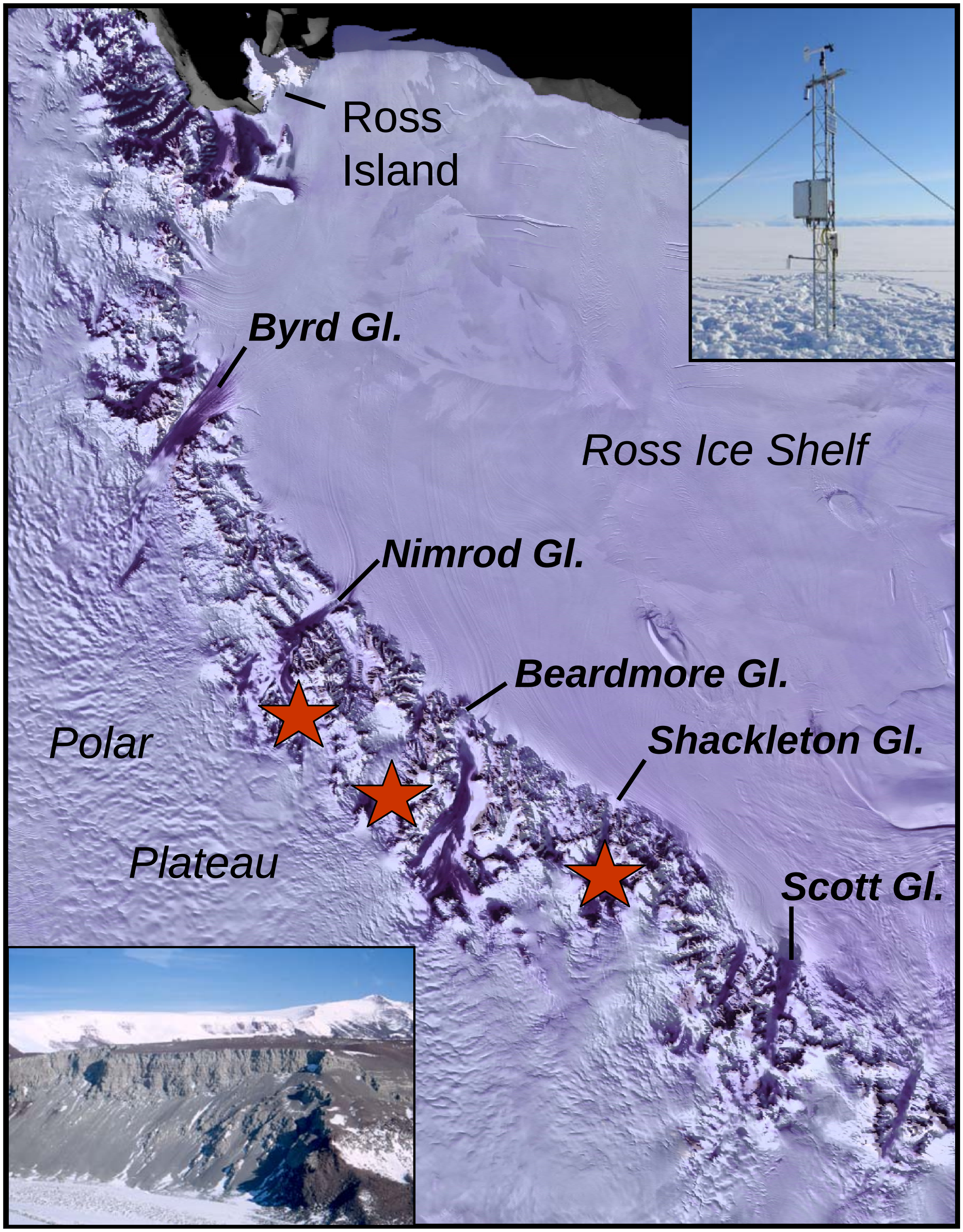
TransAntarctic Mountains TRANsition Zone

TAM TRANZ



Multidisciplinary Science Investigations

Transantarctic Mountains TRANsition Zone

TAM TRANZ Project

A Report to the

Office of Polar Programs
National Science Foundation
United States Antarctic Program

Workshop on Multi-Disciplinary Research
in the Central and Southern Transantarctic Mountains.

Convened by
W. Berry Lyons
David H. Elliot

Byrd Polar Research Center
The Ohio State University

September 6-9, 2006

URL: http://www-bprc.mps.ohio-state.edu/workshops/tam_2006.php

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http://www-bprc.mps.ohio-state.edu/workshops/tam_2006.php

Frontispiece:

MODIS image overlain with 50% transparent AVHRR image. Inset upper right: automatic weather station on the Ross Ice Shelf north of the Nimrod Glacier (image provided by M. Lazzara). Inset lower left: Upper Cenozoic Sirius Group deposits, more than 100 m thick, at Bennett Platform, Shackleton Glacier (Hambrey et al., 2003). Red stars mark locations of possible logistic hubs.

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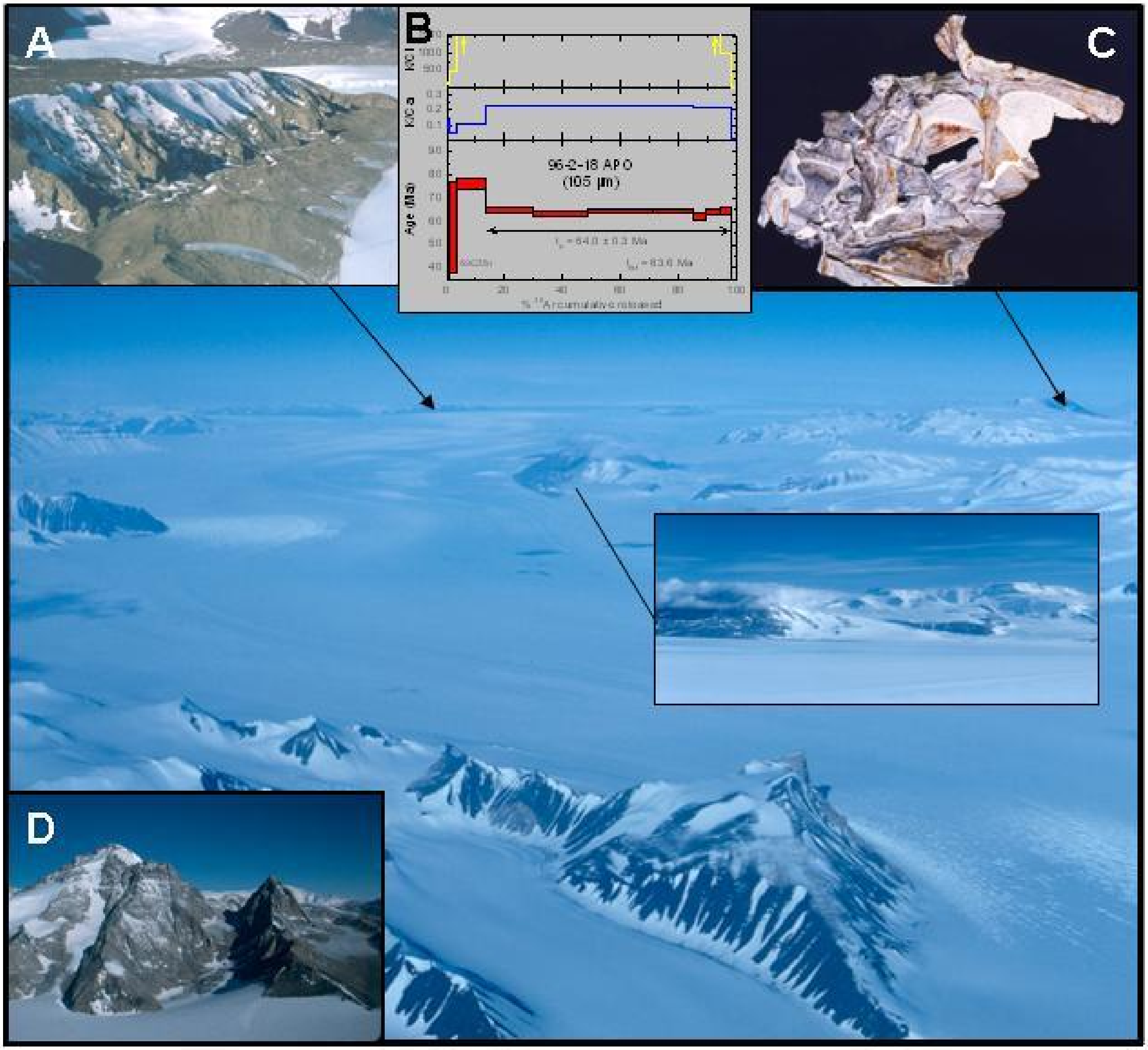
Executive Summary

This report provides background information on the scientific issues that can be addressed by research in the Transantarctic Mountains, and a set of recommendations for facilitating the science objectives. The Transantarctic Mountains divide the Antarctic continent and are the locus of barriers and gradients of interest to many disciplines. The mountains are located on the transition between two crustal provinces of contrasting characteristics. The evolution of this transition reflects the history of development of one of Earth's major intra-plate mountain belts. The mountain belt is the product of, and records, the interactions between climate, glacial and tectonic processes, and thus also documents the early stages and subsequent evolution of Cenozoic glaciation. The range forms a barrier between ice in East and West Antarctica, although the outlet glaciers provide a dynamic connection between the two massive ice bodies. The range also forms a barrier in large scale atmospheric processes, but with katabatic flow from the polar plateau, funneled down the outlet glaciers, interacting with air masses over the Ross Ice Shelf. Overlain on these physical attributes is a latitudinal gradient in ecosystems. Significant and fundamental questions in geology, glaciology, meteorology and biology, and at the dynamic interfaces between these disciplines, can be addressed by a long term program of research supported by remote logistic hubs. The workshop participants recommend that:

- USAP support a decade-long project along the Transantarctic Mountains to investigate significant and compelling research issues encompassed by a wide range of disciplines.

- the first Logistic Hub be established for the 08-09 field season on Bowden Névé near the Beardmore Glacier.

- a Project Office be established to co-ordinate activities conducted by this proposed decade-long program of multidisciplinary research. These activities would include co-ordination and support of an annual workshop, co-ordination of projects with the USAP field contractor, and co-ordination of outreach and education efforts



Beardmore Glacier rises southward from Mt. Kyffin, in the foreground and adjacent to the Ross Ice Shelf, to the barely visible Polar Plateau in the far distance. In the middle ground, The Cloudmaker (with inset) is the site of marine and terrestrial glacial deposits. Inset A: Sirius Group glacial and non-glacial strata at Oliver Bluffs, Dominion Range. Inset B: $^{40}Ar/^{39}Ar$ age spectrum for apophyllite from the Buckley Formation (Elliot et al., unpublished data). Inset C: *Cryolophosaurus* skull from Jurassic strata on Mt. Kirkpatrick. Inset D: Mt Daniel, Queen Maud Mountains, exposes Cambro-Ordovician granites and Upper Cenozoic surficial deposits in the adjacent valleys, with the escarpment of the Transantarctic Mountains in the background.

TAM TRANZ (TransAntarctic Mountains TRANsition Zone)

The Transantarctic Mountains (TAM) are a fundamental physiographic feature of Antarctica. They are continental-scale, traverse a wide range of latitudes, have high relief, contain a significant proportion of exposed rock on the continent, and represent a major arc of transition in many physical, ecological, glaciological and geological environments. Furthermore, this major feature has persisted for hundreds of millions of years since the Precambrian to the modern. Its underlying geology is key to reconstructing past supercontinents, past high latitude climates and biota. Further, it plays an important role in modern patterns of both ice flow and atmospheric circulation, and in understanding polar ecosystems. It possibly acts a a major biogeographic barrier. Thus, the TAM have both continental and global importance through time.

The TAM represent a major divide or transition zone manifested by observable gradients in all major systems from the solid-earth to the atmosphere. Significant transition zones and/or barriers are recognized for:

- lithosphere structure and evolution between Precambrian and Mesozoic time
- secular change in Paleozoic to Mesozoic climate and biota
- uplift, surfaces processes and erosion history, and the interdependent ice-sheet development
- active tectonism
- climate and weather systems on timescales from Neogene to present-day
- glacial history and present-day dynamics of east and west Antarctic ice sheets
- gradients in biodiversity and biogeochemical processes, both modern and ancient

Because the TAM transition provides important forcings on all of these systems, significant feedbacks and interdependencies that arise between subsystems can best be studied in an interdisciplinary fashion. Some of the important science questions outlined below *can only be addressed in the TAM*, such that the TAM represent an important target of opportunity for concentrated polar scientific research. Here we advocate NSF support for a new interdisciplinary initiative called TAM-TRANZ, which focuses attention on research priorities identified for the central and southern TAM at a multi-disciplinary workshop convened at The Ohio State University in September, 2006.

The challenges of interdisciplinary research in such a remote region require a concerted, coordinated, and sustained effort. We recommend a multi-year research program with science drawn from most of the OPP discipline areas, and with logistical support commensurate with the science goals. Below we outline the rationale for a sustained 10-year program of field-based interdisciplinary science involving solid-earth structure and lithosphere evolution, paleontology, neotectonics, glacial history and landscape evolution, glaciology, long-term climate change, meteorology, and ecology. This decade of new discovery will foster research for many years to come and provide training for a new generation of scientists.

Fundamental questions to be addressed by TAM-TRANZ include:

- What is the nature of lithospheric architecture in relation to Proterozoic to Mesozoic supercontinent evolution?
- What linkages and feedbacks between crustal structure, uplift history and glacial erosion have controlled nucleation of the ice sheets and evolution of the mountain range itself?
- How do the past transitions between "ice-house" and "greenhouse" regimes relate to modern day climate change?
- How do extinction and origination events at high southern latitudes relate to low latitude and northern hemisphere events?
- How do the Permian to Jurassic biotas contribute to the evolutionary and ecological history of plants and vertebrates?
- How did ancient (Proterozoic-Paleozoic) lithospheric structure affect Mesozoic and Cenozoic rift history and neotectonics?
- How have feedbacks and interactions among climatic and surficial processes shaped the unique landscapes and biotic communities of the TAM on time scales from decades to millions of years?
- Did TAM evolution exert control on the fundamental transition from temperate-glacial to polar ice-sheet regimes?
- What is the past and present interplay between the East and West Antarctic ice sheets at their nexus in the TAM?
- What changes are occurring in outlet glaciers crossing the TAM, what drives this change, and how does it relate to ice-sheet and ice-shelf dynamics?
- How does TAM physiography affect biotic distribution, long-term climate control on ice-balance, and short-term weather phenomena?
- How does TAM physiography affect mesoscale polar atmospheric systems?
- How do climatic and geologic factors affect establishment, structure and evolution of polar biodiversity and ecosystems, past and present?
- Can current biodiversity change be monitored over time and incorporated into predictive models of ecosystem response to climate.

These questions are fundamentally interdisciplinary in scope. As one example, landscape evolution links atmospheric sciences, glaciology, climate history, surficial processes, bedrock geology and biology. Weathering of rocks can be biologically mediated; bedrock composition determines the weathering products and the geochemistry of surface and near-surface fluids, which in turn affect organisms; climate influences precipitation which affects rates of weathering and the state of H_2O at the surface; and there is a current debate on the extent to which climate itself may drive tectonics.

Following an introduction to the physiography of the Transantarctic Mountains, summaries are presented of the main science goals and objectives, together with lists of references that provide entry into the literature. The science goals and objectives of the various disciplines are linked in many ways and will lead to integrated programs and interdisciplinary research results.

TAM Physiography

The Transantarctic Mountains (TAM) are a significant physiographic feature of Antarctica (Goodge, 2006). They extend over 3,500 km from the Weddell Sea along the eastern Ronne Ice Shelf, past the geographic south pole, to northern Victoria Land and the Oates Coast of Wilkes Land, making them one of Earth's great modern mountain belts. Between northern Victoria Land and the south pole region, they traverse about 30° of latitude. The TAM have over 4,000 m of relief, which is particularly pronounced along the western Ross Sea and Ross Ice Shelf where they rise abruptly from near sea level to high elevations over less than 40 km distance. The mountains vary in width up to180 km, but the inland flank is buried beneath the high-standing East Antarctic Ice Sheet.

Physiographically the TAM separates the Ross Sea and Ross Ice Shelf from the polar ice cap, and form a barrier to flow of the East Antarctic ice sheet. Major outlet glaciers, which segment the mountain range, feed ice into the Ross Ice Shelf. Polar katabatic winds, funneled down the outlet glaciers, interact with major weather systems originating in the South Pacific and profoundly influence cyclogenesis in the vicinity of McMurdo and the wider Ross Sea region. Within the broader parts of TAM from the Darwin Glacier southward, there are sites where the effects of the katabatic winds off the polar plateau and/or the low-pressure systems over West Antarctica are significantly ameliorated and these constitute optimum locations for field operations.

The TAM form a significant proportion of all the rock outcrop exposed in Antarctica, and thus provide a window into the geologic history and tectonic evolution of a major part of the continent. These outcrops provide the ground truth for remote sensing of the crust in adjacent East and West Antarctica, as well as keys to the geologic evolution and break-up of Gondwana. As a result of the geologic evolution and climate history, areas exist of relatively extensive exposure of bedrock and surficial deposits, and these sites record the interplay between tectonism, landscape evolution and climate history. Although not studied systematically, some of these areas are known to contain widely scattered aquatic and terrestrial microflora and fauna that reflect life in one of the extreme environments on earth.

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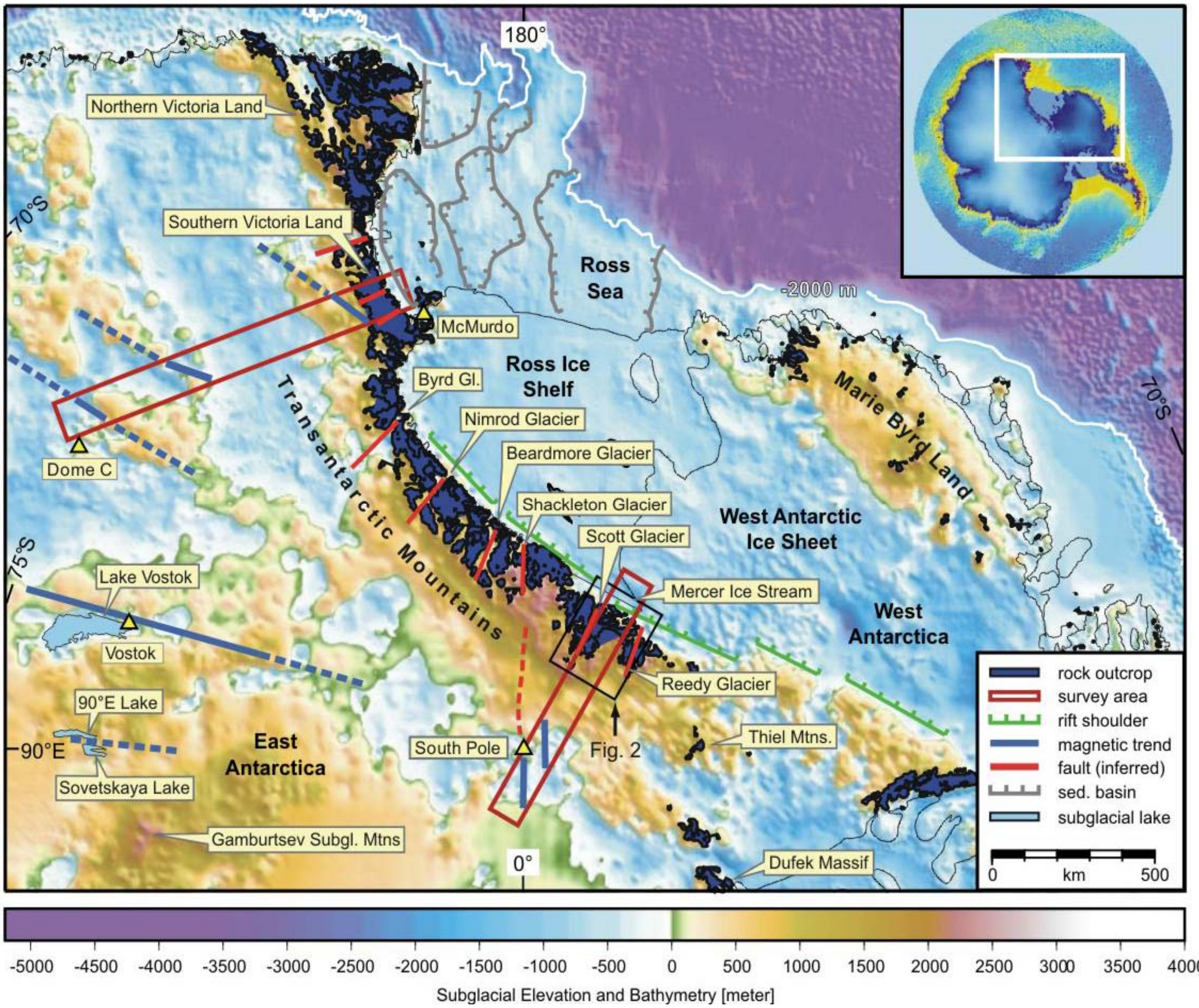
Goodge, J.W. (2006) Mountains, Transantarctic: Geology. In: Riffenburgh, B. (Ed.), Encyclopedia of the Antarctic, New York, Routledge Press, pp. 1007-1012.



Subglacial topography and bathymetry of Antarctica. The West Antarctic Rift System is the entire area of intracontinental extension defined by the region under the Ross Sea, Ross Ice Shelf and the West Antarctic Ice Sheet. The transect from Dome C to McMurdo in southern Victoria Land is discussed in Studinger et al. (2004). The transect between the South Pole and Mercer Ice Stream (formerly Ice Stream A) is discussed in Studinger et al. (2006). Dashed fault line is proposed fault by Drewry (1972) between the South Pole and the Transantarctic Mountains. Figure from Studinger et al. (2006), modified by addition of two place names: Byrd Glacier and Nimrod Glacier

Lithospheric structure and tectonic framework: a joint geological and geophysical approach

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The significance of the lithospheric structure of the TAM is twofold. First it is critical to understanding the evolution of one of Earth's major intra-plate mountain ranges and intra-plate lithospheric boundaries. Second, the development of the TAM bears on the formation and evolution of the Antarctic ice sheets.

Key questions about lithosphere structure, tectonic framework and Precambrian tectonic history in the central and southern TAM include:

- *What is the nature, composition and structure of the East Antarctic shield underlying and adjacent to the TAM, and what is its relation to Rodinia supercontinent assembly and dispersal?*
- *How did tectonic development of the Ross Orogen vary in space and time, particularly with respect to Gondwana-margin tectonics?*
- *What was the role of the East Antarctic shield and the Ross Orogen in shaping the geometry and pattern of structural-magmatic activity associated with Mesozoic and Cenozoic crustal extension?*
- *What was the role of East Antarctic lithosphere in nucleating and stabilizing the Neogene East Antarctic Ice Sheet (EAIS)?*
- *What is the structure of the lithospheric boundary between East Antarctica, the TAM and the West Antarctic rift system (WARS)?*
- *What role have inherited lithospheric structures played in the evolution of the TAM?*
- *What are the geotectonic connections between the East Antarctic shield, the TAM and the WARS?*
- *How does geothermal heat flux affect long-term ice sheet stability?*

These key questions are interdisciplinary in nature and can only be addressed using a coordinated, multidisciplinary approach. The present-day Transantarctic Mountains and West Antarctic rift system are the integrated outcome of physical interactions between the lithosphere, ocean, cryosphere, and atmosphere over time. Detailed knowledge of the lithospheric structures will broaden understanding of the connections between the East Antarctic shield, the Transantarctic Mountains and the West Antarctic rift system. These three fundamental elements are too frequently treated as discrete and unrelated entities.

