman, D. M., and Boyle, E. A., 2000, Glacial / interglacial variations in atmospheric carbon dioxide: Nature, v. 407, p. 859-869.

Steig, E. J., Hart, C. P., White, J. W. C., Cunningham, W. L., Davis, M. D., and Saltzman, E. S., 1998, Changes in climate, ocean and ice-sheet conditions in the Ross embayment, Antarctica, at 6ka: Annals of Glaciology, v. 27, p. 305-310.

Steig, E. J., Morse, D. L., Waddington, E. D., Stuiver, M., Grootes, P. M., Mayewski, P. A., Twickler, M. S., and Whitlow, S. I., 2000, Wisconsian and Holocene climate history from an ice core at Taylor Dome, Western Ross Embayment, Antarctica: Geografiska Annaler, v. 82A, p. 213-235.

Stocker, T. F., 1998, The seesaw effect: Science, v. 282, p. 61-62.

—, 2002, North-South Connection: Science, v. 297, p. 1814-1815f.

White, J. W. C., 1993, Don't touch that dial: Nature, v. 364, p. 186.