Because research on crustal composition and lithospheric structure in the central and southern TAM is constrained by the availability of rock outcrop, these problems can best be addressed using a combination of three different research approaches: (a) study of rock exposures, (b) geophysical remote sensing, and (c) proxy sampling of basement material from glacial deposits.

Outcrop Geology

Rock exposures will always provide the "ground truth" for any geological problem, such that continuing effort can be expected in the study of basement rock exposures within the TAM. With respect to TAM geotectonics, high priority geological field studies should focus on geological discontinuities underlying major outlet glaciers, regional correlation of supra-crustal units, assessment of crystalline basement distribution, lateral contrasts in development of the Ross Orogen, and ground control for geophysical surveys.

Principal target areas for coordinated geological study of TAM basement include: (a) petrotectonic, geochronologic and isotopic study of crystalline basement (Nimrod Group) exposed in the central TAM in order to understand crustal history; (b) exposures of upper Neoproterozoic and lower Paleozoic successions in the southern TAM (e.g., Shackleton to Scott Glacier areas) to address along-strike variability of the Proterozoic rift margin and early Paleozoic Ross Orogen; (c) discontinuities in basement lithologic trends (e.g., Byrd Glacier) in order to assess inheritance of crustal structures; and (d) integration of outcrop geology with "corridor-type" aerogeophysical surveys along and across the trend of the TAM, in order to provide a first-order, spatially-continuous characterization of the underlying lithosphere, and in order to image large-scale structures related to crustal amalgamation, orogenic thickening, and extension.

Geophysics

In order to address the science questions outlined above, three general approaches to collection of geophysical data can be used: (1) regional "corridor-type" geophysical surveys, (2) targeted high-resolution aerogeophysical surveys, and (3) small-scale unmanned aerial vehicle (UAV) supported geophysical mapping.

Geophysical corridors: The highest priority projects from a geophysical perspective are geophysical corridors, generally about 100 km in width and crossing key tectonic features across Marie Byrd Land, the Ross Embayment, the Transantarctic Mountains, and as much of the East Antarctic craton as possible. Transects should also target major tectonic boundaries in more detail, requiring additional corridors oriented along the strike of key boundaries (i.e. branching from the main transect) and/or local investigations at selected sites along the main transect. The corridors should consist of passive and active seismology, magnetotelluric profiling, aerogeophysics (gravity, magnetics, ice-penetrating radar and laser altimetry), and heat flow measurements. The primary constraint for the location of these transects comes from the requirement for grounded ice for seismic and magnetotelluric measurements. These measurements should be complemented by space-borne remote sensing, in particular the analysis of GRACE and CHAMP satellite data to image the deep lithospheric structure and support geodynamic modeling efforts. Of particular interest in regard to lithospheric structure is the thermal anomaly proposed to exist 50 – 100 km inland beneath the TAM due to lateral heat conduction from the warmer West Antarctic lithosphere. New results from the TAMSEIS experiment show that the lateral extent of this buoyant thermal load might be limited to the Ross Island region and decreases in intensity to the north and south of the McMurdo Sound area.

Therefore, from this standpoint, the McMurdo area may not be characteristic of the TAM as a whole.

High-resolution aerogeophysical surveys: In addition to the major geoscience corridors, high-resolution geophysical surveys are needed in conjunction with geological field mapping targeted at specific geologic science questions. These high-resolution surveys over a limited area can also be incorporated in the corridors.

UAV supported small-scale aerogeophysical mapping: Small unmanned aerial vehicles (UAVs) can operate within a 50 km radius from logistic hubs and can be used for magnetic mapping and laser scanning of surface topography for geomorphologic interpretation. Both fixed-wing and helicopter platforms exist as a low-cost solution to support geological mapping over small areas and to extend known basement structures to ice-covered regions.

New geophysical data sets will allow researchers to determine the continuity of tectonic elements between extended crust beneath the Ross Ice Shelf and the TAM-East Antarctica, and the extent and distribution of Mesozoic vs. Cenozoic extension, providing critical regional context for new research to be carried out in the southern TAM. The new data will allow the testing of hypotheses on the kinematics, mechanisms and magnitude of extension and development of mountain relief in the TAM that now come principally from marine surveys and drilling in the Ross Sea and field geological investigations along the rift flanks. Geophysical data over this vast area will be an asset to the Antarctic geology, glaciology and geophysics communities in planning for future drilling, and outcrop and geophysical programs.

Proxy Sampling

Much can be learned about crustal composition and age of the East Antarctic shield, now mostly ice-covered, by study of material derived by glacial transport from sources in the ice-covered ancient craton or by recovery of drill-core material from the glacial substrate. Such proxy sampling study should focus on glacial deposits at the head of the major outlet glaciers in order to obtain samples of transported material derived from the ice-covered EAIS. Analytical techniques that can be applied to glacial samples include: (1) petrology, geochemistry and geochronology of large rock clasts; (2) detrital mineral geochronology of glacial till matrix; (3) isotopic study of the fine fractions of glacial tills; and (4) measurement of the magnetic susceptibilities of rock clasts for comparison with aeromagnetic data in order to correlate lithologies to magnetic anomalies.

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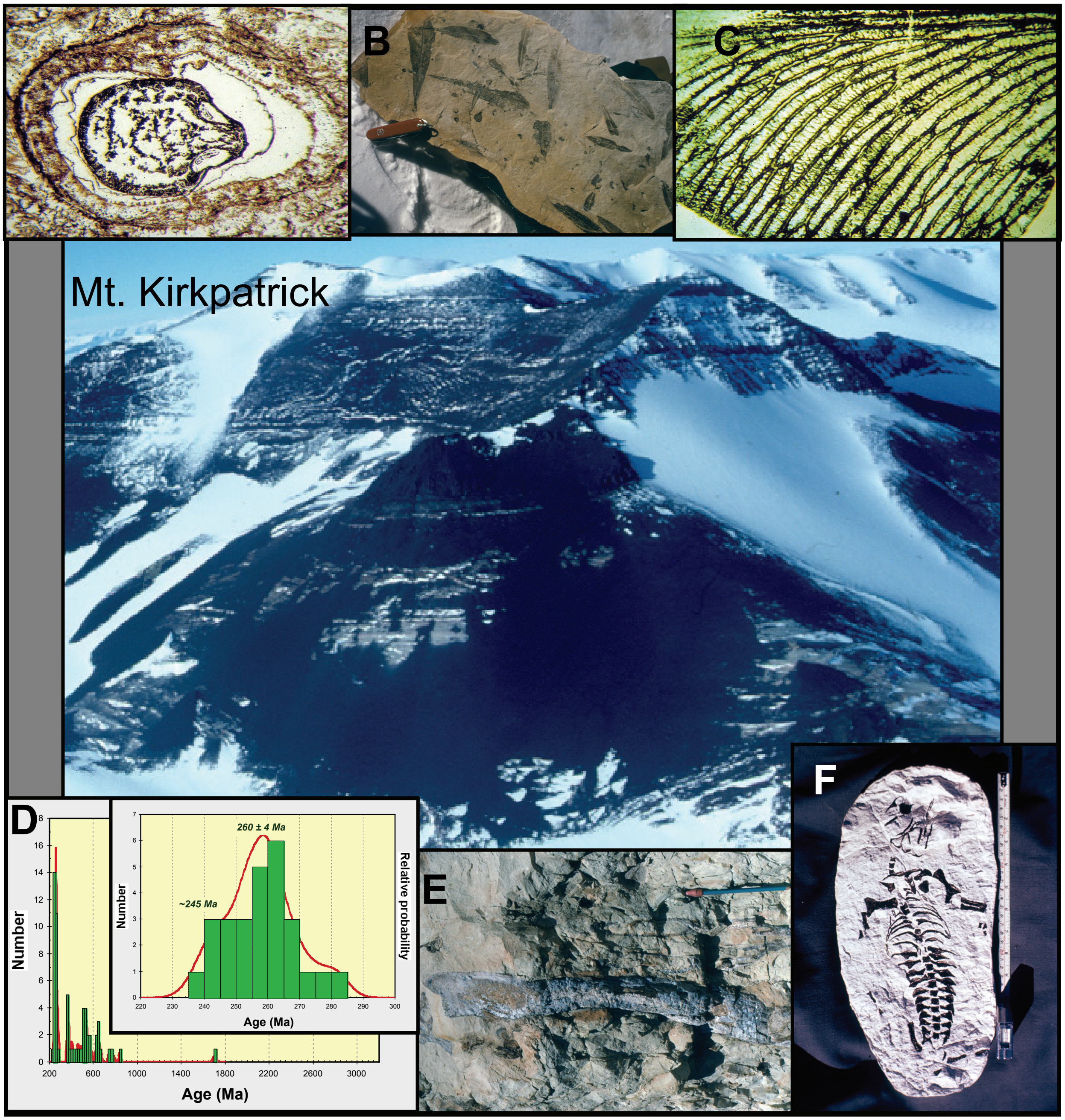

North and west faces of Mount Kirkpatrick, central Transantarctic Mountains. Inset A: the Permian seed *Plectilospermum longi*. Inset B: Glossopteris leaves. Inset C: Glossopteris leaf venation (images A and C provided by T.N. Taylor). Inset D: Probability plot for detrital zircon grains from a sandstone in the upper Buckley Formation of Permian age (Elliot and Fanning, in press). Inset E: *Cryolophosaurus* femur. Inset F: *Thrinaxodon liorhinus* cast from the Shackleton Glacier region. Images E and F provided by W.R. Hammer.

Geology and Paleontology of Paleozoic and Mesozoic Sedimentary and Igneous Rocks

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John Isbell, University of Wisconsin, Milwaukee

Globally significant geologic and paleontologic transitions are recorded in rocks of the Devonian to Triassic Beacon Supergroup and the Jurassic Ferrar Large Igneous Province in the TAM. These transitions include, but are not limited to, the following:

- *The last complete transition from an icehouse to a greenhouse Earth, and the only such transition to have occurred on a vegetated Earth (late Paleozoic Gondwanan Ice Age),*
- *Changes in fauna, flora, ecosystems, environments, and climates across the Paleozoic-Mesozoic transition including the end-Permian and the end-Triassic mass extinctions,*
- *The advent and evolution of early dinosaurs,*
- *Rifting and fragmentation of the Gondwana supercontinent during the Mesozoic.*

Much of our understanding of events that occurred during this time comes with a heavy geographical bias: faunas, floras, environments, climates, and tectonic events in equatorial Laurasia have received far more study than those from high Gondwanan paleolatitudes. In the Mesozoic, Gondwanan crustal blocks began rifting away from Antarctica leaving it isolated in a near polar position. Therefore, Antarctica provides a unique polar view of the events that shaped the current geologic, biologic, climatic and geographic configuration of Earth. Study of the Beacon and Ferrar rocks in the TAM will help to resolve a number of globally significant questions concerning the geologic history of Pangea. These questions include:

- *What was the climatic history of the polar regions during the late Paleozoic and Mesozoic, what mechanisms drove this climate, and what influence did the polar climate have on the biota, environments and climates elsewhere in the world?*
- *What was the floral history of Antarctica during the late Paleozoic and Early Mesozoic and how did these plants contribute to the evolution of seed plants and angiosperms?*
- *What impact did the Permian-Triassic and the Triassic-Jurassic mass extinctions have on Antarctica's biota and environments, and how does Antarctica's high latitude record constrain possible extinction mechanisms?*
- *What was the evolutionary history of Antarctica's faunas during Beacon and Ferrar times and how did it relate to the evolution of vertebrates including dinosaurs and mammals?*
- *What was the origin of the Ferrar dolerites and basalts and what does an understanding of their origin contribute to fundamental questions on magma genesis and emplacement?*

The most complete succession of Gondwana sedimentary and volcanic rocks in Antarctica occurs in TAM, where, in the Beardmore Glacier region, strata are ~4 km thick. These rocks record a particularly rich history of geologic time. Further fieldwork will yield new information in order to address the questions listed above.

Permian glacial and post-glacial rocks are well exposed throughout TAM. However, many exposures in TAM have not been visited since the 1960s, prior to the development of sequence stratigraphy and modern facies analysis. Despite the lack of intense study, preliminary studies are challenging traditional interpretations that an immense Antarctic centered ice sheet covered much of Gondwana during a 90 Ma interval. Although much work remains, the emerging view of the glaciation is that of numerous short discrete glacial intervals characterized by multiple small ice centers. Upper Permian fluvial coal-bearing strata occur throughout TAM. These rocks record an unusual transition from cold conditions into a vegetated and forested Polar ecosystem. Causes for this transition are unknown. However, increasing global temperatures during the latest Paleozoic may have driven plants into polar refugia. Study of abundant fossil plants and forests in TAM may help in identifying changes in global biomass during this interval and aid in determining what climatic and environmental mechanisms drove polar forestation.

A major geologic transition recorded in TAM is the Permian-Triassic boundary. This boundary, which marks the greatest of all mass extinctions, is well exposed in the Beardmore and Shackleton Glacier regions. However, the exact position and events associated with the boundary are enigmatic. The recent recognition of zircon-bearing tuffs near the boundary may help identify the boundary and aid in deciphering what influence the extinction event had on the biota and environments at high polar latitudes. Evolution of several important groups of plants also occurs across the Paleozoic/Mesozoic transition, which was a particularly critical time in seed plant evolution. Some of the gymnosperm groups from this time have been suggested as angiosperm ancestors. Because the Beardmore area, in particular, contains an abundance of fossil plants, including some of the only known sites of structurally preserved Permian, Triassic, and Jurassic plants, this area is particularly important in determining plant evolution.

The Beardmore and Shackleton Glacier regions represent the areas of greatest potential for new Mesozoic vertebrate finds in Antarctica. Numerous localities in both regions have produced well-preserved specimens of significant Triassic vertebrate taxa. However, origination of this fauna in Antarctica and how it relates to well-studied faunas in South Africa is ambiguous and requires further intensive field and laboratory study.

Jurassic strata in the Beardmore area contain perhaps the most spectacular fossil fauna in Antarctica: high-latitude Lower Jurassic dinosaurs. The geographic and temporal importance of this fossil assemblages cannot be overstated, and given the information emerging from studies of material collected to date, the vertebrate faunas of Antarctica will be critical to understanding the evolutionary dynamics of the Triassic-Jurassic faunal transition, and also to deciphering the early evolution and biogeography of many major dinosaurian groups. Reconnaissance over a period of just a few days in the 2002-2003 field season suggests unusual potential for more discoveries within Jurassic strata, and possibly in underlying Upper Triassic strata as well. Further, the lacustrine interbeds in the overlying basalt lavas host the only known examples of exceptional preservation of terrestrial non-biomineralized organisms from Jurassic strata.

The waning stages in the history of the Gondwana supercontinent, during the Early Jurassic, are recorded by emplacement of volcanic and intrusive rocks of the Ferrar Supergroup which are best exposed in the Beardmore Glacier region. Studies of these rocks address fundamental questions on magma genesis and emplacement. Fragmentary structural, petrologic, and volcanologic data suggest an extensional rift setting existed in the TAM during this period. Geochronological studies demonstrate that Ferrar magmatism was short-lived (<1m.y.) and contemporaneous with Karoo magmatism in southern Africa. Geochemical studies have suggested that the Ferrar magmas were derived from a single source which may be related, along with the Karoo province, to the inferred continental breakup plume centered in the region of the proto-Weddell Sea. Such models imply upper crustal magma transport distances of thousands of kilometers, perhaps guided by regional extension. For more than three decades, the geochemistry of Ferrar rocks has been at the heart of the debate regarding the origin of enriched isotopic and crust-like trace element signatures in continental basalts. Advances in our understanding of these features hinge on characterization of primitive end members of the Ferrar suite that occur primarily in the CTM, understanding magma flow paths, and the tectonic setting.

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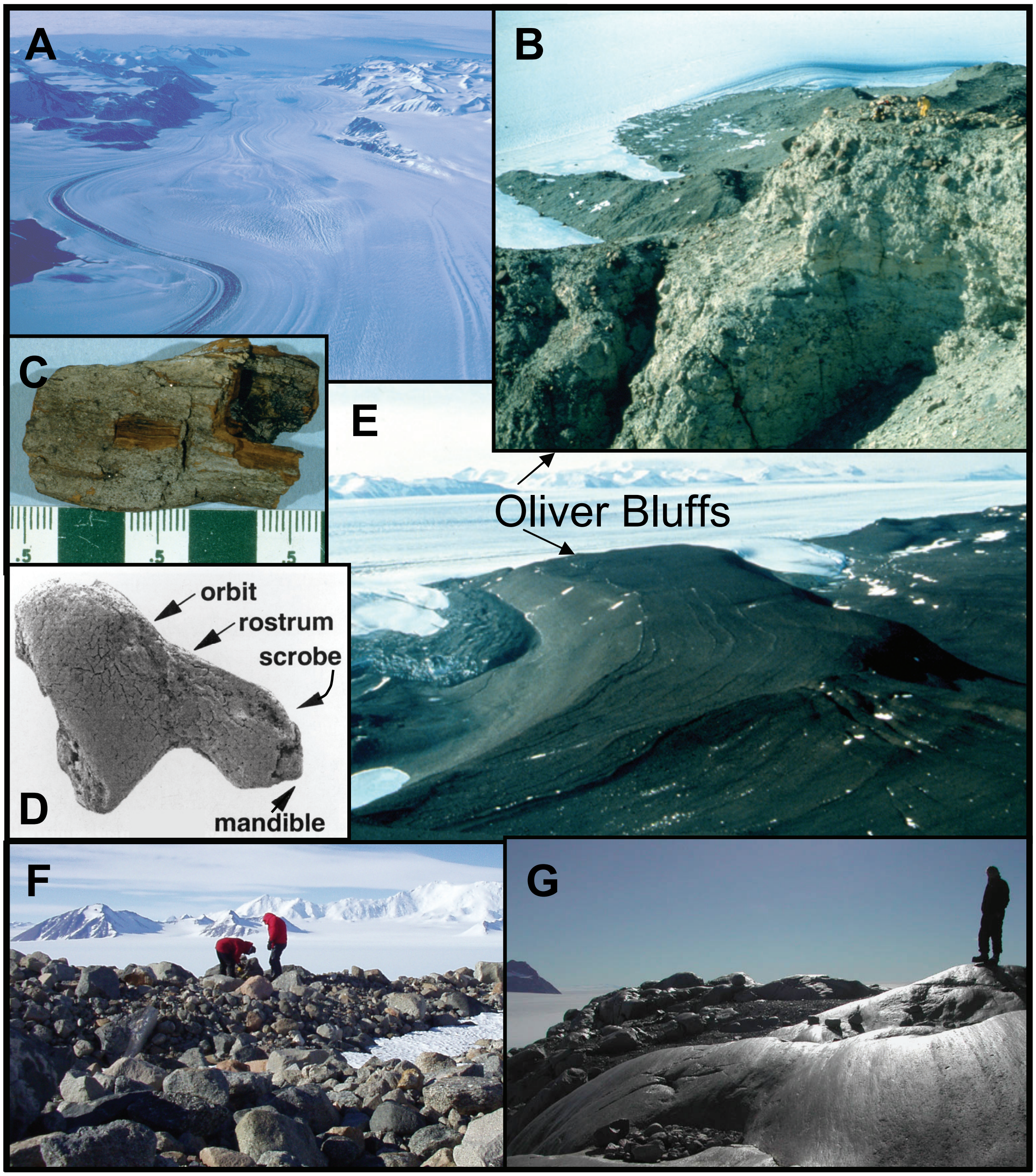

Inset A: View north down the Shackleton Glacier and the Swithinbank Moraine. Insets B-E: Oliver Bluffs, Dominion Range, adjacent to the Beardmore Glacier. Inset B: glacially-related strata of the Sirius Group. Inset C: fossil wood from Sirius beds. Inset D: beetle head (long dimension of head is 1.8 mm) from Sirius beds (from Ashworth and Kuschel, 2003). Inset E: glacial deposits on Oliver Platform. Inset F: moraine near the Last Glacial Maximum adjacent to the Reedy Glacier. Inset G: glacial pavement and erratics of Holocene age adjacent to the Scott Glacier. Images B, C, and E provided by P.N. Webb; images F and G provided by B. Hall.

Surface Processes, Glacial History, and Landscape Evolution

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Interactions between the lithosphere, cryosphere, biosphere, and atmosphere form landscapes that bear unique signatures of these processes, with the landscapes themselves subject to continual modification. Because of the extreme cold and dryness and resulting slow rates of denudation, some of the oldest landscapes on Earth occur in Antarctica. These landscapes are significant for the links they provide between many disciplines and for the history they contain of the Cenozoic ice age and past landscape evolution.

The Dry Valleys region of South Victoria Land has been studied for nearly 50 years, yet many new important discoveries are still being made. For instance, the recent discovery of small lacustrine deposits with diverse biota provides a new window into the late Cenozoic history of the continent. In contrast, investigations in the central and southern TAM have been limited and extensive swaths of the mountain range have never been studied. Given the extent of ice-free terrain and limited previous work, the likelihood of major scientific discoveries in the central and southern TAM continues to be very high.

The TAM, the most extensive discontinuous ice-free area in interior Antarctica, display a complex alpine and periglacial landscape comprising bedrock, soil, and sediment-covered elements bordering glacier ice, melt lakes, and the Ross Sea and Ross Ice Shelf. These now cold-desert surfaces are among the oldest on Earth and represent the best terrestrial analogues for those on Mars. These surfaces include extensive deposits of the oldest unlithified glacial sediments and landforms in the world and the best-preserved fossil evidence of Upper Cenozoic polar terrestrial flora and fauna. These ice-free areas constitute one of the few windows into the geological and glacial history of the ice-covered interior of the Antarctic continent.

Major Research Focus Areas

- *How have feedbacks and interactions among climatic and surficial processes (e.g., glacial, fluvial, aeolian, periglacial, salt weathering, soil formation, etc.) shaped the unique landscapes and biological environments of the TAM on time scales ranging from a few years to tens of millions of years?*

The TAM form a natural laboratory to study fundamental geomorphological processes that operate in extreme terrestrial cold and dryness. For example, recent research in the Dry Valleys region has revealed significant soil erosion by as yet unidentified geological processes. Whether or not the central and southern TAM are subject to comparable and counterintuitive degradation is not known. In fact, little is known of the processes and rates that shape the environment in the TAM. Yet resolving the stability of the landscapes in the TAM not only will illuminate rarely accessed surface processes at a terrestrial limit but also has obvious planetary science and exobiological implications. The expected development and exposure of soils to hyper-arid and frigid conditions for millions of years provide unique opportunities to study rates of weathering and the dynamics of salts and ice in the soil profile in the virtual absence of bulk liquid water.

These conditions and processes are of immediate interest to the planetary science community interested in life in extreme environments and in geomorphic processes on Mars.

- *What is the history of both the East and West Antarctic Ice Sheets, as recorded in the TAM, over time scales ranging from decades to tens of millions of years? What is the relationship between this history and global climate change?*

Current and future research projects will focus on understanding the development of the Antarctic ice sheets and their relationship to global climate change. On short time scales, records of past ice-sheet behavior will help clarify the response of the ice to global warming. Most pressing is an understanding of the future contribution of the ice sheets to eustatic sea-level change. In addition, the south polar climate and Antarctic ice sheet behavior also potentially affect Southern Ocean circulation, sea ice dynamics, and CO_2 contributions, all key players in abrupt climate change. On longer time scales, it will be possible to reconstruct past changes in the ice sheets that reflect the transition from temperate alpine glaciers to polar ice sheets, which are tied to global climate events on the order of millions of years. How the development of the Antarctic ice sheets and the thermal isolation of Antarctica is reflected in, and contributed to, the progression of the Cenozoic ice age remains uncertain. Further, Earth's transition from the warm Mesozoic and Early Cenozoic into the present ice age is poorly understood. The development of the first of Earth's Cenozoic ice sheets occurred in Antarctica and research currently focuses on where, when, and how that ice sheet was initiated.

- *How have interactions among glaciation, surface processes, and tectonics contributed to the development of the TAM?*

Significant feedbacks exist between glaciation, tectonics, and surface processes, all of which have contributed to the formation of the TAM. On one hand, TAM uplift must have affected the initiation, growth, and dynamics of the ice sheets. Yet, glacial erosion and downcutting, as well as long-term denudation of the landscape and redistribution of sediment from the continent to adjacent basins also must have contributed to the uplift. One long-term goal, therefore, is to understand the complex relationships and feedbacks between TAM uplift and the glacial history and landscape evolution of Antarctica.

Summary

The TAM constitute a transition zone in many disciplines, and landscape evolution in the broadest sense is the link between them. Thus, the proposed research has broad, interdisciplinary implications for the fields of: planetary geology, exobiology, global climate change (abrupt climate change, global warming, development of the Cenozoic ice age), sea level, development and extinction of ecosystems (particularly tundra), geomorphology (development and long-term preservation of landscapes), surface processes (the dominant geological processes that erode, transport and redistribute the regolith) and biodiversity. The research will be accomplished through intensive field programs coupled with lab studies such as image analysis, cosmogenic and radiometric dating, landform, soil and subsurface ice analysis, and paleontological studies. An important component of the field programs will be the installation of automated ground observatories to define current physical and chemical conditions (temperature, humidity, salinity of surface-bound water, soil motion) below the ground surface in a region essentially lacking this information, which is essential for understanding not only contemporary surface processes but also the environmental constraints on organisms. These observatories could be advantageously positioned to complement the existing and proposed automatic weather stations (AWS).

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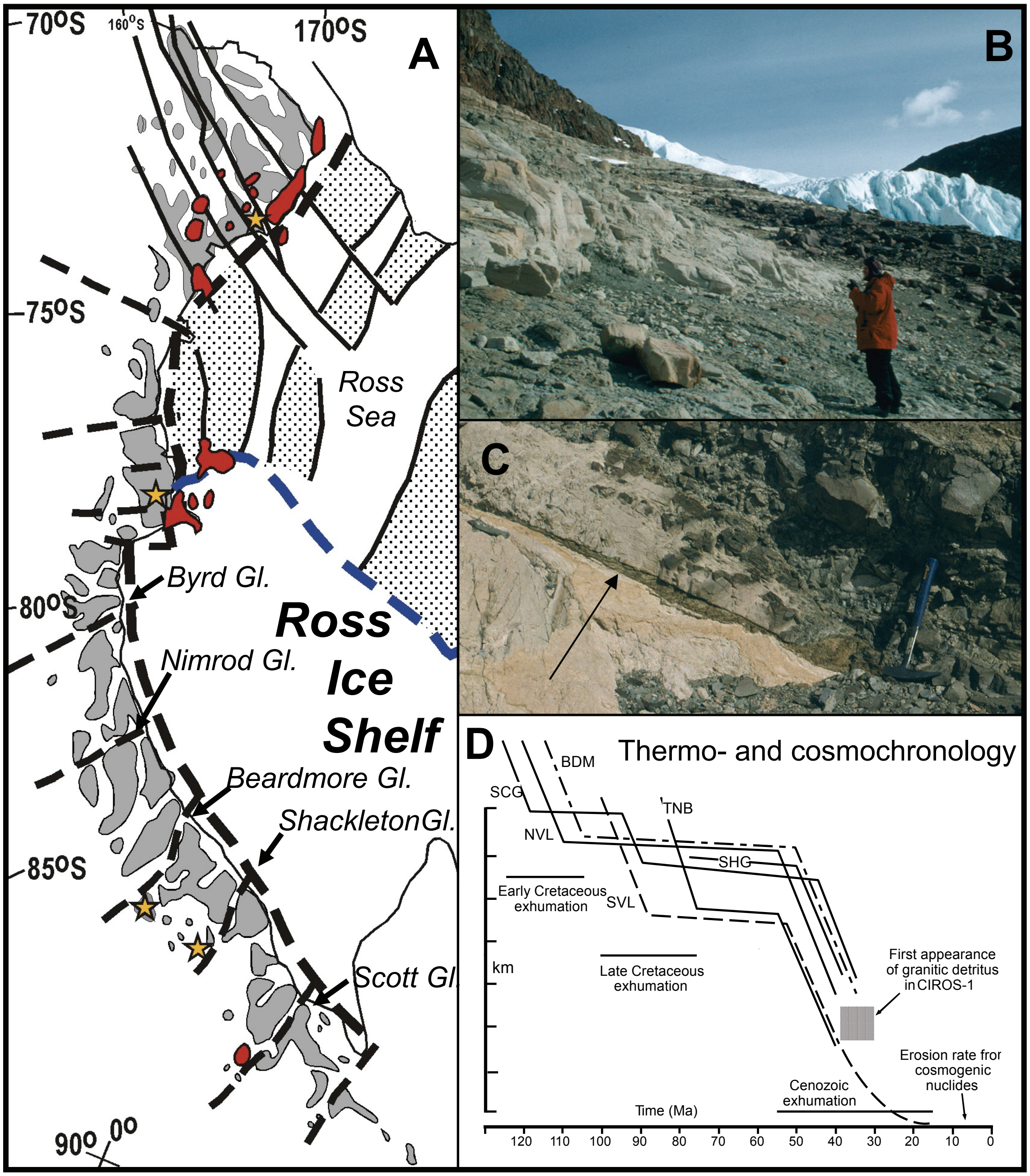

A: Segmentation of the Transantarctic Mountains; heavy dashed lines in black are inferred faults; areas colored red are Upper Cenozoic volcanic rocks (image provided by T.J. Wilson). B: tilted Triassic strata adjacent to a fault at Roberts Massif, Shackleton Glacier region. C: fault gouge (arrow) in Triassic beds at inset B. D: Uplift history from thermo- and cosmochronology, demonstrating episodic exhumation (from Fitzgerald, 2002); BDM: Beardmore Glacier region; NVL: north Victoria Land; SCG: Scott Glacier region; SHG: Shackleton Glacier region; SVL: south Victoria Land: TNB: Terra Nova Bay.

Post-Gondwana and Active Tectonics

Terry Wilson, The Ohio State University

The tectonics of the Transantarctic Mountains (TAM) has global significance on two grounds. First, it is one of Earth's major intra-plate mountain ranges. Second, the Cenozoic evolution of the mountain range is intimately linked with the inception and growth of the Antarctic ice sheets and thus with climate history.

The TAM form one part of the lithospheric gradient between the thin crust of West Antarctica and the thicker crust of East Antarctica, and also form the rift shoulder of a major rift system, the West Antarctic Rift System, that differs in several important respects from the well known East African Rift system and the Basin and Range Province of the western US. In the structures developed, the TAM document the upper crustal development of that boundary and rift shoulder. Although the structures mainly indicate vertical movements, there is evidence for a component of strike slip displacement, which possibly may relate to the discrepancies in the closure of the global plate motion circuit. The exhumation history, which has been deciphered mainly by fission track studies, begins in the early Cretaceous although the principal movements started at about 50 Ma during the Eocene. At present, there appears to be little earthquake activity, but slow movements in response to Holocene deglaciation may be occurring.

Key questions that must be addressed in order to understand the structure and evolution of the mountain range include:

- *What is the deep structure of the mountain range and how does it relate to the intra-plate boundary?*
- *What are the upper crustal structures and how do they relate to the inferred uplift and exhumation history?*
- *What are the drivers for uplift?*
- *What is the relationship between surface processes and the tectonic evolution?*
- *What is the relationship between TAM uplift, exhumation and sedimentation in the adjacent West Antarctic basins?*

In order to address these key questions, a variety of studies are required and include: field-based observations of rocks, remote sensing and geophysical investigations of the mountain range, geochronologic data, and drilling of sedimentary sequences in adjacent basins.

The deep structure of the TAM requires knowledge of the crustal thickness and its spatial changes, the thermal regime beneath and adjacent to the range, and the rheology of the crust and upper mantle. These attributes require seismic and magneto-telluric investigations, and link into the lithospheric investigations discussed in an earlier section.

Shallow crustal investigations need to focus on fault geometry, kinematics and timing. These can be achieved through field mapping, data analysis, and where possible dating of fault-related minerals. In addition, regional-scale structural analysis is aided greatly by remote sensing imagery, in particular ASTER imagery where available, and digital elevation models. The occurrence of exposed faults is very limited, so offset stratigraphy (as in the Shackleton Glacier region) and secondary structures without significant displacement are most important in inferring fault locations and kinematics. These types of data together with imagery allow identification of regionally significant trends to complement the sparse outcrop-specific information on faults.

The principal episode of TAM exhumation is inferred from fission-track dating to have begun in the Eocene (ca 50-55 Ma). Rapid sedimentation in the McMurdo Sound region at 34-31 Ma is inferred to either mark the maximum rates of erosion due to uplift or climate change with the inception of wet-based alpine and ice sheet glaciation, which is commonly accompanied by high rates of erosion. Tectonic stability and little surface erosion since the late Miocene (ca. 14 Ma) have been suggested. The uplift history is intimately linked to the record of surface processes, which will have operated under changing climate, topography, and ice cover. Linked in is the relationship between tectonics and the deposition of glacial and non-glacial sediments. For the pre-Holocene in the central and southern TAM, such strata have been placed in the Sirius Group, which occurs in a variety of topographic settings and over a large range in altitude, and has a much disputed age. Further fission track and U-Th-He age dating will refine the exhumation history of individual blocks forming the TAM, and provide age constraints for geomorphological and glacial geologic interpretations. Cosmogenic radionuclide analysis of surficial material will provide much needed age control on younger (less than about 10 Ma) surficial deposits.

Knowledge of the deep structure and thermal state of the lithosphere, obtained from geophysical studies, is important in evaluating isostatic rebound following the major ice retreat in the last 20,000 years. Active tectonics can be addressed through passive seismicity and GPS networks; the former suggests little or no lithospheric earthquake activity and the latter just measurable (over five years) vertical and horizontal movements. Co-ordinated instrument arrays are a prerequisite to understanding the extent of active tectonism.

Uplift and exhumation of the TAM is recorded by erosional processes and scattered terrestrial deposits, and by deposition in adjacent sedimentary basins. A prior geophysical traverse identified stratified rock beneath the Ross Ice Shelf offshore from the Beardmore-Nimrod Glacier coastline. Drilling this sequence will yield important information on the uplift history, such as the provenance of detritus, exhumation, glacial episodes, timing of rift events, and the unroofing history, let alone information on Cenozoic climate evolution from interbedded fossiliferous marine strata.

Summary

Tectonics constitute one of the principal threads connecting many of the investigations of the TAM. The Cenozoic tectonic history provides the framework for understanding modern processes, but is itself built on the earlier history of Rodinia and Gondwana, which is reflected in lithospheric properties and structures. The qualitative and quantitative aspects of modern earth processes in the TAM are intimately connected to that history.

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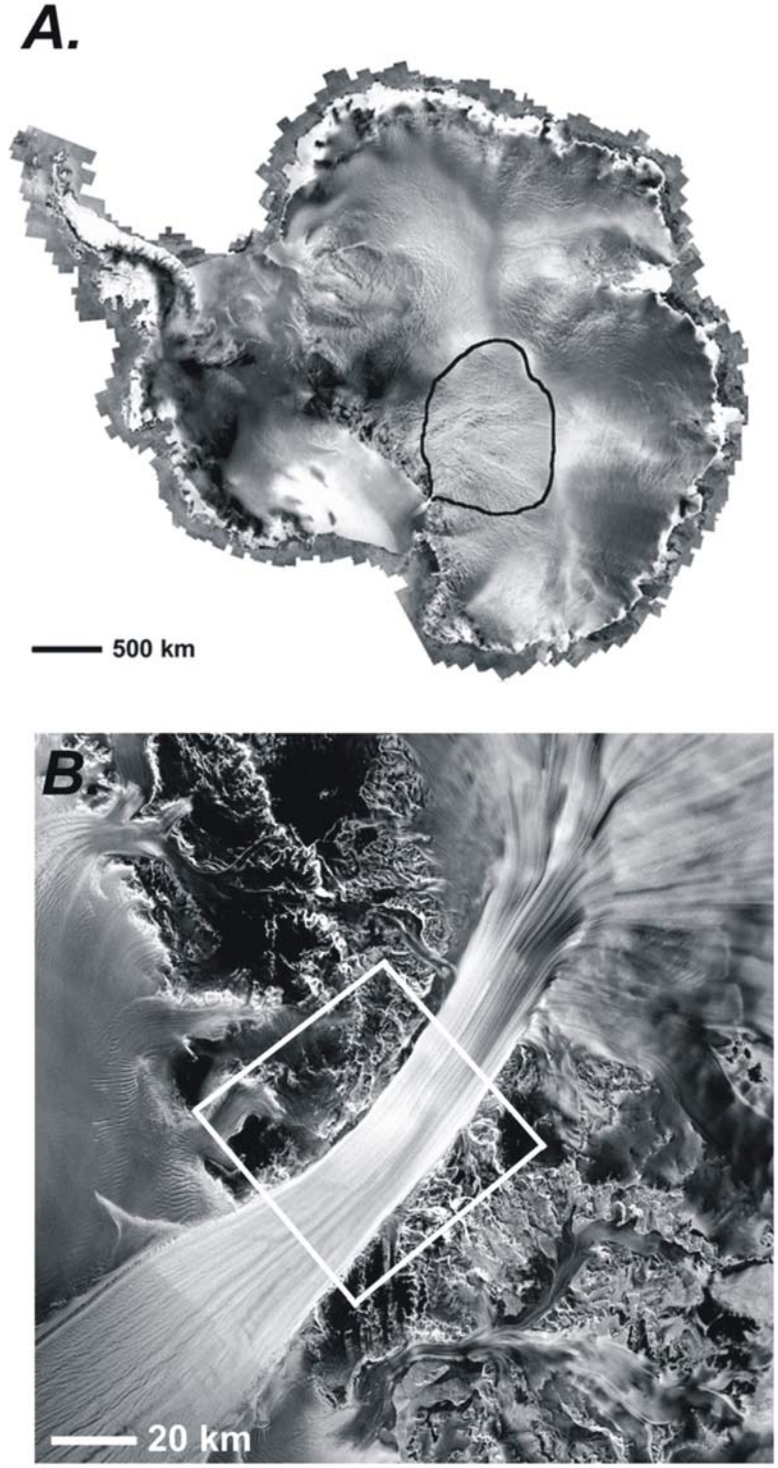

A: Antarctica with the catchment area for the Byrd Glacier outlined. B: Byrd Glacier. Images provided by G. Hamilton.

TAM Glaciology: Outlet Glaciers

Gordon Hamilton, University of Maine

The outlet glaciers flowing through the central and southern Transantarctic Mountains are significant for the connections they form between the East Antarctic ice sheet and ice in the Ross embayment, and as the conduits they form for katabatic winds draining the polar plateau and interacting with weather systems in the Ross Ice Shelf region.

This part of the Transantarctic Mountains (TAM) buttresses the high, cold East Antarctic ice sheet (EAIS) and separates it from the relatively low, warm ice in West Antarctica (WAIS). Glaciers flowing through the TAM, and forming some of Earth's largest outlet glaciers, currently drain much ice from the EAIS and nourish a large portion of the Ross Ice Shelf with cold stiff ice from East Antarctica. Unlike the WAIS, very little is known about the distribution of snow accumulation on the ice sheet plateau, about the ice dynamics of most outlet glaciers draining through the TAM, and about the overall mass balance conditions for this portion of the East Antarctic ice sheet. Only Byrd Glacier has been studied in detail; speeds in excess of 700 m/yr have been documented, significant decadal-scale changes in flow speed have been observed, and rapid inland migration of its grounding line has been inferred. TAM outlet glaciers are probably more dynamic than commonly assumed. In addition, TAM outlet glaciers experience an increasing amount of ice shelf buttressing from north to south, with potentially important ice dynamic effects. Further, the northern outlet glaciers occupy fjords, unlike those to the south, which probably reflects latitudinal gradients in past climate and erosion.

Better knowledge of the characteristics of the outlet glaciers, now and in the past, is necessary for understanding of the coupled Antarctic ice sheet-ice shelf system, its response to present and past climate changes, and its role in modulating global sea levels. Compelling glaciological science questions, which can be addressed through study of this part of Antarctica, include:

- *What is the mass balance of this sector of the EAIS including ice exiting through the outlet glaciers?*
- *Are the recent dynamic changes of Byrd Glacier unusual, or are they widespread on other TAM outlet glaciers?*
- *What is causing the observed changes on Byrd Glacier?*
- *How do glacier dynamics affect fjord erosion and landform development?*
- *Is the seismic activity that is associated with fast ice motion and acceleration in other outlet glaciers, especially in Greenland, a more universal characteristic and what does it mean about ice dynamics and, perhaps, glacial erosion?*
- *What is happening on the inland margin of the ice sheet, and can it explain anomalous uplift rates in the TAM?*
- *Are there suitable blue ice sites where ancient ice samples can be recovered in the form of horizontal ice cores?*
- *What happens on the Ross Ice Shelf at the boundary between ice from East Antarctica and West Antarctic ice?*

A common set of field measurements are required for each research task, and include the collection of baseline glaciological data such as ice thickness, surface topography, ice flow, and accumulation rate. Both terrestrial measurements (GPS surveys, firn cores, ground-penetrating radar, seismic surveys) and aerogeophysical data collection (ice-penetrating radar, lidar) will be required. Related satellite remote sensing studies would extend the range of measurements, and coordinated modeling activities would provide much of the interpretive framework.

Several related studies are underway or in the proposal stages, including: US ITASE which will traverse the inland margin of the TAM from Taylor Dome to South Pole yielding key data on accumulation rate, ice dynamics and glaciochemistry; a detailed aerogeophysical study of Byrd Glacier to understand its surface and bed topography; and remote sensing studies of major TAM outlet glaciers. Answering the science questions requires collaboration with groups studying atmospheric processes, glacial geology, neotectonics and geodynamics, biology and life in ancient ice.

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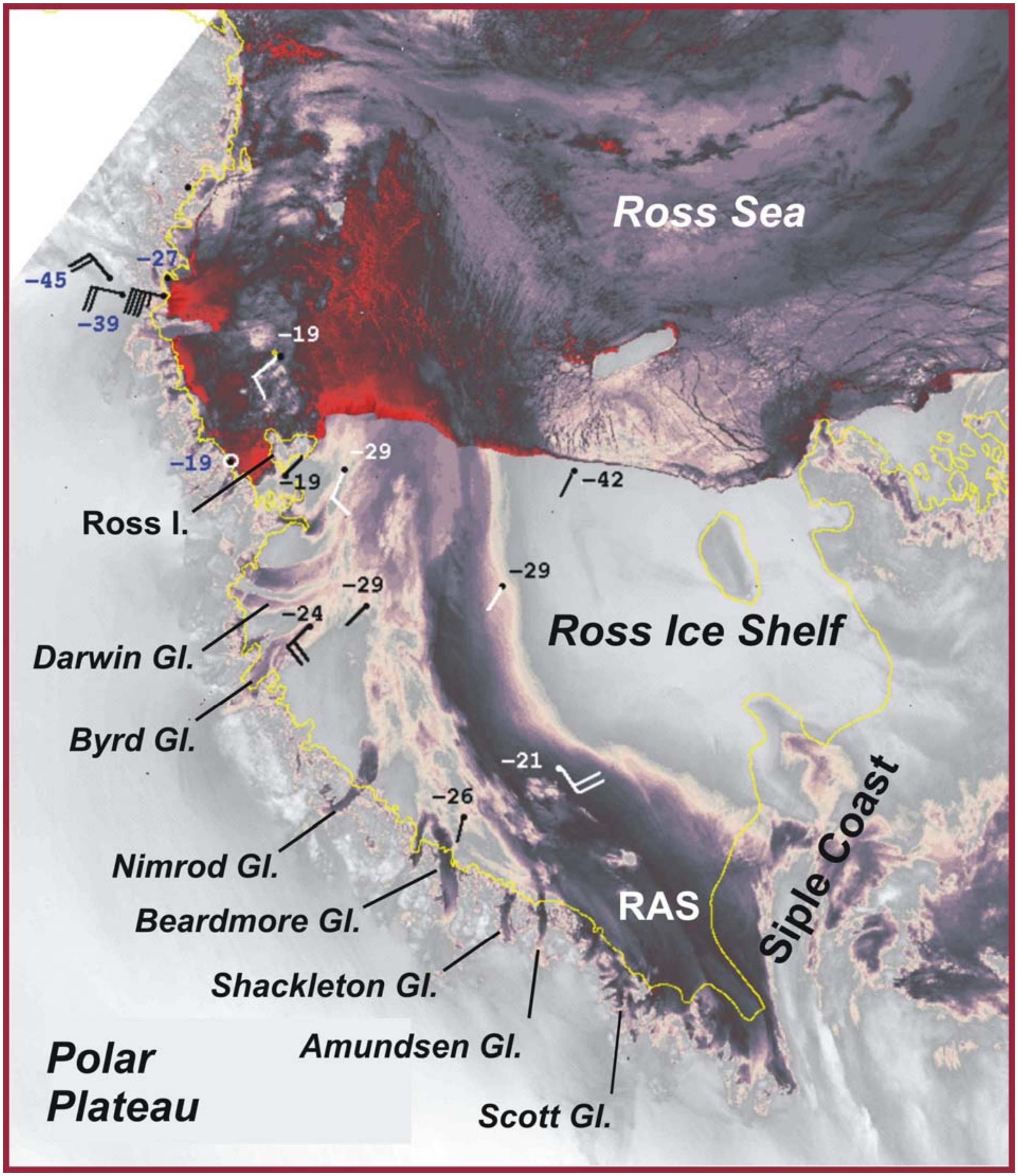

Thermal infrared satellite image of the Ross Ice Shelf Air Stream (RAS), which appears as the dark feature from Siple Coast across the Ross Ice Shelf to the Ross Sea. The katabatic outflow along the major glaciers is well displayed by the dark "fingers" extending down the glaciers and out onto the Ross Ice Shelf. Image provided by D. Bromwich.

Atmospheric Processes: Katabatic Flows and the Ross Ice Shelf Air Stream

David Bromwich, The Ohio State University

The Transantarctic Mountains form both a significant barrier and a transition zone in the Antarctic atmosphere. Winds over the Ross Ice Shelf are deflected as well as steered by the mountain range, and katabatic airflow, channeled down the outlet glaciers from the polar plateau, interacts with these mountain-parallel winds. Katabatic winds from West Antarctica that feed the mountain-parallel winds, and perhaps katabatic winds from East Antarctica, are associated with mesoscale cyclogenesis. Such atmospheric conditions probably have existed for at least the last 15 million years when full ice sheet conditions first prevailed, and prior to that the uplifting mountains must have caused orographic precipitation and enhanced ice formation at the onset and early stages of glaciation.

Key Research Topics Addressable by Observations near Beardmore Glacier:

- *What is the horizontal and vertical structure of the atmosphere along a transect across the TAM?*

Automatic weather stations (AWS) have provided extensive information about the atmospheric behavior close to the surface of Antarctica but there is little detailed understanding of how this changes in the vertical. By focusing on the horizontal and vertical atmospheric structure along a transect from the Ross Ice Shelf, up Beardmore Glacier and onto the polar plateau, the following important science questions can be addressed:

a. *The Ross Ice Shelf air stream* (RAS) flows northward along the Transantarctic Mountains and couples Antarctica with lower latitudes. Components of the RAS are katabatic winds from West Antarctica that blow across Siple Coast, katabatic winds that blow from the polar plateau to the Ross Ice Shelf via the primary glacier valleys dissecting the Transantarctic Mountains including Beardmore, and barrier winds that form from deflection of low-level air by the mountains. Very little is known about the lateral and vertical structure of these air flows or the dynamics that control them and their interactions, despite their climatic importance.

b. *Air flow* over the Transantarctic Mountains generates orographic clouds and precipitation as well as mountain waves. The latter are important for stratospheric dynamics. Very little direct study of these important phenomena has been conducted.

- *What are the spatial and temporal variations of the circumpolar vortex?*

The circumpolar vortex is the dominant atmospheric circulation feature in the middle and high latitudes of the Southern Hemisphere. Its center fluctuates between the northeast Ross Sea and the Ross Ice Shelf. Its position and intensity governs the typical weather experienced at McMurdo station with profound implications for the logistical operations there. The circumpolar vortex is a key player in the behavior of the large-scale modes of atmospheric variability that control the weather and climate of West Antarctica and the Ross Ice Shelf, namely the Southern Hemisphere Annular Mode (SAM) and the El Niño-Southern Oscillation. The detailed structure and the controls on its behavior are unknown. Systematic rawinsonde programs from the Ross Ice Shelf near Beardmore Glacier and at Siple Dome, in conjunction with routine balloon observations from McMurdo, South Pole, and Terra Nova Bay, will document the detailed spatio-temporal variability for the first time, will describe the impacts, and perhaps will allow isolation of the generation mechanisms of the variability.

- *What are the causal mechanisms for mesoscale cyclogenesis over the Ross Ice Shelf?*

Mesoscale cyclones form with great frequency over the southeastern Ross Ice Shelf and Siple Coast area, especially in autumn when warm, moist air is advected into the region from the open ocean. They can result in severe weather that impacts field parties in the area and may be involved in regeneration of synoptic-scale cyclones near Siple Coast that subsequently bring adverse weather to Ross Island. It has been conjectured that the formation of mesoscale cyclones is associated with the katabatic winds that converge into this area but no systematic study of their causal mechanisms has been conducted.

Field Measurements

A transect along one of the outlet glaciers, for instance the Beardmore Glacier, should extend from the glacier mouth out onto the Ross Ice Shelf and link up with the existing AWS array and also extend onto the Polar Plateau. The AWS sites should be complemented by a rawinsonde program, boundary layer studies, and remote sensing of fog and cloud cover.

These research objectives constitute one part of a broader science program required to understand atmospheric processes in the Ross Sea sector of Antarctica, in particular the Ross Ice Shelf Air Stream. In addition to the field program briefly described above, a rawinsonde program at Siple Dome and aircraft measurements are integral to the overall program which is described in greater detail in the Appendix.

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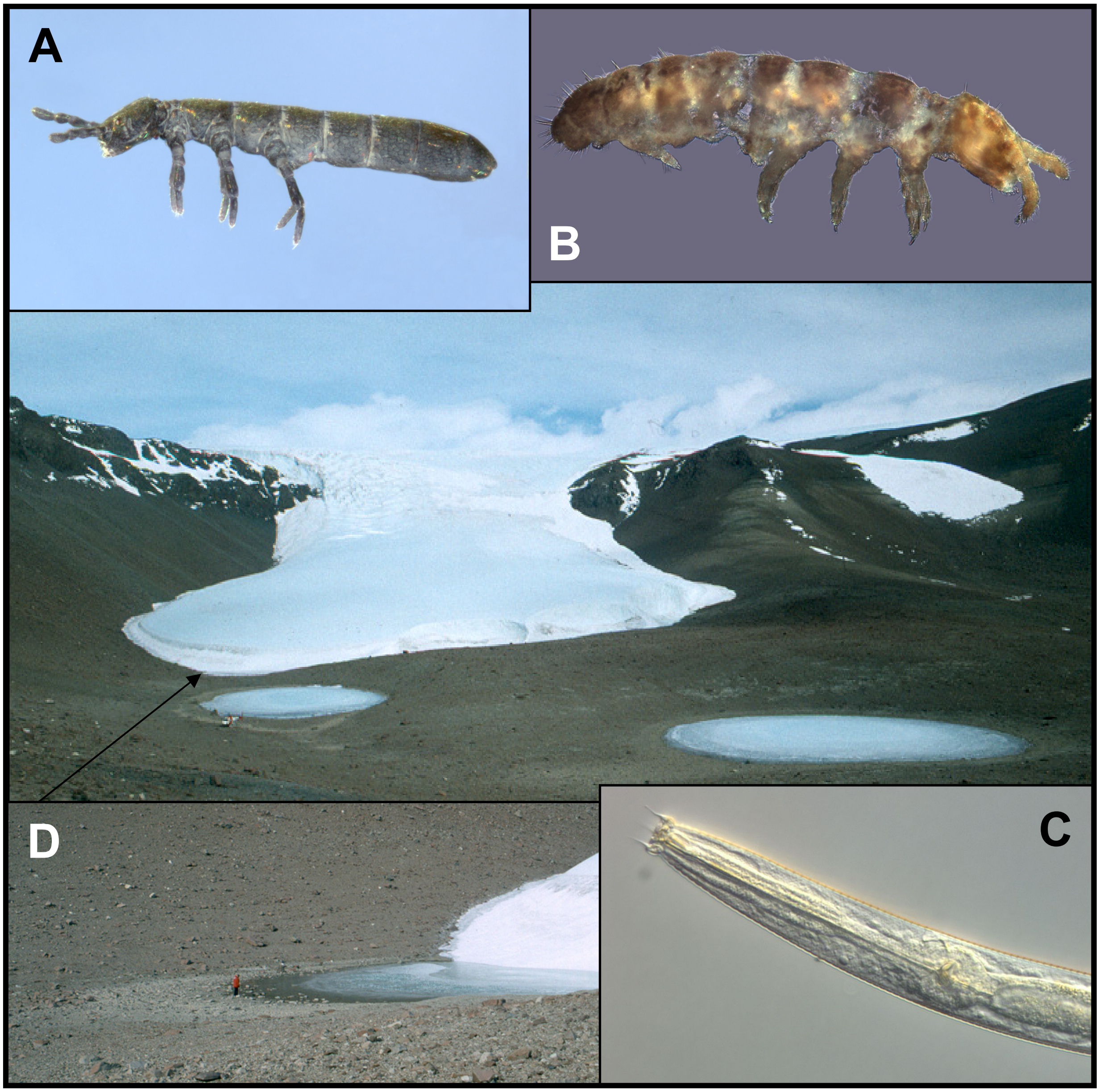

Dry valley near Mt. Heekin adjacent to the Shackleton Glacier. The right hand lake is about 150 m in diameter; the left hand lake, with helicopter for scale, is about 65 m by 150 m; a small lake, barely visible, lies at the front of the glacier. Inset A: *Antarctophorus subpolaris*, a species of Collembola (springtail). Inset B: *Biscoia subpolaris* (springtail). Inset C: the nematode *Scottnema lindsayae*. The illustrated springtails and nematode are from soils in the Dry Valleys, south Victoria Land. Inset D: proglacial lake rimmed by pale-colored algal mats (figure for scale). Images A and B provided by B. O'Brien (U. Waikato); image C provided by D.Wall.

Ecosystems: Polar Environments South of 80 °S

Diana Wall, Colorado State University

Significant changes have occurred in the earth's polar regions, but missing is basic knowledge on terrestrial ecosystems towards the interior of the Antarctic continent. Research focusing on factors controlling the distribution of life across geological, environmental and latitudinal gradients in the central and southern TAM provides the opportunity to address fundamental research questions and responses to global changes.

A number of broad but *overarching* research themes relevant to ecological investigations are listed below in order of importance. All of these topics have to do with past and present factors affecting species and their distribution.

- *What is the Distribution of Organisms on Earth?*

Two major ecological questions currently being addressed for all life on earth are: what are the factors determining the geographical distribution of species? and how will global changes affect species and consequently ecosystem functioning?

a. ***Do latitudinal gradients determine the distribution of terrestrial biodiversity?*** Previous work in the McMurdo Dry Valleys (MCM) and Cape Hallett regions has tested the ecological hypothesis that fewer species or communities exist at higher latitudes and that factors other than latitude, such as whether habitats are suitable or too extreme for life, determine biogeography of species. Research is proposed at Darwin Glacier, but little data currently exist on biodiversity, biomass, production or biogeochemical processes in either terrestrial or aquatic environments, further south. It is thought that gradients in biodiversity and biocomplexity exist across latitudes parallel to the Victoria Land coastline and perpendicular across elevations as well. A habitat suitability model for microflora and fauna as well as an environmental legacy model developed for the McMurdo Dry valleys have been tested at Cape Hallet, but need to be extended to ecosystems further south and integrated with knowledge of earth system science across various spatial scales Additionally, the recent past history of glacier advance and retreat, the influx of marine waters and the waxing and waning of lakes and ponds due to climate change have had significant impact on the contemporary ecosystem structure and function. Yet we have no knowledge of species distribution, diversity or processes to enable us to predict how these climate changes might affect the ecosystems across gradients. Both these concepts can be tested in the environment of the central TAM. We hypothesize that environmental pressures, both physical and chemical, will vary with latitude in the TAM and because of this each location will favor certain organisms. These investigations will help better define our understanding of diversity and ecosystem structure that is observed in the MCM is consistent over a broader latitudinal gradient.

b. ***Does the TAM act as a barrier to dispersal of East Antarctic and West Antarctic biota?*** Our knowledge of both biogeography and phylogeography of organisms on the continent is very fragmented and limited to only a few ice-free regions (Peat *et al*., 2006). There has been little research completed on the relationship between physical barriers such as large outlet glaciers (e.g. Byrd glacier) and the distribution of organisms. The controls on organism dispersion may be different for different taxa *and/*or habitat types. Are habitats this far south dominated by endemic or more cosmopolitan species? What role does aeolian transport play in ecosystem evolution? How do atmospheric drivers affect patterns of dispersal and colonization? Another key issue is, whether or not there is an extreme for life on the continent; that is, is there a continuum of complexity of life and how can this continuum serve as a laboratory for investigating issues such as ecosystem evolution, community resilience and stability, and species diversity? It is important to understand the limitations of life and the physiological adaptations that allow organisms to arrive, survive and actively metabolize in these extreme environments. For example, enhanced pigment production or the ability to nucleate ice may allow microbes to survive high altitude transport, intense UV radiation and freeze-thaw cycles that occur with this type of dispersal. An island biogeography model might be used to address these issues. This work would require integration with both atmospheric sciences and landscape evolution studies.

- *What are the Substrate-Age Relationships to Biological Community Structure?*

The soil and aquatic environments in the central TAM vary in age. The age of the environment should have important effects on the biological communities found there. This might be reflected in the accumulation of diversity and/or biomass, as well as the biogeochemical processes occurring, such as nutrient availability. Given a series of different aged surfaces within a location in the TAM, successional studies could be undertaken. Studying a wide range of substrates and substrate ages should provide a gradient allowing us to examine nutrient limitation (N vs. P), biodiversity, as well as ideas on competition theory and horizontal gene transfer. In addition, one could examine the evolution of organisms and genes and identify hot spots or cold spots of biodiversity.

- *What are the Controls on Biogeochemical Cycles?*

Research in the MCM has demonstrated that the sources of nutrients and carbon to both terrestrial and aquatic ecosystems can vary due to legacy effects and landscape age. These are probably very important controls in the central TAM as well. It is important to understand whether or not legacy or contemporary processes dominate the biogeochemical dynamics of the environment. Because P is introduced via chemical weathering, the rates of weathering processes from location to location are also an important ecosystem consideration. Linking biogeochemical cycling to microbial investigations may allow determination of the minimum trophic levels necessary to have functioning nutrient cycling. These investigations must be tied closely to on-going landscape studies.

- *What are the Temporal Changes in Ecosystems?*

It is important to determine what changes (climate, invasive species, other human impacts) are occurring in these environments and their effects on biodiversity and ecosystem processes. Ongoing MCM-LTER research has documented biological changes that can be directly related to climatic variations. One surprise of this work is that the ecosystem response is rapid. A key question is whether or not similar changes are occurring in the central TAM. Any data collected in these locations can be used in the future to better assess the impacts of climate warming on community ecosystem change and even the mode and tempo of colonization of invasive species.

Field campaigns in the TAM will provide an unprecedented opportunity to examine soil and aquatic biodiversity and ecosystem processes, and intimately link them to landscape age. Data from these studies will be used in various models (i.e. biogeography, evolution, biodiversity-species traits and ecosystem function) to better test ecological theory. The integration of ecological investigations with atmospheric sciences, landscape dynamics, glaciological and paleontological studies will provide important new insights into the structure and functioning of present day terrestrial and aquatic continental ecosystems. This knowledge can be integrated for the first time, to larger polar and global questions.

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Logistic Hubs

Logistic support provided at remote field camps has evolved over the course of the last several decades. Helicopter support was mandatory for the USGS geodetic surveys in the late 50s, and soon thereafter was provided to geology projects to enable access to otherwise inaccessible localities (Fig. 1). The size and scope of the operations has increased markedly and at the last major earth science remote field camp, at Shackleton Glacier in the 1995-96 field season, 12 projects with 46 project personnel were supported by two A-Star helicopters for eight weeks and by a Twin Otter aircraft for two separate time periods of a week. The Twin Otter support facilitated deployment of field projects, provided access to sites beyond reasonable helicopter range, and enabled aerial photography of key locations.

The requirements for major field operations supported by helicopters and fixed-wing aircraft place constraints on possible hub locations. The sites should have good and consistent surface for fixed-wing operations, and therefore they should not be strongly affected by katabatic or other strong winds, and should not be prone to cloudy weather and heavy snowfalls. Such sites within the central and southern TAM have been identified and used previously, but probably there are others. Some of those used previously, e.g. Coalsack Bluff, were less than ideal.

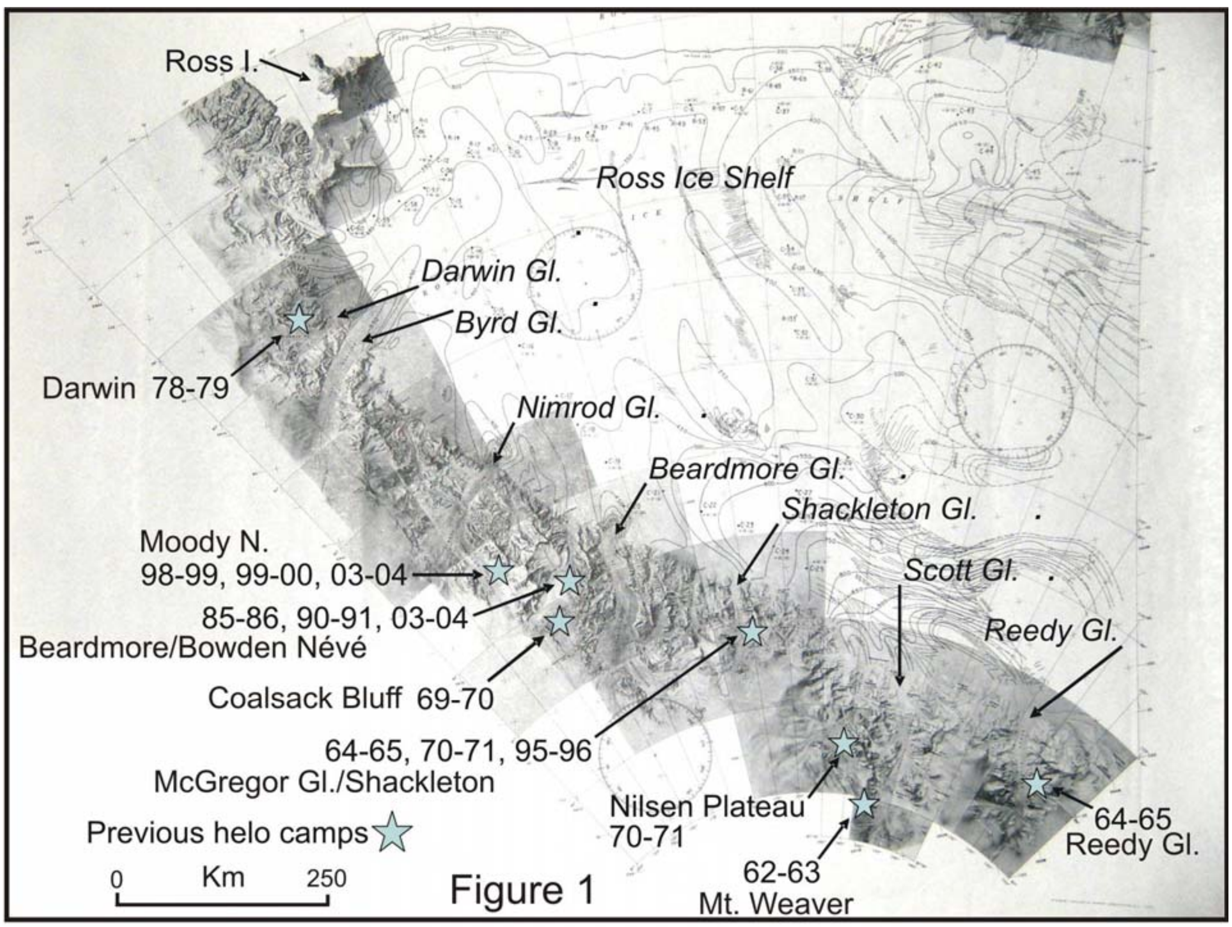

Figure 1. Sites of previous helicopter-supported earth-science field operations in the Transantarctic Mountains. Base map: U.S.G.S. 1:2,200,000 Ross Ice Shelf (1972).

The sites proven by experience to be best suited for large scale operations are at the conjunction of the McGregor and Shackleton Glaciers, the eastern Bowden Névé (Beardmore South), and Moody Nunatak (Table 1, Fig. 2). It must be recognized that even these sites may suffer adverse weather conditions that seriously impede research. The Darwin Glacier is included on Figure 2 but it is accessible from McMurdo by helicopter and hence has somewhat different constraints.

Table 1. Recent field camps with helicopter and Twin Otter logistics support.

Hub	Lat.	Long.	Elevation
Moody Nunatak	83° 07' S	159° 38' W	1700 m
Bowden Névé	84° 00' S	164° 26' W	1700 m
Shackleton Gl.	85° 05' S	175° 23' E	1300 m

Given the research interest in the southern and central Transantarctic Mountains, the Workshop participants **recommend** that a series of logistic hubs be established, to enable and facilitate access to much of the mountain range for a decade-long research effort. Several alternatives were discussed, including:

- A sequence of hubs at different locations every other year.
- Back-to-back seasons at one hub followed by a break of one or two years; then another pair of back-to-back seasons at another hub; etc.
- A central hub occupied for several seasons, followed by a series of hubs at various sites.
- A pair of hubs, established sequentially over two field seasons, that remain in place over several years; followed by hubs in various other locations.

Recognizing some major limitations, the fourth alternative is favored as the initial stage in a decade-long effort because it would provide the maximum flexibility for operations and research:

- The costs of establishing and decommissioning hubs would be markedly reduced because the infrastructure can remain on site from one season to the next.
- Multi-year hubs would enable an earlier start to the field season in the second and following years of operation.
- Logistic support, whether helicopters or fixed-wing aircraft, would have the option to move from one hub to the other during the field season.
- From the research perspective, the region of potential investigation would be markedly increased and might remove the need for projects requesting additional field seasons.

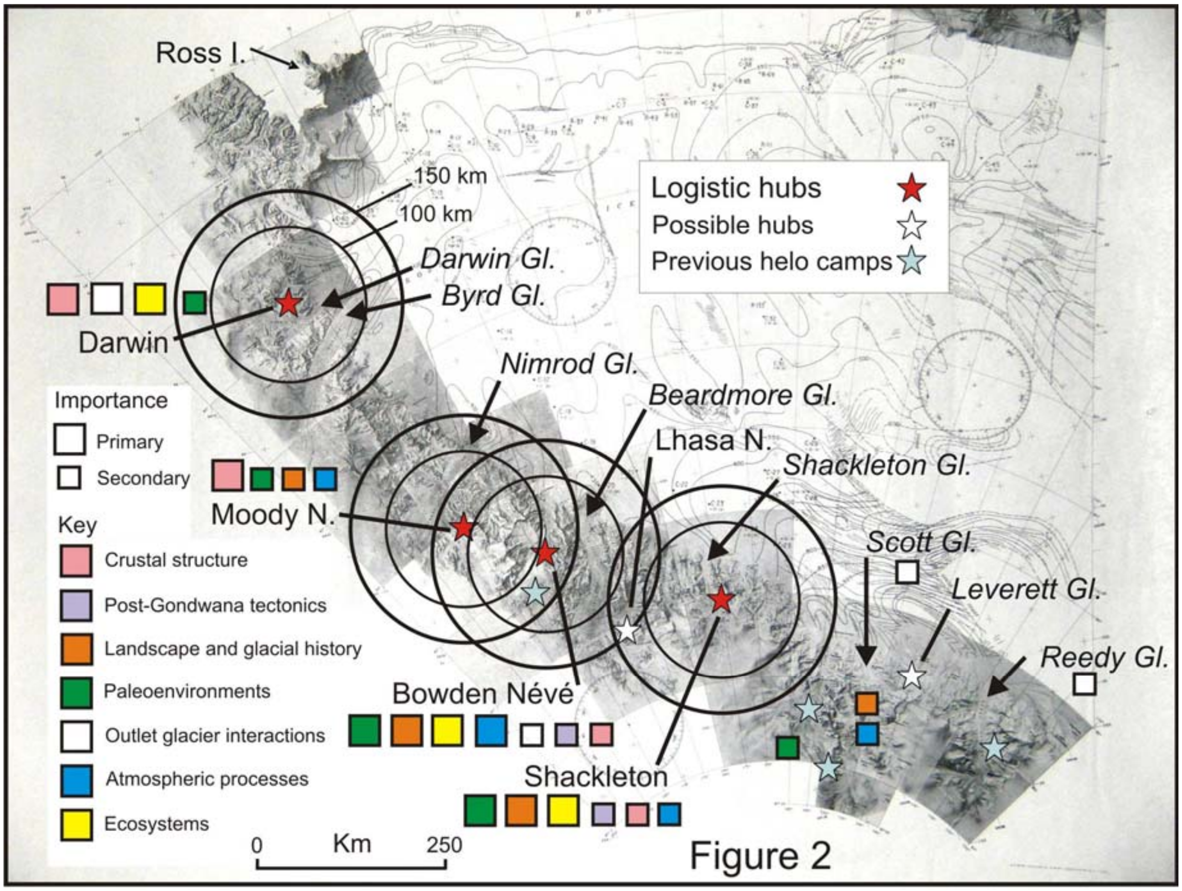

Figure 2. TAM gradients: research topics

- **Crustal structure and evolution**: geophysical framework; Precambrian shield evolution; early Paleozoic Ross Orogen structure; controls on TAM fabric.
- **Post-Gondwana tectonics**: Gondwana Plate rifting; late Cretaceous-Cenozoic uplift history and processes; Neo- and active tectonics.
- **Landscape evolution and glacial history**: Interactions between TAM uplift, erosion, denudation, climate, and ice; ice inception and growth, ice sheet fluctuation, transition from warm-base to cold-base ice, ice evolution from the LGM to the present.
- **Paleoenvironments**: Late Paleozoic to mid- Mesozoic paleoenvironments; floral and faunal evolution consequent on the transition, at the end of the last complete glacial age, from Permian “icehouse” to “warmhouse” conditions; transitions encompassing the Permian-Triassic and Triassic-Jurassic mass extinction events.
- **Outlet glacier interactions**: dynamics of outlet glaciers, decadal-scale changes and their causes, relations to the East Antarctic ice sheet and the West Antarctic Ice Sheet/Ross Ice Shelf.
- **Atmospheric processes**: Ice-atmosphere interactions; synoptic mesoscale processes.
- **Ecosystems of the Interior**: Latitudinal gradients of aquatic and terrestrial biodiversity and biogeochemistry; controls exerted by ice, atmosphere and geologic substrate.

Base map: U.S.G.S. 1:2,200,000 Ross Ice Shelf (1972).

Recognizing the potential for an unsupportable impact on OPP logistic capabilities from maintaining two hubs, and the short time span before the necessary commitment of resources for an initial 08-09 field season, an alternative **recommendation** is presented:

A commitment to one hub for the 08-09 season, followed by an ongoing review of science priorities, starting in autumn 2007, that would lead to recommendations for future hub locations and field seasons of research activity. Given the priorities placed by the workshop participants, it is **recommended** that the initial hub be established on the *Bowden Névé* and the next hub be located on the *Shackleton Glacier*.

Further, the mix of logistic support should include, depending on the science requirements, helicopters, fixed-wing aircraft (Twin Otter and/or Basler), and traditional surface transport capabilities. The field season at any one hub should be a minimum of eight weeks to enable a range of projects with different logistic requirements, or other constraints, to be supported. A short field season can too easily be affected by adverse weather conditions and may lead to projects not attaining even their minimum objectives. The mix of logistic support and its on-site duration will depend on the specific projects that are approved.

Annual Workshops

The participants further **recommend** that there be annual workshops at which researchers may present results, discuss up-coming programs, plan for future field seasons and develop interdisciplinary projects. The workshops could also form the venue for developing international collaboration. The workshops will provide the springboard for recommending future logistic hubs to satisfy new and emerging research findings and evolving scientific objectives. It is recommended that for an initial two years the workshops be funded by OPP as community workshops. Thereafter participants should be supported on project awards, but with limited funding available from OPP to support new investigators or those temporarily without grant funds.

Hub Facilities

Remote field camps with air support require some major logistic support systems. An LC-130 skiway, which automatically is suitable for a Basler or Twin Otter, requires preparation with heavy equipment. Fuel bladders for helicopters and fixed-wing aircraft. Maintenance sheds for the air support; generator sheds and radio and meteorolgy offices. Simple buildings for air crew and support personnel. A galley for use by all personnel in camp, and a communal science building for use by project personnel.

Most of the earth sciences do not require in-field laboratory facilities, although geophysical projects may require dedicated space for immediate data analysis and review. However, ecological studies often require on-site laboratory analysis. Provision should be made for a dedicated lab, one possibly built in McMurdo and shipped out by LC-130. Similarly, glaciology projects may have requirement for immediate analysis of ice cores.

Project Office

The workshop participants propose a decade-long series of investigations in the central and southern Transantarctic Mountains. The investigations will involve a number of different logistic hubs and will involve a changing set of projects, scientific objectives and scientific disciplines. Logistics planning prior to the field season and the co-ordination of logistics in the field requires an on-site co-ordinator familiar with the science objectives and priorities of each project, as well as knowledge of the region being served by any particular logistic hub.

A multi-year effort should have an outreach and education component. Because of the diversity of research, each project should undertake its own education and outreach, but there is much value in having a point source for information. Such a point source could develop outreach efforts on a larger scale, such as major displays for science museums, and/or an educational web site. In addition, a point source would provide an avenue for encouraging participation in the PolarTREC program, and a point of reference for possible press and publicity efforts.

Further, the recommendation that annual workshops be held entails an office that will provide the structure and support for such meetings, and a mechanism for funding participants.

Therefore, it is **recommended** that a Project Office be established and funded by OPP. A project office would facilitate co-ordination of the field projects prior to and during field operations, act as a liaison between the scientific groups and the contractor states-side and at McMurdo, and co-ordinate education and outreach efforts.

Abstracts

Effects of Taxonomic Precision on Studies of Distribution Ecology and the Relationship Between Biodiversity and Ecosystem Functioning

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The extreme southerly terrestrial ecosystems of Antarctica are devoid of vascular plants, and the food webs consist solely of microbes and a few species of soil animals. The low abundance and diversity of the players in these food webs makes these ecosystems excellent models for studying the structure and functioning of soil communities, such as the biotic and abiotic controls over habitat suitability, the distribution ecology of soil biota, and the relationship between biodiversity and ecosystem functioning. However, each of these research questions is sensitive to the taxonomic designation of species, which serves as the fundamental unit of biodiversity. We use the tools of phylogeography, molecular systematics, and morphological approaches, in a logical context for species delimitation, in order to make more precise inferences about habitat suitability models, food web structure and assembly, ecosystem functioning and ecosystem stability. We show that in simple, Antarctic ecosystems, failure to account for cryptic species artificially inflates estimates of ecosystem stability and range of habitat suitability, while masking the effects of biodiversity on food web complexity and ecosystem functioning. The ecosystems of the extreme southern exposed soils provides a unique opportunity for integrating past and present geophysical controls on ecosystem assembly, function and stability.

Combined Geomorphological, Paleoclimatological and Ecological Studies of Cyanobacterial Mats

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Discoveries were made in 2003 of a cyanobacterial crust on the margins of a small lake which formed at the junction between the Beardmore Glacier and the ice-cored moraine which flanks it. The location, between lat. 85-86°, is one of the southernmost for the occurrence of cyanobacteria and an embedded single-celled eukaryote. When placed in Woods Hole media, the crust turned from pink-brown to green with obvious growth of cyanobacteria that resemble *Leptolyngbya* and *Phormidium*. A partial 16S rDNA sequence generated from the cyanobacterial growth was most similar to that of an uncultured Antarctic cyanobacterium (GenBank AY151728). Four cyanobacteria with distinct morphologies and one green alga have been isolated from the crust. The 18S rDNA sequence generated from the green alga was very similar to *Pleurastrum insigne*, a green alga previously reported from soil in northern Victoria Land. However, our isolate differs slightly in morphology from *P. insigne* and probably represents a distinct species of *Pleurastrum*. We are characterizing additional isolates by rDNA sequencing and microscopy and also examining the uncultured diversity of the crust.

The cyanobacterial crust occurs several centimeters above the frozen surface of the lake. On two visits to the site in 1995 and 2003, during the months October to December, the lakes remained

completely frozen. This raises the question of when and how these organisms obtain their moisture. It is possible that liquid water becomes available in January and that moisture for the development of the mat becomes available by wicking through an evaporative pump mechanism. The alternative is that the organisms are freeze dried surviving from a time when water-level in the lake was higher. The lake receives its water from melting of the surface of the Beardmore glacier and from ice within the ice-cored moraine. Exposed and incised small-scale deltas, and evidence for multiple 'raised beach' levels more than a meter above existing lake levels, indicate significant melting and climate change. If the cyanobacterial mats are not active every year, it is possible that they exist in a dormant condition, waiting for melting and water level rise associated with climate change. Geochemical and chronological studies of lake sediments could provide a record of climate change, which in combination with geomorphological and biological studies should provide further information on the survival strategy of these extremophiles.

A Bright Future for Paleoecological Studies in the Transantarctic Mountains

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Fossil assemblages from the Oliver Bluffs, upper Beardmore Glacier, 85°S, are providing new information regarding the paleoecology, paleoclimate and biogeography of the Neogene biota of Antarctica. The fossils include wood, leaves, root systems, vegetative growths, seeds and pollen of *Nothofagus* and other vascular plants, in addition to stems, leaves and cushions of mosses. Invertebrate animals include fossils of a higher fly, fossils of beetles including weevils and a ground beetle, ostracods, and freshwater molluscs including a species of *Pisidium* and a lymnaeid gastropod. The only vertebrate fossils to be discovered so far are a tooth and pharyngeal bones of a small fish.

Collectively the fossils indicate a tundra environment that colonized the head of a fjord during a retreat of the glacier occupying a shallow Beardmore valley . The lodgement tills and outwash deposits of the Oliver Bluffs are those of a dynamic, wet-based glacial system which advanced and retreated several times. For many organisms, the fossil occurrence from the Oliver Bluffs is the first record for Antarctica. In this respect, the fossils are of considerable biographic significance. The discovery of several organisms previously not thought to have ever occurred in Antarctica is requiring a reassessment of the role of Antarctica and Gondwana as an evolutionary center.

Volumetrically within the Oliver Bluffs stratigraphic sequences, fossiliferous beds constitute less than 1%. Because of their value in deciphering landscape, vegetation, climate and biogeography, however, they are of major importance. It is improbable that the fossiliferous beds are unique. Indeed, similar fossil assemblages have been recently discovered in the Dry Valleys (Lewis and Ashworth, this volume). The probability is that exploration of other outcrops of Sirius Group deposits exposed on the flanks of other major glaciers in the Transantarctic Mountains e.g. Mill Glacier will provide new opportunities for the study of Neogene paleoecology. With results becoming available from the Andrill and terrestrial based paleoecological studies we can expect major advances in the knowledge of Neogene climate, ice sheet history and biogeography within the next few years.

Palynological Investigations of the Neogene Sirius Group

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Sirius Group sediments from a few locations in the Transantarctic Mountains include terrestrial palynomorphs (spores and pollen) produced by land plants that grew at the time of deposition. They thus reflect the adjacent land vegetation and provide an indication of the prevailing climate. The best known Sirius Group palynomorphs are from Oliver Bluffs near the head of the Beardmore Glacier. Originally thought to include one species of *Nothofagus* (pollen *Nothofagidites lachlaniae*, leaf and wood remains *Nothofagus beardmorensis*), one podocarp pollen species, and very few additional angiosperm pollen and moss and liverwort spore species, the palynomorph flora is now known to be somewhat more diverse, in keeping with seeds, leaves and other plant remains found by Allan Ashworth and colleagues.

Most productive samples from Oliver Bluffs are from Member 2 of the Meyer Desert Formation. Thus far, palynomorph assemblages include 4 species of *Nothofagidites* (although *N. lachlaniae* is overwhelmingly dominant), a few other angiosperm pollen species and at least 2 species of podocarpaceous conifers. The bryophyte component includes mainly mosses with 4 species of *Coptospora*, plus one other possible bryophyte and Marchantiaciae spores.

Precise ages of these Neogene floras remain contentious, and the relative stratigraphic position of the individual samples is not firmly established. Major objectives in Sirius Group studies include the recovery of samples with unambiguous stratigraphic control, and determination of the succession of vegetational change and how this succession relates to Neogene data obtained from the Ross Sea region. Oliver Bluffs and other Dominion Range sites are important targets, as are other Transantarctic Mountains sites with well-preserved Sirius Group outcrops. Of particular interest in the Beardmore Glacier area is the collection of productive samples from The Cloudmaker, which includes a succession of marine Sirius deposits, the Cloudmaker Formation, underlying the Meyer Desert Formation. Both terrestrial and potentially marine palynomorphs from this unit have stratigraphic and paleoenvironmental significance. It is intended that this work be done in collaboration with Ian Raine (GNS, New Zealand).

Exceptional Preservation of Organic Tissues in the Beacon Supergroup (Devonian-Triassic) and Ferrar Group (Jurassic), Transantarctic Mountains, Antarctica

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Sedimentary deposits of the Beacon Supergroup (Devonian-Triassic) and Ferrar Group (Jurassic), which crop out in the Transantarctic Mountains of Antarctica, provide opportunities for enhancing our understanding of the processes and timing of fossilization of non-biomineralized (organic) tissues. Special importance attaches to deposits containing non-biomineralized fossils (deposits of exceptional preservation or Konservat-Lagerstätten) because of the high level of morphological information preserved. Access to fossilized organic tissues increases the number of paleobiological inferences that can be developed compared to those made possible through the more typical preservation of only biomineralized bodily parts. Fossilization of non-biomineralized anatomy provides the critical evidence necessary for developing detailed inferences about phylogenetic history, and it can provide valuable paleoecological information.

Remarkably, the fundamental question of how fossilization occurs has remained largely a matter of speculation, and it has remained essentially untested until recently. Although it has often been assumed that fossilization is a slow process that takes place over thousands or millions of years as burial and lithification of sediment proceeds, experimental work suggests this is not normally the case. Fossilization apparently involves a number of factors that must fall into place at just the right time, and there is a clear difference between the taphonomic history of biomineralized skeletal elements and the taphonimic history of non-biomineralized bodily components. As we are now beginning to understand, fossilization of non-biomineralized tissues must occur rapidly, and long before the lithification of most types of sediments. Biodegradation (carnivory or herbivory and microbial breakdown) within a few days of mortality is a major taphonomic filter, and perhaps the most important determinant of the survival of non-biomineralized tissue to fossil form. Lithification mediated by microbial action is also emerging as a key component of the early taphonomic history of some organic tissues.

To date, few tests of hypotheses developed from laboratory-based taphonomic experiments have been applied to ancient strata, but one instance where tests have been carried out with encouraging results is in the Jurassic of Antarctica. Sedimentary interbeds of the Ferrar Group have long been known to yield abundant chitinous arthropod cuticle and cellulose plant tissue. Other instances of exceptional preservation include arthropods in proglacial lake deposits of the Pagoda Formation (Permian), and *Glossopteris* leaves in lowland deposits of the Buckley Formation (Permian). Preliminary investigations on sedimentary interbeds of the Ferrar Group show the presence of fossil microbes preserved in intimate association with fossil arthropod cuticle, and it is possible that microbes played a role both in the decay of organic tissue and in its early diagenesis.

Strata of the Beacon Supergroup and the Ferrar Group record sedimentary circumstances that seem to have been limiting to some types of biodegraders. Exceptional preservation of organic tissues and microbes in these strata is probably due in part to the relatively limited diversity of animals present in high-paleolatitudes. One inference that can be drawn is that postmortem taphonomic filtering operated at a reduced level compared to that operating in coeval, lower latitude environments. Because of the unique combination of limited biotic diversity and a range of depositional environments yielding exceptionally preserved fossils, Beacon and Ferrar strata can be expected to yield insight into the processes of fossilization not readily obtainable through such a broad range of sedimentary environments elsewhere on Earth.

The Importance of Temperature and Nitrogen Speciation on Bacterial Diversity in Stream Sediments in the McMurdo Dry Valleys

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Once called the Valleys of the Dead, the McMurdo Dry Valleys in Antarctica have been shown to harbor life that can withstand some of the coldest, windiest, driest and extreme conditions on Earth. The Dry Valleys are often referred to as 'ecosystems waiting for water' because of the rapid response of biological activity when liquid water appears. Although our understanding of life in the Valleys is progressing, there are numerous unanswered questions about how the organisms survive there. Most of the attention in this delicate ecosystem has been focused on nematodes and lake and stream algal mat communities. However, microbe cell counts in stream sediments not associated with mats are only an order of a magnitude less than that found in temporal streams, yet very little is known about their metabolic capabilities, energy demands, nutrient requirements and genomes.

In December of 2004, sediment and water quality samples were collected from 19 streams in Taylor Valley. Bacterial DNA was extracted from the sediments and 16s rRNA amplified using 8f and 926r bacterial primers. Terminal Restriction Length Polymorphism (tRFLP) was used to attain community diversity fingerprints for all stream sites. The Bonney Basin was shown to have the most diverse bacterial assemblages using this technique. There was no correlation between bacterial diversity and algal mat presence or absence, indicating that bacterial diversity is not a function of mats. Statistical analysis comparing water chemistry data and diversity indicates that temperature and nitrogen speciation and concentration are important factors when assessing diversity in these oligotrophic streams. 5 clone libraries were sequenced and used to determine the major bacteria present in all streams in the Valley. Approximately 15% of the sequences had less than a 97% similarity to any known bacterial sequence present in GenBank, indicating a high abundance of bacterial species unique to the Dry Valleys.

This research is the first step toward understanding the microbial communities in this ecosystem and will provide the foundation for more function orientated studies and survival methods, which will not only be important for better understanding the dry valleys but will likely give insights into new anti-freeze proteins, desiccation mechanisms and UV-damaged DNA repair strategies which are of societal importance.

Microstructural Characterization of Ice and Firn

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Recently, we have developed techniques to fully characterize the microstructure of firn and ice in a more sophisticated fashion that previously possible using both an environmental, cold-stageequipped scanning electron microscope (SEM) equipped with an energy dispersive x-ray spectrometer and an electron backscatter pattern system, and a confocal scanning optical microscope equipped with a Raman spectrometer.

In this presentation, we will show how, using these systems, we determine the grain size and, for firn, observe grain boundary grooves and ridges, if present. We will show how we determine both the microchemistry and microstructural location of impurities, and the complete threedimensional orientations of grains with high angular (~0.1o) and spatial (<100 nm) resolution (not just the c-axis orientation as normally determined by optical microscopy) of both firn and ice. The latter analysis enables both the misorientations between grains to be determined and pole figures to be produced of their orientations. The latter analyses allow the determination of whether recrystallization or polygonization is contributing to or replacing the deformationinduced fabric. Finally, we show that for firn, we can determine both the porosity and the internal surface area per unit volume of the pores with potentially more accuracy that typical liquid infiltration methods.

The presentation will show results for ice core specimens from Byrd and Vostok Station, Antarctica and GISP2, Greenland, and from firn specimens from the U.S. ITASE.

The Transantarctic Mountains

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Biodiversity in terrestrial Antarctica is limited by an array of extreme conditions including low temperatures, moisture and organic matter availability and high salinity. In the Trans-Antarctic Mountains of Southern Victoria Land which encompasses the largest area of ice-free terrestrial habitats on the Antarctic continent, significant progress has been made in understanding controls over the distribution of terrestrial flora (moss, lichens, algae, and endolithic communities), fauna (protozoans, rotifers, nematodes, tardigrades, mites and collembolans) and microbes (fungi, bacteria and archea). However, little information on the distribution, structure and activity of soil communities in the far southern regions of the Trans-Antarctic Mountains (south of 80º) are available. Our research interests concern the physical (climate and edaphic) variables that define limits on the suitability of terrestrial habitats for life, i.e., survival, metabolic activity and reproduction in locations with extreme environmental conditions. Our research in the McMurdo Dry Valleys and Northern Victoria Land shows that the distribution and activity of soil communities is predictable based upon underlying variation in soil properties. For example, we can account for suitable and unsuitable habitats for soil invertebrates in a numerical model, and predict the occurrence of different nematode species based upon the physical and biogeochemical properties of the soil. We are interested in testing this habitat suitability model further south in the Trans-Antarctic Mountains, an area currently lacking description of soil communities, and to extend knowledge of biodiversity and ecosystem functioning to some of the most extreme terrestrial ecosystems on Earth.

Crustal and Lithospheric Structure of the West Antarctic Rift System from Geophysical Investigations - A Review

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The active West Antarctic rift system, which extends from the continental shelf of the Ross Sea, beneath the Ross ice Shelf and the West Antarctic ice sheet (WAIS), is comparable in size to the Basin and Range in North America, or the East African rift systems. Geophysical surveys (primarily marine seismic and aeromagnetic combined with radar ice sounding) have extended the information provided by sparse geologic exposures and a few drill holes over the ice and sea covered area. Rift basins developed in the early Cretaceous accompanied by the major extension of the region. Tectonic activity has continued episodically in the Cenozoic to the present, including major uplift of the Transantarctic Mountains. The West Antarctic ice sheet, and the late Cenozoic volcanic activity in the West Antarctic rift system, through which it flows, have been coeval since at least Miocene time. The rift is characterized by sparse exposures of late Cenozoic alkaline volcanic rocks extending from northern Victoria Land throughout Marie Byrd Land.

The aeromagnetic interpretations indicate the presence of $>5 \times 10^5$ km^2 ($>10^6$ km^3) of probable late Cenozoic volcanic rocks (and associated subvolcanic intrusions) in the West Antarctic rift. This great volume with such limited exposures is explained by glacial removal of the associated late Cenozoic volcanic edifices (probably hyaloclastite debris) concomitantly with their subglacial eruption. Large offset seismic investigations in the Ross Sea and on the Ross Ice Shelf indicate a ~17- to 24-km-thick, extended continental crust, and ~30 km in one area beneath the WAIS. Gravity data suggest that this extended crust of similar thickness probably underlies the Ross Ice Shelf and Byrd Subglacial Basin. Various authors have estimated maximum late Cretaceous-present crustal extension in the West Antarctic rift area from 255-350 km based on balancing crustal thickness. Plate reconstruction allowed <50 km of Tertiary extension. However, paleomagnetic measurements suggested about 1000 kilometers of post-middle Cretaceous translation between East Antarctica and Pacific West Antarctica.

Because a great amount of crustal extension in late Cenozoic time is unlikely, alternate mechanisms have been proposed for the late Cenozoic volcanism. Its vast volume and the ocean island basalt chemistry of the exposed late Cenozoic alkaline volcanic rocks were interpreted as evidence for a mantle plume head. An alternative or supplemental explanation to the mantle plume hypothesis is significantly greater lower lithosphere (mantle) stretching resulting in greater decompression melting than the limited Cenozoic crustal extension allows. Because of very slow rates of late Cenozoic extension in the West Antarctic rift system, the amount of advected heat is small compared with the conductive heat. Therefore, phase transition probably would not explain the large subsidence with low extension observed in the West Antarctic rift system.

The Transantarctic Mountains

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The high elevation and considerable length of the Transantarctic Mountains (TAM) have led to much speculation about their origin. To date, no model has been able to adequately reconcile the juxtaposition of the high, curvilinear TAM with the adjacent West Antarctic Rift System (WARS), a broad region of thin, extended continental crust exhibiting wide rift characteristics. We present a preliminary investigation into the possibility that the WARS / TAM region was a high elevation plateau with thicker than normal crust before the onset of continental extension. With extension, the WARS underwent a topographic reversal, and a plateau edge with thickened crust, representing the ancestral TAM, remained. Supported by geological evidence, this scenario is investigated using two-dimensional numerical models to determine under what conditions plateau collapse is plausible. Model results indicate that elevation of a remnant plateau edge decreases with increasing initial Moho temperature. Very cold initial Moho temperatures, < 650° C, under the plateau that leave a thick plateau edge do not exhibit wide rifting. A cold to moderate initial thermal structure, Moho temperature 650° C – 850° C, is needed to retain the plateau edge and still exhibit wide rifting in the middle of the plateau. We conclude that a plateau collapse scenario is feasible from a geological standpoint and is supported by our model results.

Permafrost and Soils Database and Maps of the Transantarctic Mountains

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We would like to utilize the McMurdo Station-South Pole supply route through the Transantarctic Mountains (TAM) to achieve the following goals: (1) to test hypotheses regarding factors controlling the distribution of permafrost and soils in the TAM; (2) to validate maps of permafrost and soils that we are preparing for the region; and (3) to investigate soils along the southernmost latitudinal gradient in Antarctica. Our estimates suggest that the TAM comprise over 50% of the ice-free area of Antarctica We have prepared provisional permafrost and soil maps from digitized 1:250,000 topographic maps of the entire TAM that are based on our detailed investigations in the McMurdo Dry Valleys, the Darwin-Byrd Glacier region, and the Beardmore Glacier region. These data eventually will be transferred to the high-resolution Landsat 7 composite image that is being prepared for Antarctica by NASA and the USGS. We are particularly interested in several large ice-free areas south of the Byrd Glacier for which the surficial geology has not been examined in detail. We propose to access these areas from the supply route, map the surficial geology, describe the soils and permafrost features, and collect soil samples for analysis. The data will be archived on the Soils Portal at Landcare Research New Zealand, with whom we are cooperating in the field, and also will be used to refine our permafrost and soil maps for distribution to the scientific and general community.

How Can Field Activities in the Southern Transantarctic Mountains Benefit the Atmospheric Sciences?

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The Transantarctic Mountains (TAMS) field efforts will be focused on the southern Ross Ice Shelf. Relative to other regions in the Ross Embayment, this area represents a gap in the atmospheric observational network. Leveraging the logistical advantages that TAMS will provide, targeted aircraft observations, additional weather station deployments, and a weather balloon program will fill in these gaps. These new measurements will complete an extensive atmospheric observational network allowing, for the first time, comprehensive studies of the following poorly understood phenomena: 1) the *Ross Ice Shelf Air Stream (RAS)*, a broad, northward-flowing airstream adjacent to the Transantarctic Mountains that is thought to be an important mechanism for mass, heat, and momentum transport to lower latitudes; 2) the *Circumpolar Vortex (CPV)*, a time-averaged cyclonic circulation that extends over the southern Ross Ice Shelf that modulates West Antarctic climate, and McMurdo weather, on a variety of timescales; and 3) *mesoscale cyclones*, intense storms that have been shown in satellite imagery to form frequently along the Siple Coast and may have important implications for the climatology of the region. Aside from a handful of studies employing numerical models and satellite imagery, there have been no wide-ranging in-situ measurements of any of these phenomena, all of which have important implications for climate in Antarctica and beyond.

Elucidating the Environmental Drivers for Microbial Biodiversity in the TransAntarctic Mountains

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Organisms that thrive in extreme environments have challenged our understanding of the physical and biochemical constraints on the limits of life and stimulated new theories on how life originated (Baross and Hoffman, 1985; Pace, 1991). In these environments, microbial and geochemical interactions are tightly interwoven, ultimately governing the structure and function of the biotic component. Microbial ecologists have long desired to resolve these subtle interactions in order to understand biological community metabolic processes and activities in relation to the extreme nature of the environment. The only means of successfully doing this is through culture-independent methods that link specific biological communities to *in situ* metabolic activities. These studies are often hindered by the overriding complexity (both in scale and biology) of the system, or the difficulties associated with sampling from these environments. Ideally, investigations of microbial processes in extreme environments would involve relatively simple ecosystems that are small in scale and easily accessible.

The Antarctic continent offers access to one of the most physically and chemically demanding environments on earth inhabited by microorganisms. Antarctic Dry Valley ecosystems, in particular, experience large fluctuations in temperature and light regimes, along with steep chemical gradients, which greatly impact physiological adaptations and life cycle strategies. These ecosystems provide an extraordinary opportunity to examine metabolic adaptations that allow microbial communities to function in extreme environments. With the lack of higher trophic levels, microbial community dynamics and ecological function are directly related to the chemical and physical environment. Yet, after decades of research we still know little about the microbial community biodiversity and processes in Antarctic ecosystems and the environmental factors that structure them. At a recent US National Science Foundation sponsored workshop (Synthesis of Soil Biodiversity and Ecosystem Functioning in Victoria Land, Antarctica, Jekyll Island, Georgia, USA , April 21-23, 2005) it was concluded that our current understanding of bacterial diversity in Victoria Land and continent-wide was minimal at best and that an international community research priority should be to inventory the extent and depth of this diversity. With access to more southern ice-free sites as propoposed we will have the ability to not only contiue to catelog and archive microbial biodiversity but understand how changes in local physicochemical environment contiues to impose pressures on how these communities are composed and structured.

We would propose an interdisciplinary program combining expertise in microbial ecology, genetics and geochemistry to elucidate the key environmental drivers that sustain microbial biodiversity in Antarctic mineral soils. We would seek to determine the diversity and structure of the soil microbial communities using a suite of molecular genetic techniques linked closely with geochemical and mineralogical analyses. This study would link to several ongoing programs in the Victoria Land Dry Valleys to detemine if the environmental drivers for biodiversity are consistant across these latitudinally separated biomes.

Unmanned Aerial Vehicles (UAVs) for Scientific Research in the Antarctic

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A description of the Aerosonde unmanned aerial vehicle (UAV) will be presented, focusing on both the capabilities of the aircraft and possible Antarctic research applications that could benefit from Aerosonde observations. Results from multiple deployments of the Aerosonde in the Arctic, at Barrow, AK, will be shown. Plans for a research program that will utilize the Aerosonde to study air-sea interactions at the Terra Nova Bay polynya will also be presented to highlight the research capabilities of this aircraft.

The Properties of Microbially-Derived Dissolved Organic Matter in the Antarctic

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We have isolated and studied the properties of dissolved organic matter (DOM) in Pony Lake on Cape Royds, Antarctica (Lat: 77^{o}, 38' S). The lake is hyper-eutrophic and derives most of its nutrients from the adjacent Adelie penguin rookery. The primary phytoplankton in the lake is a *Chlamydomonas intermedia* in the early season (soon after ice-out) and is subsequently replaced by *Cryptomonas spp.* (a mixotroph) in the late season. Unlike other water bodies on the continent, the DOM levels in this lake are very high (several mM carbon). The humic fraction of the DOM is similar in its chemistry to that found in lakes in the McMurdo Dry Valleys in that there is a low aromaticity and high contents of N- and S-containing functional groups. However, there may be a greater content of carbohydrate moieties associated with the greater microbial productivity in Pony Lake. We suspect that the level and possibly type of non-humic DOM formed in this unique environment may be replicated in other seasonally productive water bodies in the Antarctic, especially small ponds such as cryoconite holes. However, it may be different from that found in more dilute oligotrophic environments such as the streams, especially those south of this latitude and in the interior as the influence exerted by a dense population of phytoplankton or periphyton diminishes. Preliminary spectroscopic analyses of the non-humic DOM reveal a DOM that is enriched in fatty acids and nitrogen and sulfur enriched organic moieties.

Microbial Biogeography: Does Antarctica Have Endemic Terrestrial Microbiota?

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Biological investigations of glacial environments (i.e., cryoconite holes, subsurface glacial ice, accreted ice, and subglacial streams and lakes) in polar and non-polar locations indicate that strong phylogenetic relationships exist between bacteria and yeast from geographically distant environments. The distribution of related microorganisms in worldwide glacial environments implies that members of these genera evolved under cold circumstances and likely possess similar strategies to survive freezing, and possibly, to metabolize at very low temperatures. Given the general absence of free water in glaciated locales, the atmosphere is inferred to be the primary mode of biological dissemination between environments. In the era of genomic analysis, powerful tools are available to evaluate genetic similarity between microorganisms using contemporary techniques in molecular biology coupled with classical principles of population genetics and phylogenetics. For bacteria, the most refined and robust tool for such analysis is multi-locus sequence typing (MLST), whereby the DNA sequences of 7 genes of the core or stable part of the bacterium's chromosome are determined. These genes are considered to evolve very slowly and only via mutation (errors in replication during cell division). Hence, very similar strains can be considered to have originated from the same parent strain whereas divergent strains are from different parental lines. Using this tool, we can closely evaluate if strains of the same parental lines are restricted to the Transantarctic Mountain ecosystem, are related to species in the dry valleys, or cluster with organisms from frozen environments from around the world (available in our culture collections, some from ice core samples >750k yrBP). The evolutionary history of Antarctica's terrestrial microbiota has not been examined experimentally.

Research interests: Microbial ecology, physiology, and diversity; molecular biology; microbiology of the cryosphere.

Holocene Deglaciation of the Ross Sea Embayment: Constraints from East Antarctic Outlet Glaciers

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East Antarctic outlet glaciers that drain through the TransAntarctic Mountains were dammed by grounded ice in the Ross Sea Embayment during the last glacial maximum (LGM). The surface elevation history of the outlet glaciers contains information about the thickness and configuration of the grounded ice sheet both at the LGM and during deglaciation through the Holocene.

Mapping and dating moraine and drift sequences at rock outcrops along the glacier margin constrain the evolution of the along-glacier surface profile since the LGM. Interpolating profiles between outcrops and extrapolating beyond the last outcrop to the Ross Sea Embayment requires an ice-flow model. The model is used to: (i) establish Holocene elevations of grounded Ross ice that are consistent with geologic evidence from the outlet glaciers; (ii) establish glacier response to changes in configuration of the expanded Ross ice sheet – in particular, establish *when* the grounding line retreated past each of the outlet glaciers; and (iii) investigate glacier responses to future possible environmental change.

We are using a simple, time-dependent flowband model to interpret geologic data that we have collected from Reedy Glacier. Existing glaciological and climate data are useful for the modeling effort, but additional measurements are needed. Specifically, the present-day surface velocity field has been measured for many glaciers using synthetic aperture radar (Joughin & Tulaczyk, 2002). Present-day surface topography is available from the RAMP data set (Liu *et al*., 2001) and from recent ICESAT missions. However ice thickness measurements of the glaciers are not adequate. BEDMAP coverage (Lythe *et al*., 2001) is sparse and supplementary ice-thickness measurements using ice-penetrating radar are needed. Constraining ice thickness is important for estimating the ice flux, as well as for estimating possible future responses. Surface mass balance measurements (Giovinetto & Zwally, 2000; Vaughan *et al*., 1999) are also sparse. Existing accumulation maps are subject to much uncertainty; supplementary measurements of accumulation and ablation are needed.

Our long-term goal is to apply these methods to other outlet glaciers in order to define the spatial and temporal pattern of grounding-line retreat in the Ross Sea Embayment. The pattern of past deglaciation provides clues for the future. Our first target is Scott Glacier, the last glacier to have been coupled to grounded ice in the Ross Sea. Synthesis of results from Scott, together with those from Reedy

Glacier (still buttressed by grounded ice) will establish whether grounding-line retreat in the Ross Sea Embayment has ended or whether it is still ongoing.

Reconstructing Past and Present Polar Environments from Remotely Sensed Data

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Geomorphologic mapping and landscape interpretation provide key information toward understanding the climate, tectonic and volcanic evolution of the McMurdo Sound region. The objective of this study is using a variety of airborne and spaceborne remote sensing methods combined with advanced pattern recognition and landscape analysis techniques for mapping physical properties and chemical composition of the Earth's surface and for computing geomorphometric parameters and features.

The sheer amount of data and the disparate data sets (e.g., LIDAR, stereo imagery, multi- and hyperspectral and SAR imagery) make their joint interpretation (fusion) a daunting task. However, new, interdisciplinary approaches benefiting from recent advances in photogrammetry, remote sensing and image understanding enable the reconstruction of past and present polar environments with unprecedented details and accuracy. Development of rigorous camera models, calibration methods and novel methods for sensor invariant registration of images, LIDAR data and topographic maps provide a uniform reference frame for change detection. The use of advanced pattern-recognition techniques greatly facilitates the delineation of different landscape units and the recognition and analysis of geomorphological features from multisensor data sets.

The McMurdo Sound region has been the focus of topographic, geologic, glaciological and soil mapping for many decades, making it an ideal site for validation of new approaches. In our study we combine the analysis of spectral and textural information from satellite and airborne imagery with spatial operations, such as morphological filtering and active contour modelling applied on high resolution DEMs, to delineate and characterize patterned ground. Other examples include the mapping of soil distribution and landscape units by using object-based contextual image classification of multi- and hyperspectral satellite imagery and high resolution DEMs, and the characterization of volcanic terrains by delineating lava flows and extracting morphometric information describing the shapes of volcanic cones. Application of these advanced remote sensing and GIS methods for comprehensive mapping and monitoring the McMurdo Dry Valleys could advance understanding of this area's volcanic activity, glacial geomorphology, hydrology, and climate, while at the same time providing data sets that will be of interest to numerous other scientific disciplines, including planetary research, and applicable to operational planning.

Antarctic Gondwana Geologic History: Some Possible Lines of Research

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The broad outlines of the Permo-Triassic Victoria Group strata, the Antarctic Gondwana sequence, and their history are well known. They accumulated in two separate intra-cratonic basins, in north and south Victoria Land, and in a foreland basin located along the central and southern Transantarctic Mountains. Relationships to sediment sources have been inferred from petrology and paleocurrent data, and tectonic settings proposed. The subsequent history of these basins is less well established. The transition from foreland and intracratonic basin settings to the Early Jurassic extensional regime during which Ferrar magmas were erupted and intruded is poorly known, and the post-Jurassic history is essentially unknown although obviously affected by late Mesozoic and Cenozoic rift-shoulder uplift.

The tectonic setting and evolution of the Victoria Group basins must reflect the active Gondwana plate margin and the corresponding developments on the East Antarctic craton. Detrital zircon geochronology can provide complementary data for understanding the sediment sources and tectonics of the plate margin. Three samples from the Shackleton Glacier region support the presence of a Permian magmatic arc, but also suggest that Devonian and/or Lower Permian Beacon strata were significant sources exposed in a fold and thrust belt which was possibly initiated in latest Permian time (Elliot and Fanning, in press). Detrital zircon geochronology will clarify the provenance of Beacon strata and provide a window onto the East Antarctic craton in Late Paleozoic-Early Mesozoic time.

Termination of Beacon strata deposition in latest Triassic time was followed by an episode of silicic volcanism associated in the central TAM with rifting. The onset of rifting and silicic activity is not well constrained, although one silicic tuff clast enclosed in the basaltic Prebble Formation has given an age only slightly older than that of the Ferrar (Elliot and Fanning, unpublished data). The relationship of this episode of silicic magmatism to the active plate boundary and to Ferrar magmatism remains uncertain.

The post-Ferrar history is commonly viewed as passive involvement in uplift of the Transantarctic Mountains. Secondary minerals, however, provide a potential path for examining events with respect to the inferred uplift history. In particular, secondary minerals record paleohydrologic events which themselves reflect changes in climate (precipitation) and tectonism. Dating and stable isotope analysis of secondary minerals is fraught with difficulties and uncertainties. Nevertheless, apophyllite dates (Fleming et al., 1999) constrain the timing of changes in hydrologic systems involving the Kirkpatrick Basalt lavas, and in exceptional circumstances Beacon strata as well (Elliot et al., 2004).

Beacon strata hold important information for understanding the poorly exposed Permo-Triassic Gondwana plate margin and the tectonic evolution of the depositional basins. Similarly, the strata hold information complementary to the thermochronologic data that have formed the basis for the uplift history of the Transantarctic Mountains. And not the least, the Permian to Jurassic Gondwana rocks record the initial stages of the break-up of the supercontinent and the inception of crustal thinning and formation of the collage of blocks and basins forming West Antarctica.

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Studies of the Ferrar Large Igneous Province in the Central and Southern Transantarctic Mountains

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Jurassic tholeiites of the Ferrar Large Igneous Province (FLIP) crop out in a linear belt that extends for more than 3500 km from northernmost Victoria Land to the Theron Mountains. Rocks of identical age and composition are found in an extension of this belt in southern Australasia. The FLIP consists of a layered intrusion (Dufek Intrusion), basaltic pyroclastic rocks (Prebble, Mawson and Exposure Hill Formations), hyperbyssal sheet intrusions (Ferrar Dolerite) and flood lavas (Kirkpatrick Basalt). The latter three components are well exposed in segments of the central and southern Transantarctic Mountains providing access to a vertically and laterally extensive view of the FLIP's magmatic architecture. Geochronologic studies demonstrate that both the intrusive and extrusive phases of FLIP magmatism were short lived (<1 m.y.) and contemporaneous over the entire outcrop belt. Chemically and isotopically, FLIP magmas are notable for their highly enriched Sr, Nd, and Pb isotopic compositions and crust-like trace element ratios. The Ferrar represents an extreme case of the development of these chemical features also observed in many other basaltic large igneous provinces. In areas where they have been studied in detail, chemical and isotopic compositions show a remarkably consistent pattern of variation that is best described by a processes of fractional crystallization combined with crustal assimilation. A number of outstanding questions remain to be addressed regarding the origin of the FLIP. These include: 1) What is the geographic distribution of the mantle source(s) ? Although temporally related to the breakup of Gondwanaland the distribution of FLIP magmatism does not follow any well defined plate boundaries associated with breakup. Petrologic and structural studies, however, indicate a Jurassic tectonic rift system was developed within the Transantarctic Mountains at the time of FLIP emplacement. Prior to the mid-1990's, studies of the FLIP implicitly assumed that its mantle source was a broad region lying beneath the present area of exposure and several localities have been tentatively inferred to represent major vertical magma conduits. The chemical distinctiveness and short duration of Ferrar magmatism, on the other hand, has more recently led to the suggestion of a geographically restricted mantle source, possibly located in the proto-Weddell Sea region, combined with large scale upper crustal transport of magma geographically focused by Jurassic extension. These contrasting models are best addressed by geophysical studies aimed at identifying the feeder system and detailed field studies of magma flow patterns using anisotropy of magnetic susceptibility, petrofabrics, and structural analysis of intrusive architecture. 2) What is the cause of the unique chemical and isotopic compositions of Ferrar rocks ? There has been long-standing debate whether the unique chemical features reflect the composition of their subcontinental mantle source(s) or an overprint due to interaction with the continental crust. The early history of magmatic evolution in the province is best addressed by examination of primitive, olivine-bearing dolerites which have been identified in several areas of the central and southern Transantarctic Mountains. 3) How is Ferrar magmatism related to breakup of Gondwana and what are the relationships to compositionally distinct basaltic rocks of similar age that occur in Dronning Maud Land and southern Africa ?

A New Method for Assessing Biotic and Abiotic Particles from Glacial Ice Cores

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Glacial ice contains an important reservoir of information on past climatic events. Information derived from the ice-core record allows predictions of changes in climate and provides critical data to anticipate how these changes will impact future societal issues on our planet. Unfortunately, the biogenic nature of aeolian dust particles in ice has received relatively little attention despite its known role in microbial transport.

Particles in ice cores are typically measured on discrete core segments using instruments based on the Coulter principle. These investigations focus on the size, concentration and source of the particles but fail to discriminate between biotic and abiotic forms, collectively referring to them as "dust". Most of the data on the abundance of microorganisms in ice cores comes from microscopy. Although microscopic methods allow characterization of the microorganisms both morphologically and physiologically, they are tedious and subject to large errors, particularly when cell density is low. Hence, microscopic analysis does not lend itself to high resolution, routine determinations of biogenic matter in ice cores.

Flow cytometers offer a promising method to detect and characterize biogenic matter rapidly in ice cores. Flow cytometers examine particles in a focused stream of fluid directed individually in front of an optical beam. Morphological characterization and enumeration of the particles (biotic and abiotic) can be made by their light scattering properties. The physiological properties of the microbial component of the "dust" can be determined by either auto-fluorescence or fluorescence induced by the addition of specific fluorescence probes.

Our laboratory has begun to use flow cytometry to characterize particulate matter in ice cores from Antarctic and Greenland. Initial tests on Vostok glacial (1686 and 2334 m) and accretion ice (3612 m) showed that counts of total particles and DNA containing bacterial cell can be successfully determined. We are continuing our analysis of ice cores and have run parallel analyses with a Coulter counter.

Despite the wealth of information trapped in ice cores, little information exists on the microorganisms immured within the ice. While we are developing methods specifically related to ice cores, these may also be modified for aquatic and terrestrial systems. It is important that biologists be included in future geological and glaciological efforts if a comprehensive view of past conditions on Earth is to be obtained, which would benefit all sciences involved.

The Future of Basement Geology Research in the Central and Southern Transantarctic Mountains

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Following several decades of broadly based and nearly continuous field-based geological research in the Transantarctic Mountains (TAM), USAP-supported geology programs seem to have waned through the late 1990's and into the first decade of the 21st century. Two contributing factors in this decreased activity are: (1) emphasis by the NSF in logistical support of large-scale infrastructure projects (e.g., South Pole) and large-scale multi-institution research efforts in other areas of Antarctica (e.g., WAIS projects); and (2) a demographic shift from researchers who became active principally in the 1960s and 1970s and who had many common interests, to a newer but perhaps more scientifically diffuse cadre of land-based researchers. In some cases, the currently active researchers have conducted interdisciplinary research that may be a sign of things to come, and field activities have taken on a smaller, more custom profile compared to the large coordinated field campaigns of the past.

Future research priorities for basement geological research in the central and southern TAM will be defined by the availability of rock outcrop, which dictates both method and logistics**. Rock exposures** will always provide the "ground truth" for any geological problem, such that continuing effort can be expected in study of basement rock exposures found within the TAM proper. [By "basement" I refer here to any rock units that stratigraphically underlie the Beacon Supergroup beneath the Kukri erosion surface.] In addition to direct rock exposure, however, much can be gained scientifically by either remote sensing or proxy sampling of basement terrain in the adjacent ice-covered regions beneath the polar ice cap. **Remote sensing** methods include magnetic anomaly, gravity anomaly, and seismic reflection and refraction studies, and **proxy sampling** includes study of material derived by glacial transport from sources in the ice-covered ancient craton or by recovery of drill-core material from the glacial substrate. Except for recovery of rock material from the bottom of ice cores, all of these indirect methods have been used in successful but geographically limited studies to characterize the basement geology beneath the ice cap adjacent to the TAM. Integration of both types of study is essential not only for developing scientific lines of inquiry but also for coordinating logistical support.

Research objectives and opportunities that we can address with these methods:

- Nature, composition and structure of the ice-covered East Antarctic shield, and its relation to Rodinia supercontinent assembly and dispersal;
- Tectonic and erosional development of the Ross Orogen, including its Precambrian ancestry and role in Gondwana tectonics;
- Influence of the East Antarctic shield and Ross Orogen on structural and magmatic development of the Mesozoic rift margin facing the Ross Sea;
- Role of East Antarctic shield geology in nucleating and stabilizing the Neogene East Antarctic ice sheet; and
- Interdisciplinary opportunities for cooperative study of rock, ice, snow, air and biota in geographic areas of common interest.

Coupled Hydrologic and Biogeochemical Cycles at High Latitudes

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To date, studies of hydrologic and aquatic ecosystems in the Dry Valleys of Antarctica (~77^{o} S) have shown that climate and physical hydrologic processes strongly control the presence, flux, and residence time of biogeochemically important constituents, such as dissolved nutrients and weathering products. There has been little work done to investigate terrestrial (i.e., not just glacial) hydrology and biogeochemistry at higher southern latitudes. In the Transantarctic Mountains there is likely limited exposed land area that resembles the Dry Valleys, yet these locations are likely to function similarly to Dry Valley systems, under a different climate, sans oceanic influence. In the coastal Dry Valleys, it has been observed that surface waters and precipitation tend to be more depleted in deuterium and ^{18}O stable isotopes with increasing distance from the coast (the "rain out effect"). At higher latitudes, similar to coastal areas, we expect that meltwater generation is the first order control on the presence of surface water, but that water chemistry and isotopic signatures are more likely to reflect local flowpath, water-atmosphere interaction, and weathering signals than waters of the Dry Valleys, which are subject to marine aerosol deposition. A preliminary study of surface water features in the Transantarctic Mountains is proposed, focusing on water chemistry, stable isotopic signature of surface waters, and water body size and type, to determine the origin and function of these surface waters.

Potential for Glacial Geologic Research in the Southern Transantarctic Mountains

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The southern Transantarctic Mountains (TAMS) is an important area for future glacial geologic research in Antarctica. Situated in the key area on the edge of the Ross Sea, the TAMS can afford information on the history of both the West and East Antarctic Ice Sheets. To date, ice-free areas of the TAMS have yielded important data concerning not only the last glacial maximum (LGM), but also glaciations dating back to the Oligocene. This makes this region unique on Earth.

My talk will focus primarily on issues surround the LGM ice extent and thickness in the southern TAMS, although earlier glaciations also will be explored briefly. LGM ice thickness is poorly constrained, except at Beardmore and Darwin Glaciers (Denton, Bockheim and others) and at Reedy Glacier (Stone, Hall, and others). Knowledge of ice-sheet thickness in the inner Ross Embayment is critical for reconstructing the LGM Ross Sea ice sheet. An accurate reconstruction of this ice sheet is important for global sea-level calculations and for understanding ice-stream dynamics at the LGM.

Landscapes, Soils, Subsurface Ice and Microclimate in Hyper Arid, Cold Regions, and Their Implications for Understanding Similar Features on Mars

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Access to the Trans-Antarctic Mountains provides a unique opportunity to study processes underlying the landscapes, soils and buried ice, and to examine archives of paleoclimate in a region of extreme cold, and aridity. This is relevant for 1) for understanding the interaction between climate and surface processes in this extreme environment and its implications for paleoclimate investigations, and 2) for extending soil temperature and climate records to interior regions of the continent, which lack such monitoring. We are eager to extend the geophysical and geochemical work we have conducted in the Dry Valleys to ice-free areas further south to cover a wide range of microclimate settings and to assess how these processes change at even colder and dryer conditions that more closely approach those on Mars. This work includes state-of-the-art monitoring of the microclimate and ground conditions, and the related theoretical and laboratory studies,

The fundamental understanding the distribution, state, and transport of H_2O below the ground surface in this extreme environment on our planet is relevant for understanding the development of these landscapes, soils, and subsurface ice bodies, as well as for interpreting archives of past conditions on Earth. Furthermore, efforts to define and understand the subsurface properties of well-characterized terrestrial cold-climate analogs of Mars are receiving special interests from the planetary science community. Such understanding is "an especially high priority objective of the Mars Exploration Program." Given the growing importance of geophysical investigations to the exploration of Mars, and the utility of testing these techniques in analog environments on Earth, much attention is focusing on geological and geophysical investigations of a broad range of analog environments, as well supporting laboratory and theoretical work (most current is a special session on this topic for the 2006 AGU Fall Meeting in San Francisco).

Glaciological Research Objectives in the Central Transantarctic Mountains

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The Ross Sea sector of the East Antarctic Ice Sheet (EAIS) contains some of Earth's largest glaciers and is responsible for nourishing a large portion of the Ross Ice Shelf. It is also one the least well understood glaciological provinces of the continent. Very little is known about the distribution of snow accumulation on the ice sheet plateau, about the ice dynamics of outlet glaciers draining through the Transantarctic Mountains (TAM), and about the overall mass balance conditions of this portion of the ice sheet. Better knowledge of these characteristics is necessary if we are to fully understand the coupled Antarctic ice sheet-ice shelf system, its response to present and past climate changes, and its role in modulating global sea levels.

Much of what we know about this sector of East Antarctica is the product of glaciological field campaigns in the 1970s and 1980s, and more recent satellite remote sensing studies. While the geographic extent of both datasets is limited, either by logistical constraints on fieldwork or the orbit characteristics of satellites, we do know that:

- TAM outlet glaciers are fast-flowing and drain an area of EAIS that is larger than West Antarctica (Brecher and Hughes);
- There is a latitudinal gradient in the amount of buttressing applied to outlet glaciers, with northern glaciers draining into the open ocean, southern glaciers fully buttressed by the Ross Ice Shelf, and glaciers in between subject to intermediate amounts of buttressing (Hughes, Frezzotti);
- The speed of at least one of these glaciers (Byrd Glacier) has varied by more than 25% over the past ~20 years (Stearns and Hamilton);
- There are indications of significant and rapid inland migration of the grounding line on Byrd Glacier (Reusch and Hughes);
- The mass balance characteristics are close to steady-state over regions of satellite data coverage, but with both significant spatial variability and sensitivity to parameterizations of snowfall distribution and ice thickness (Rignot).

These observations are key to guiding future field-based exploration of the Ross Sea sector of the EAIS.

There are several important research objectives, including:

- The collection of baseline glaciological data for major outlet glaciers, including ice thickness, surface topography, ice flow, and accumulation rate;
- A thorough study to explain the cause of recent changes in the flow dynamics (ice speed, grounding line position) of Byrd Glacier, and to assess whether other TAM outlet glaciers are behaving the same way;
- An investigation of the mechanisms responsible for ice streaming and rapid flow in this portion of EAIS, for comparisons with other ice streams in West Antarctica and Greenland.

These objectives are best addressed with coordinated field programs and related satellite remote sensing. Several studies are underway or in the proposal stages, including US ITASE which will traverse the inland margin of the TAM from Taylor Dome to South Pole yielding key data on accumulation rate, ice dynamics and glaciochemistry; a detailed aerogeophysical study of Byrd Glacier to understand its surface and bed topography; and remote sensing studies of ice flow speeds for major TAM outlet glaciers. These studies demonstrate an emerging US glaciological interest in the Ross Sea sector of East Antarctica, and provide a basis for additional and expanded research programs to understand the glaciology of EAIS.

Future Fossil Vertebrate Research in the Southern Transantarctic Mountains

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The first vertebrates from the Early Jurassic Hanson Formation were collected during the 1990-91 austral summer from a siliceous siltstone on Mt. Kirkpatrick in the Beardmore Glacier region. During the 2003 season a field team returned and collected more material from the original site. In addition , the 2003 group discovered a second vertebrate locality about 30 meters higher in the section on Mt. Kirkpatrick.

To date the most complete specimen from this assemblage is the partial skeleton of the crested theropod dinosaur *Cryolophosaurus ellioti* . More fragmentary material belonging to a plateosaurid prosauropod, scavenging theropods, a *Bienotheroides* clade tritylodont and a dimorphodontid pterosaur has also been identified. Material from the 2003 season is still under preparation, however, elements recently identified from the new Kirkpatrick site include the ilium and two articulated sacral vertebrae from a true sauropod dinosaur.

As few Mesozoic vertebrate faunas have been recovered from Antarctica, new taxa and/or assemblages such as those from Mt. Kirkpatrick have the potential to supply significant new information about the evolution and distribution of Gondwana vertebrates. The Early Jurassic fauna from the Hanson Formation represents not only the first from Antarctica, it is also one of only a very few Early Jurassic faunas from the entire supercontinent of Gondwana. In fact, worldwide Early Jurassic faunas are rare compared to later Jurassic and Cretaceous dinosaur assemblages. *Cryolophosaurus* has offered significant new information about the early evolution of the large tetanuran theropods. For example, the skull is quite advanced for a theropod this old, yet many of the postcranial elements retain primitive features. The new sauropod represents one of the oldest true sauropods in the world. The study of the evolutionary and biogeographic implications of any new vertebrates collected continues to be a major objective for this project.

Despite the short field season due to weather and helicopter problems, the group of six managed to collect between 3-4,000 pounds of bone bearing rock matrix from the two sites on Mt. Kirkpatrick during the 2003 field season. However, much more material was exposed than could be collected during the shortened eight day season, so a primary object for another season in the Beardmore area will be to finish collecting at Kirkpatrick. Some of the material left behind belongs to partial skeletons previously collected, while some could pertain to new animals. Since this is currently the only known Jurassic dinosaur locality on the entire continent, this is an extremely important site to revisit.

During the 03-04 season PI William Hammer and senior research associate Philip Currie did get a chance to do some aerial reconnaissance along the Queen Alexandra Range from Mt. Kirkpatrick and Mt. Falla toward the polar plateau. They identified and took GSP readings for 23 additional areas of extensive exposure of units in the upper part of the stratigraphic section, that includes the Hanson and Falla Formations. The group original planned to search some of these sites in 03-04, but given the short season all six field party members spent the entire time excavating at Kirkpatrick. For the next field season we hope to have a larger field party to allow some of the group to continue excavations at Kirkpatrick while others prospect new possible bone bearing areas in the Falla and Hanson Formations. In addition the team would include Chris Sidor, who would lead a smaller third group prospecting the Triassic Fremouw Formation for new vertebrate material. If any new localities were to be discovered, the team would be large enough to begin excavation without needing help from the Kirkpatrick group.

The Transantarctic Mountains

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Continental biota are related to sediment through feeding, dwelling, locomotion, reproduction, and searching behaviour evident as tracks, trails, burrows, nests of animals and rooting patterns of plants. Such vestiges are preserved in the geologic record as trace fossils. The lateral and vertical distribution of modern trace-making organisms within an environment is controlled by sediment characteristics, soil moisture, water-table levels, ecological associations, and more. Trace fossils in the geologic record can be used to interpret the palaeoenvironmental, paleoecologic, paleohydrologic, and palaeoclimatic settings because a well-defined relationship exists between climate, hydrology, soils, environment, and all biodiversity. Trace fossils also relate information about soil formation and development, the type of biologic activity, topography of the landscape and its relationship to groundwater profile, and duration of time that a body of sediment has been stable at the surface with respect to sedimentation rate. Thus, trace fossils in the continental realm are proxies for: 1) biodiversity in terrestrial and aquatic paleoenvironments not recorded by body fossils; 2) above- and below-ground paleoecological associations; 3) palaeosol formation, 4) paleohydrology and palaeo-groundwater profiles; and 5) seasonal and annual palaeoclimate indicators and climate change.

The approach to continental ichnology outline here has been applied successfully to trace fossils and deposits in the Queen Maud Mountains. The goals of a project in 1997 were to return to Permian and Triassic continental units in the Queen Maud Mountains, Shackleton Glacier area to (1) study, describe, and quantify purported decapod crustacean burrows from the Lower Triassic Fremouw Formation at Kitching Ridge and (2) collect freshwater decapod crustacean fossils from the Lower Permian Pagoda Formation at Mount Butters. Earlier expeditions discovered these body- and trace-fossil-bearing units in this area, and publications described the discoveries as the earliest evidence of freshwater crayfish in the world. Major implications were that decapods originated at high paleolatitude in glacial conditions with a cold climate, opposite of trends where origination and radiation takes place in the tropics.

The new fieldwork and approach to ichnology demonstrated that the body fossils and burrows were misinterpreted. We reinterpreted them as 1) euthycarcinoid arthropod body fossils and 2) as tetrapod burrows likely excavated by therapsids, or mammal-like reptiles, respectively. These results came about from intensive fieldwork by the new expedition and subsequent laboratory work, and have furthered our knowledge of Gondwanan tectonic, paleontologic, and paleoclimatic history. Euthycarcinoids are known largely from high-latitude, Gondwanan deposits, and the discovery of a complete specimen is a new, previously undescribed taxa. The tetrapod burrows are similar to burrows in the Karoo basin in South Africa, and further demonstrate a faunal relation between Africa and Antarctica when both were part of Gondwana. The presence of the burrows suggests that the climate during deposition of Lower Triassic units had a sufficiently warm season to allow large-rodent-sized vertebrates to thrive at high latitudes. The burrows also imply that therapsids may have had the ability to hibernate during the winter season similar to the way in which extant mammals hibernate in Arctic regions. The research also shows that paleolatitudinal and paleoclimatic distributions of burrowing therapsids and their mammalian descendents can be assessed by focusing search efforts on their burrows, and the use of well-established burrow morphologic criteria can clarify the extent to which the burrowing habit originated and persisted in high latitudes.

General Research Interests:

- Continental Ichnology-microbial, plant, invertebrate, and vertebrate behavior as indicators of hidden biodiversity in the fossil record;
- Ichnologic signatures of microbial consortia and communities in modern and ancient environments;
- Marine trace fossils and utility in reconstructing shallow to deep-marine environments;

- Invertebrate Paleontology;
- Ichnologic signatures of mass-extinction events—how infaunal organisms respond to major perturbations in the environment and on the climate;
- Ichnology of paleosols and the role of organisms in ancient soil formation;
- Continental sequence stratigraphy, stratigraphy and sedimentology; and
- Interpretation and reconstruction of continental and marine paleoenvironments, paleoecosystems, paleohydrologic regimes, and paleoclimates

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The Transantarctic Mountains

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Flow of the East Antarctic Ice Sheet (EAIS) into the Ross Sea is limited to a few outlet glaciers that cut through the Transantarctic Mountains (TAM). Currently, these outlets discharge over 10% of the ice loss each year. The long-term evolution of the outlet systems and the mountain range provide context for interpreting the sedimentary record of the Ross Sea with respect to the evolution of the EAIS, as well as important parameters for models of future stability of the EAIS. Orogen-scale, quantitative, landscape analysis reveals a direct correlation between the presence of sea-level channels that cut through the TAM and landscapes without significant glacial modification. We interpret this correlation as evidence that these deep channels have always provided efficient drainage of the EAIS. This efficient drainage has limited local thickening of the ice sheet and prevented ice flow over the mountain-tops to the Ross Sea. Thus, these regions lack small fjords and preserve the older, fault-controlled, landscape. In contrast, landscapes dominated by fjords are associated with outlet glaciers that flow through mountain passes at high elevations. In these regions, the outlets accommodate limited drainage of the EAIS, and would have allowed thickening of the EAIS. This local thickening would have resulted in region-wide flow over the mountain range to the Ross Sea and the development of fjords. Thus, these landscapes are dominated by numerous small fjords. This suggests that the sea-level channels formed prior to the onset of glaciation and have always provided efficient drainage of the EAIS.

Upper Paleozoic and Lower Mesozoic strata in the Central Transantarctic Mountains

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The central Transantarctic Mountains (CTM) contain some of the best exposures of upper Paleozoic and lower Mesozoic non-marine strata in the world. Included within these rocks are extensive and well preserved plant and vertebrate fossils. Both the deposits and the fossils record biologic and environmental upheavals that included: 1) a change from icehouse to greenhouse conditions; 2) major changes in the landscape due to tectonism, loss of vegetation, and climate change; 3) the end-Permian mass extinction; and 4) biotic and environmental recover during the Triassic. Because Antarctica was the sole Gondwanan crustal block to occupy a high southern latitude throughout this time, study of these strata provide the only polar view of an evolving Earth during the Permian and Triassic.

Lower Permian rocks in CTM consist of thick glacial, glacimarine and post-glacial deposits that are exposed over a distance of 1300 km from the Darwin Glacier to the Ohio Range. During the deposition of these strata, Earth was emerging from perhaps its longest and most extensive glaciation, the late Paleozoic Gondwanan Ice Age (LPGIA). This ice age, and the following climate amelioration, represent Earth's last complete transition from glacial to non-glacial conditions, and Earth's only such transition following the advent of land plants. Thus, the climatic record contained within Lower Permian strata provide one of the best analogues for future climate change during Earth's current transition out of a glacial age. Rocks in CTM are important because they contain the only proxy polar record for the late Paleozoic climatic transition.

Upper Permian strata in Antarctica consist of thick coal-bearing fluvial deposits, while carbonaceous material is absent within lower Triassic fluvial strata. However, coal reappears higher in the Triassic. Fossil plants occur in both Permian and Triassic strata; whereas vertebrate fossils have only been found in the Triassic rocks. All of these strata were deposited during changing climatic, tectonic, and biologic conditions. Establishment of coal-bearing fluvial deposits are part of the continued transition out of the LPGIA and into an ice-free Earth. During this transition, the area of the present CTM evolved into a retro-arc foreland basin, which developed due to convergent margin tectonism along the Panthalassan margin of Gondwana. The CTM rocks also contain one of the few known terrestrial areas where sedimentation may have been continuous across the Permian-Triassic boundary. Therefore, these strata may record conditions associated with the end-Permian mass extinction and the following Triassic recovery. Despite the possibilities of multiple drivers having influenced the deposition of these rocks and the fossils they contain, CTM remains an important site for deciphering high latitude biologic and environmental change during the late Paleozoic and Early Mesozoic. To better determine and understand how Earth systems operated during this important geologic interval, future studies need to be multidisciplinary and include sedimentologists/stratigrphers, paleobotanists, paleontologists, paleoecologists, and geochemists.

Remote Meteorological Observations of the Antarctic

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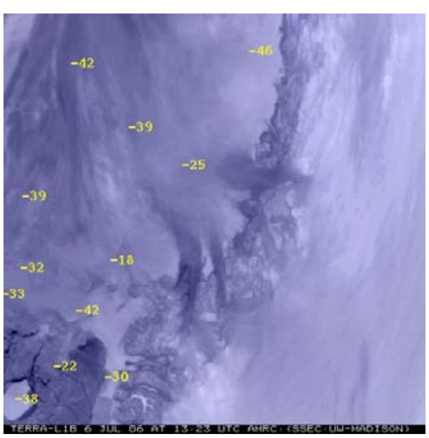
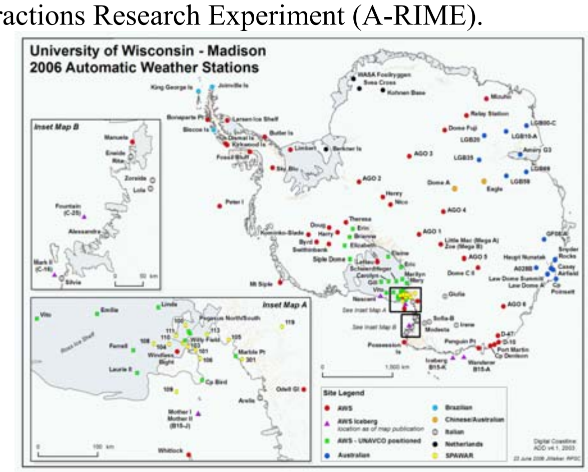
Meteorological observations of the Antarctic are critical to both the atmospheric sciences and non-meteorological disciplines. Whether used for operational logistics planning, weather forecasting, or glaciological studies, remotely sensed observations from ground based automatic weather stations (AWS) and space based satellites are primary means of acquiring meteorological observations around the Antarctic. For over 25 years, the University of Wisconsin has been and continues to maintain an Automatic Weather Station network in the Antarctic. For nearly 14 years, the University of Wisconsin has also created satellite composites over the Antarctic and Southern Ocean by merging a variety of satellite platforms. Both sets of observations have and continue to be of great value toward the United States Antarctic Program and other Antarctic programs, and will be an essential contribution to the International Polar Year (IPY) and Antarctic Regional Interactions Research Experiment (A-RIME).





Applications of these and other remote meteorological observational datasets in and around the Transantarctic Mountains will benefit both atmospheric and non-meteorological sciences. For example, a more detailed investigation of the boundary air flows in and around the Transantarctic Mountains will become possible with additional AWS installations and continue to document a critical aspect of atmospheric transport over the Antarctic, the Ross Ice Shelf Air Stream (RAS). Another example is focused satellite observations of clouds will provide a satellite perspective cloud climatology. An example in the non-meteorological arena would include detailed boundary layer studies of atmospheric turbulence with an aim toward selecting ideal optical astronomy sites for the installation of large array telescopes.

This presentation will review the status of the Antarctic Automatic Weather Station program as well as touch upon the status of other meteorological observations, such as those via meteorological satellite. Applications of meteorological observations from in and around the Transantarctic Mountains will be reviewed, including possible atmospheric science initiatives as well as those outside meteorology. Collaborations and suggestions will be encouraged.

Fossil-Rich Deposits Within the Dry Valleys Glacial Record: A Possible Link to Glacial Deposits Throughout the Transantarctic Mountains

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Extensive suites of glacial deposits reflecting fluctuations of East Antarctic outlet glaciers and locally derived alpine glaciers occur within the Dry Valleys sector of the Transantarctic Mountains. Analyses of numerous interbedded volcanic ash deposits have allowed this glacial record to be set into a chronologic framework, which shows, 1) that alpine-glacier thermal regimes shifted from being wet- to cold-based before 13.9 Ma, 2) that East Antarctic outlet glaciers thickened and were at their maximum extent between 14 and 12 Ma, and 3) that little change has taken place in the region, both climatically and glacially, from ~12 Ma up to the present. Although valuable for establishing the nature and timing of these major climate/glacial phases, the record provides no direct evidence for plaeoclimate conditions in the Transantarctic Mountains; climatic inferences have come only from indications of glacial thermal regimes and from the presence or lack of evidence for melt-water generation and related geomorphic effects.

Now, for the first time, fossil-rich deposits are available from the Dry Valleys that can be used to directly estimate surface conditions in the Transantarctic Mountains. These fossil-rich sediments were deposited where recessional moraines impounded small ponds in the Olympus Range, located in the west-central Dry Valleys. Evidence of a rich biota existing under much warmer-than-present climate includes remarkably well-preserved leafy moss beds, insect fragments, ostracods, and abundant freshwater diatoms. Crucially, these deposits are positioned within a well-dated local glacial stratigraphy, which shows that they are older than ~14 Ma. Ongoing analyses of thin, in-situ ash beds that occur within the lake sediments will provide a precise chronology for Miocene climate estimates.

The only other place in the Transantarctic Mountains where the paleoecology of Neogene-aged deposits has been studied is in the Beardmore Glacier region, 700 km south of the Dry Valleys (see abstract within this volume). A crucial objective for future work will be to correlate these two records and also those obtained from the ANDRILL project. An ultimate goal is to provide information on continental-scale climate change that can be compared to marine records.

Till Evolution and Provenance in the Ross Embayment

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We are conducting an integrated, interdisciplinary study of glacial deposits in the Ross Embayment that will help to constrain Antarctica's Late Quaternary (~18,000 yrs ago) glacial history and improve our knowledge of the rocks that underlie the massive East Antarctic ice sheet. Our goals are to use till provenance to evaluate paleo-ice flow models for the Ross Embayment during the last glacial maximum (LGM) and to characterize rocks eroded from the East Antarctic craton while constraining physical changes to till during transport. Understanding glacial transport is essential to interpreting Ross Sea provenance data used to provide constraints on past Antarctic ice sheet flow paths. A pilot provenance study suggests that the east-to-west variations in the sand and Nd-isotopic composition of Ross Sea till can be linked to East and West Antarctic source terranes (Licht et al., 2005; Farmer et al., in press). Western Ross Sea tills exhibit mineralogic and lithological similarities to East Antarctic tills, whereas eastern Ross Sea tills are compositionally similar to West Antarctic tills, particularly in their dearth of mafic components. Similarly, tills from the eastern Ross Sea have Nd and Sr isotopic compositions similar to West Antarctic tills and in the western Ross Sea, the till samples have higher εNd values (-4 to –7), similar to East Antarctic till samples. Central Ross Sea tills have εNd values ranging from –7.1 to –12.5, and a mixed source sand composition, thus, the central Ross Sea trough contains components of both East and West Antarctic derived till.

Because till samples were not available for many of the major outlet glaciers draining into the Ross Ice Shelf, new samples were collected from sixteen moraines at the head and along the length of the Byrd and Nimrod Glaciers in November 2005. Bulk sediment (till) and >300 pebbles were collected at each site in order to assess changes in particle size and composition during transport in a polar environment. Sites at the head of both glaciers contain more abundant silt and clay (fines) than downstream sites. In particular till from the Lonewolf Nunataks at the head of the Byrd Glacier contains >50% fines. Till collected from active lateral moraines along the trunk of both glaciers typically has <10% fines. A comparison of two Nimrod Glacier moraine sites, both adjacent to exposed Beardmore Group rocks, do not have similar particle size distributions. The KonTiki Nunatak site, which outcrops in the midstream of Nimrod Glacier and forms a medial moraine, is significantly finer-grained than its lateral moraine counterpart. A simple proportional model of size distributions from surrounding upstream sites shows that the KonTiki till appears to be a mixture of sediment eroded from the Geologists Range metamorphic rocks, Beacon Supergroup volcanic and sedimentary rocks (25-90km upstream) plus a locally-derived component from Beardmore Group rocks. The presence of abundant fine sediment in upstream and midstream Byrd and Nimrod Glacier till indicates a subglacial component whereas lateral moraines lack fines and are dominated by locally-eroded bedrock. This observation is supported by preliminary analysis of the pebble composition. Pebble composition reflects local bedrock outcrops in all lateral moraines from the trunk of both glaciers, whereas upstream sites contain a component of non-locally derived material.

Additional samples will be collected from the outlet glaciers south and east of the Beardmore Glacier during the 2006-2007 field season to build a complete database of samples from the Transantarctic Mountains.

Biogeochemistry of TAM Ponds and Lakes

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Lakes and ponds exist to at least the Shackleton Glacier area (85º S) along the ice-free regions of the Transantarctic Mountains (TAM) (Elliot et al., 1996). However, little to no biogeochemical data exist south of Lake Wilson at ~80º S. We desire to investigate both the geochemistry and the hydrology of these lakes and ponds in order to better constrain the role of climate on the ecology of these aquatic systems as well as to determine their geochemical age and evolution. This will be accomplished by the placement of in-situ sensors to monitor climatic/hydrologic variables and by the direct sampling and analysis of the pond/lake waters. We will use isotopic techniques to discern the sources of water and solutes to these systems, as well as to establish the ages of these features. Detailed inorganic chemical analyses will be used to help understand the geochemical history of these water bodies, and to better relate the biological processes within these systems to the chemical environment. These data will be compared to on-going work by the MCM-LTER personnel in the McMurdo Dry Valleys, as well as other research in Southern Victoria Land by New Zealand workers, and in Northern Victoria Land by Italian researchers. The research outlined here will be done in collaboration with my MCM-LTER colleagues, John Priscu and Andrew Fountain and with Jenny Webster-Brown at the University of Auchland.

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Distribution of Endemic Diatoms in Meltwater Streams and Fluvial Deposits in the Transantarctic Mountains: An Approach for Understanding Past Conditions

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To understand biotic responses to a two-decade long cooling trend in the McMurdo Dry Valleys in South Victoria Land, we analyzed diatom samples from glacial meltwater streams in the Fryxell basin of Taylor Valley, the focus of research conducted by the McMurdo Dry Valleys Long-term Ecological research project. Because the silica frustules of diatoms are well preserved in sediments and some diatom species are characteristic of certain environmental conditions, diatoms can be used as a proxy for interpreting past conditions from the sediment record. In the McMurdo Dry Valleys, diatoms are abundant in the perennial algal mats which occur in stream reaches with stable substrates. Twenty-four of the forty diatom species in these streams have only been found in the Antarctic, suggesting that these endemic species are adapted to harsh conditions of episodic wetting and drying of the stream channel during the period of glacial melt in the summer. We found that the percentage of these Antarctic diatom species increased with decreasing annual stream flow and increasing harshness of the stream habitat, which was quantified using the long term stream flow monitoring record. The species diversity of assemblages reached a maximum when the Antarctic species accounted for 40 –60% of relative diatom abundance. Further, the dominance of these Antarctic species increased to levels above 60% during summers with lower solar radiation and colder air-temperatures, which reduce annual stream flow. Given that cooling favors the Antarctic diatom species, analysis of the species distribution of diatoms in perched deltas and other sedimentary deposits may provide an additional tool for understanding past conditions in the region. To facilitate the study of freshwater diatoms in the Antarctic, we have developed a web-based resource that presents the taxomic and distributional information (http://huey.colorado.edu/diatoms/about/index.php). Through collaborations with other researchers we plan to expand this resource to include taxa from the sub-antarctic.

Citation

Esposito, R. M. M., S. L. Horn, D. M. McKnight, M. J. Cox, M. C. Grant, S. A. Spaulding, P. T. Doran, and K. D. Cozzetto (2006), Antarctic climate cooling and response of diatoms in glacial meltwater streams. *Geophysical Research Letters*, **33**(L07406), doi:10.1029/2006GL025903, 2006.

Permian Tetrapods in Antarctica?

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Discovery of Permian tetrapods in Antarctica would allow correlation with the standard continental section in South Africa, improve reconstruction of timing of Permian and Triassic events, and increase resolution of polar climate history during the Permian.

There is mounting evidence that failure to find evidence of tetrapods in Permian strata reflects their absence from the present-day Transantarctic Mountains region rather than insufficient searching.

Absence of body fossils: No body fossils were found in Permian rocks during field work in the 1960's, 1970's, mid 1980's, 1990's, or since 2000. In contrast, many specimens of tetrapods have been found in Triassic rocks in the same areas, except for southern Victoria Land (SVL).

Absence of trace fossils: In the last 10 years it has been well documented that burrows formed by tetrapods are locally abundant in Triassic deposits at Kitching Ridge and Shenk Peak in the Shackleton Glacier area and present, if not abundant, in Triassic strata at Graphite Peak and Wahl Glacier (Beardmore area) and in the Allan Hills (SVL). Tetrapod burrows are easy to spot from a distance if burrow fill is lithologically distinct from the surrounding rock. In spite of extensive searching in the Beardmore Glacier area (2003) and in SVL (2001, 2006) no tetrapod burrows have been found in Permian rocks of TAM. There are also no structures with features indicative of a burrow-origin described in measured sections of Permian strata from SVL or the Shackleton/Beardmore areas.

Choosing among possible causes for the probable absence of tetrapods is difficult. Presence of mature, productive forests suggests that temperatures were not too low for tetrapods, at least during the growing season. Retreat into a burrow would have provided protection from environmental extremes during the long polar winters. Efficacy of this strategy is demonstrated by abundance of tetrapod burrows in Permian and Triassic rocks of South Africa and in Triassic rocks of the TAM. However, water table levels probably were high in the Permian, as demonstrated by shallow Glossopteris roots, immature soils and trace fossils. High water tables would prohibit use of burrows as refuges, and possibly exclude colonization of southern polar latitudes by tetrapods during the Permian.

Productive Permian Polar Forests, Beardmore Glacier Area

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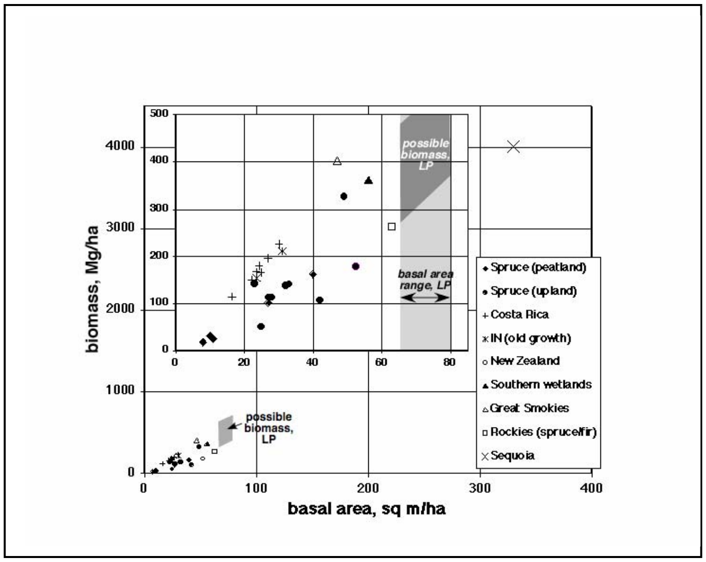
When and at what rate did the climate warm during the Permian? The answer to this question is important for reconstructing the history of the most recent icehouse to greenhouse transition and for assessing the relation between climate change and the end-Permian extinction event. The warming would be most marked at the poles, so the thick continental sequence deposited at polar paleolatitudes in the

Beardmore (BDM) and Shackleton (SHG) Glacier areas provides a unique glimpse into Permian paleoclimate. Flora and fauna can constrain climatic conditions and, unlike geochemical proxies, are not affected by diagenesis or metamorphism.

Two closely spaced horizons in the (Upper Permian part of) the Buckley Formation at Lamping Peak in the Beardmore Glacier area contain 74 stumps interpreted to be *in situ* based on roots and associated leaf mats. The stumps allow reconstruction of characteristics of forests flourishing at ~75º south at ≤ 1 Ma before the end of the Permian. Tree density and basal area coverage of these fossil forests is greater than or equal to that of other high latitude fossil forests and greater than that of many modern forests. The biomass is also large compared to that of modern forests, indicating that the forests were very productive and implying a benign growing environment.



At left: Basal area (m^2 covered by trees per hectare) vs. biomass per hectare of diverse modern forests. Shaded areas represent the projection of trend in modern forest biomass relative to basal area to the Lamping Peak (LP) basal areas.

The wood has been replaced and permineralized by magnetite, which does not preserve structure in detail. Possible stumps were described elsewhere in the Beardmore area, but their stratigraphic and geographic distribution are not known, nor has their potential for elucidating Permian climate history been fully realized, nor have the implications for global carbon cycling been assessed.

Eolian Dunes Composed of Gravel: Shackleton Glacier Area

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At Bennett Platform (BP) and Mt. Rosenwald (MR) in the Shackleton Glacier area, gravel sized particles comprise dunes with wavelengths on the scale of tens of meters and with decimeter scale amplitudes that are inferred to be formed by wind; smaller wind-formed dunes were noted subsequently at Mt. Robison and in the Allan Hills, southern Victoria Land (SVL). These wind-blown gravel dunes are significant because they potentially constrain maximum wind velocities, and because they provide a modern example applicable to the stratigraphic record that demonstrates that wind transport of coarse grained material occurs today and presumably has occurred throughout earth history given high winds and sediment unbound by vegetation or soil cover.

The dunes occur in areas where winds are funneled through topographic lows. At MR one dune overlies (postdates) a frost crack, suggesting relatively recent formation. The MR bedforms are barchan dunes composed of gravel sitting on bedrock (Triassic sandstone); wavelengths range from 12 to 21 m and amplitudes are ~0.6m.. At BP there are 13 relatively straight crested dunes that become more distinct downwind; wavelength ranges from 15 to 50m (mean 31m) and amplitude from 0.6 to 0.8 m (mean 0.7 m). In both areas, the stoss sides have superimposed smaller bedforms (wavelengths 50 to 60 cm, amplitudes < 5 cm). At BP, the dominant grain size class by weight is 3.5 – 4.0 cm, and is similar at MR. We calculate that wind velocities required to initiate transportation of these gravels range from ~190 to 230 km/her at Bennett Platform and from ~230 to 270 km/her at Mt. Rosenwald. For comparison, mean monthly maximum gusts at Mawson Station (1954-1996) range from 185 km/hr (March) to 220 (June) to 248 (August).

These dunes were recognized ten years ago but have not been described in the scientific literature for several reasons, including difficulty in relating the large grain size of these deposits to process-oriented studies of finer-grrained eolian deposits. Since then smaller dunes (decimeter wavelengths, amplitudes of a few cm) have been found at the margins of bowl-like depressions in the Allan Hills and at Mt. Robison.

An interdisciplinary effort between atmospheric scientists, fluid transport specialists, and sedimentologists is needed in order to document the distribution of these deposits, interpret the transport processes, and assess their significance for understanding the prevalence and potential of wind transport and for recognizing eolian deposits in the stratigraphic record.

P And S Velocity Structure of the Upper Mantle Beneath the Transantarctic Mountains, East Antarctic Craton and Ross Sea from Travel Time Tomography

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P and S wave travel times from teleseismic earthquakes recorded by the Transantarctic Mountains Seismic Experiment (TAMSEIS) have been used to tomographically image upper mantle structure beneath portions of the Transantarctic Mountains (TAM), the East Antarctic (EA) craton, and the West Antarctic rift system (WARS) in the vicinity of Ross Island, Antarctica. The TAM form a major tectonic boundary that divides the stable EA craton and the tectonically active WARS. Relative arrival times were determined using a multi channel cross correlation technique on teleseismic P and S phases from earthquakes with $m_b \geq 5.5$. 3934 P-waves were used from 322 events and 2244 S-waves from 168 events. Relative travel time residuals were inverted for upper mantle structure using VanDecar's method. The P-wave tomography model reveals a low velocity anomaly in the upper mantle of approximately $\delta Vp = -1$ to -1.5% in the vicinity of Ross Island extending laterally 50 to 100 km beneath the TAM from the coast, placing the contact between regions of fast and slow velocities well inland from the coast beneath the TAM. The magnitude of the low velocity anomaly in the P wave model appears to diminish beneath the TAM to the north and south of Ross Island. The depth extent of the low velocity anomaly is not well constrained, but it probably is confined to depths above ~200km. The S wave model, within resolution limits, is consistent with the P wave model. The low velocity anomaly within the upper mantle can be attributed to a 200-300 K thermal anomaly, consistent with estimates obtained from seismic attenuation measurements. The presence of a thermal anomaly of this magnitude supports models invoking a thermal buoyancy contribution to flexurally driven TAM uplift, at least in the Ross Island region of the TAM. Because the magnitude of the anomaly to the north and south of Ross Island may diminish, the thermal contribution to the uplift of the TAM could be variable along strike, with the largest contribution in the Ross Island region. The tomography results reveal faster than average velocities beneath East Antarctica, as expected for cratonic upper mantle.

Potential Use of Cenozoic Volcanic-Glacial Records from the Upper Scott Glacier to Interpret Antarctic Cryosphere History and Constrain Mantle Source and Geodynamic Evolution in the Southern Transantarctic Mountains

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Volcanic records of glaciation have placed important constraints on the cryospheric history of Antarctica and the geochemical characterization of the volcanism has been essential to our understanding of the tectonic evolution of the continent. Stump et al. (1980; 1990) report on two well exposed subglacially erupted volcanoes that reveal subglacial to emergent volcanic sequences and suggest the presence of an Early Miocene glaciation in the southern Transantarctic Mountains. The volcanic stratigraphy of Sheridan Bluff and Mount Early, located at the head of Scott Glacier, consist of basal exposures of pillow and hyaloclastite breccias that are capped by subaerially erupted lavas. The sequences are similar to other well studied sub-ice volcanoes in Iceland and Antarctica that have produced valuable information on ice-sheet history. For example, a detailed geochronologic, geomorphologic and lithofacies study of subglacial volcanism in Marie Byrd Land by Wilch and McIntosh (2002) has revealed Miocene-Pleistocene ice-level changes in West Antarctica. Smellie and Skilling (1994) used volcanic lithofacies analysis to distinguish volcanic-ice interactions associated with thin versus thick ice. In the southern McMurdo Sound, reconstructing the behavior of the Ross Ice Shelf and former Ross Sea Ice Sheet using volcanic-glacial records at Minna Bluff is the primary goal of a recently awarded 3-year study proposed by Wilch, Panter and McIntosh. Reconstructions of ice history require a combination of detailed interpretations of volcanic lithofacies and stratrigraphy and a robust and precise chronology and stratigraphic interpretation. Neither the stratigraphy or the chronology of volcanism in the upper Scott Glacier are well established. The Early Miocene age for Sheridan Bluff and Mount Early is based on 5 whole-rock samples dated by the conventional K-Ar method, two of which were also dated by the $^{40}Ar/^{39}Ar$ method but at much lower precision. At Sheridan Bluff, the age of the lowest dated unit (19.21±0.39 Ma) and the upper-most dated unit (18.54±0.37 Ma) are indistinguishable within analytical error and only a single date (15.86±0.3 Ma) has been determined for Mount Early, yet a minimum of 13 separate volcanic stratigraphic units are indicated for Sheridan Bluff and at least 6 units for Mount Early (Stump et al., 1990) and other volcanic deposits may also exist within the area (E. Stump, pers. commun., August, 2006). A comprehensive dating study using state-of-the-art $^{40}Ar/^{39}Ar$ techniques coupled with detailed mapping-lithofacies analysis is likely to supply significant new information about the past behavior of the East Antarctic Ice Sheet.

The magmas erupted are olivine-bearing basalts that range from tholeiite to mildly alkaline and are viable as geochemical tracers of melting processes and mantle sources. The fundamental cause of Cenozoic magmatism and tectonism in Antarctica is still a matter of debate. Geochemical investigations using basalts have produced a plethora of models to explain sources and causes of volcanism, which include deep mantle plumes, warm asthenospheric upwellings, melting related to reactivation of translithospheric faults and active rifting. A general consensus is that sources for Cenozoic magmas in west Antarctica are similar to sources for basalts erupted on widely scattered continental fragments of East Gondwana (New Zealand, Australia) and therefore may have a common origin. Many researchers also agree that the mantle sources are metasomatized and enriched in highly incompatible elements (e.g., Th, Nb, K, etc.) relative to primitive mantle but the timing and cause remains controversial (Finn et al., 2005; Panter et al., 2006). Neogene basalts (14-0.25 Ma) erupted at the base of the Transantarctic Mountains, South Victoria Land, were derived by small degrees of melting of a metasomatized source. Results from major-trace elements and isotopes of Sr, Os and oxygen suggest that the source of metasomatic fluids/melts may be associated with ancient subduction (500-100 Ma) that occurred along the East Gondwana margin (Panter et al., 2003). A detailed geochemical study of basalts from the upper Scott Glacier would provide a unique perspective on problems related to mantle sources and the geodynamic evolution of Antarctica. For instance, Sheridan Bluff is the only known occurrence of tholeiitic basalt of Cenozoic age outside of the subduction-related volcanism at the northern-end of the Antarctic Peninsula. It is also important to note that in Hawaii, geochemists use tholeiitic shield lavas to infer characteristics of the Hawaiian plume rather than low volume alkaline lavas. With respect to age and location, Sheridan Bluff and Mount Early represent one of only a few occurrences of Early Miocene basaltic volcanism in Antarctica and are the only know occurrences of Cenozoic basalts south of ~78º.

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Variability in Provenance and Weathering History of Sirius Group Strata, Transantarctic Mountains: Implications for Landscape Evolution and Antarctic Glacial History

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Studies of bulk X-ray diffraction, heavy mineral analysis, detrital modes and major element and trace element geochemistry of the Sirius Group were carried out to determine the provenance and stratigraphic relations of geographically widespread outcrops in the Transantarctic Mountains (Passchier, 2001; Passchier, 2004). Analyses of mineralogy and paleodrainage indicators demonstrates the complex origin of the Sirius Group, and it is proposed that deposition occurred within different ice-sheet drainage systems, which operated during consecutive stages of glacial denudation of the Transantarctic Mountains. Two end-member petrofacies of Sirius Group deposits can be distinguished. Major and trace element ratios indicate that the majority of the Sirius Group sediments have an East Antarctic provenance and that a few high-elevated deposits are locally derived. The degree of chemical weathering of the materials in the Sirius Group, expressed as the chemical index of alteration (CIA), has a wide range (41-70). Based on provenance, weathering history, and morphostratigraphic position, the Sirius Group can be subdivided into three subgroups, which probably represent multiple glacial phases: 1) Sediments with a local provenance from high-elevated outcrops on spurs and mountain summits, > 2000 m, which contain abundant weathered materials; 2) Sediments in high-elevated outcrops, > 2000 m, originating from an East Antarctic Ice Sheet, which was overriding parts of the Transantarctic Mountains; 3) Sediments recovered within, or on the margins of, the present glacial troughs at 1500-1800 m, with an East Antarctic provenance. Comparison with the weathering history inferred from drilling records in the nearby Victoria Land Basin reveals that glaciation in the Transantarctic Mountains probably commenced with small ice caps and alpine glaciers prior to the Eocene/Oligocene transition, and from the Oligocene onward continued with multiple phases of continental glaciation. These results and interpretations contribute considerably to the understanding of the landscape evolution of the Transantarctic Mountains, the Sirius Group debate, and the history of East Antarctic glaciation.

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Fault Kinematic Studies of the Transantarctic Mountains, Antarctica

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Regional fault arrays associated with the development of the Transantarctic Mountain rift flank uplift have yet to be mapped throughout the range. Consequently, the detailed kinematic development of the range remains problematic. Did the Transantarctic Mountains develop by orthogonal or oblique extensional processes? Did orthogonal and oblique extensional episodes occur at different times during rifting and associated rift-flank uplift? Each model predicts diagnostic fault geometries and kinematics, but can only be distinguished by detailed mapping and obtaining field-based data on the slip-trajectories of mesoscopic and regional faults. Key targets for such structural analyses in the central and southern TAM include regions near the Byrd, Nimrod, the upper Shackleton, and Scott Glaciers, where regional structures are suspected but little is known about the slip-trajectories of faults that occur in these regions. For example, previous work in the vicinity of Scott Glacier suggests the presence of two regional faults sets, one subparallel and another transverse to the mountain front. What role have the longitudinal and transverse structures played during mountain belt development? Do these faults reflect longitudinal normal and transfer faults that accommodate different rates, magnitudes, directions of extension and uplift within the mountains? Such data are critically needed in order to develop more robust kinematic models for the structural evolution of the mountain belt. Understanding the kinematic roles of these fault sets would also help establish whether orthogonal extension or transcurrent motions occurred during rifting and uplift in this sector of the mountains.

Glaciological Questions in the TransAntarctic Mountains

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The TransAntarctic Mountains (TAM) form the boundary between the East and West Antarctic Ice Sheets (EAIS and WAIS). The glaciers that flow through these mountains connect these two ice sheets, and interact with the ice-sheet landscape on two important timescale. First, over thousands to tens of thousands of years, the glaciers respond to climate-induced changes in the East and West Antarctic Ice Sheets (recently, the retreat from the Last Glacial Maximum, LGM, to present). Therefore, the flux of ice flowing from the EAIS to the WAIS changes through time. Second, over a longer timescale, the erosion of deep glacial troughs through the TAM has impacted the tectonic evolution of the mountain range (Stern and others, 2005). On this timescale, TAM is a modern representation of the development of fjord landscapes.

During the LGM the Ross Embayment was covered with grounded ice of the West Antarctic Ice Sheet (WAIS), which had a higher surface elevation than present. The glaciers flowing through the TAM contributed to the flow of this grounded ice. Because glacier flow is driven by surface slope, the retreat of the grounded ice and lowering of the surface of WAIS resulted in changes in the glaciers of the TAM and the overall flux of ice through the mountains. Specifically, a steepening of the surface slope would have increased the velocity of and thinned these glaciers. Also, the eventual floating of the ice would affect the dynamics of the lower regions of the glaciers which have beds below sea level. Depending on how quickly the Ross Ice shelf surface dropped, the glaciers may have been able to adjust dynamically to lowering surface and remain in a "quasi-steady state" condition. If the surface of RIS dropped quickly, it would take time for the glacier dynamics to respond. Each glacier will respond on a different timescale, depending on the depth of its valley (up to 1250 meters below sea level, Stern and others, 2005) and the thermal conditions at its bed (the larger ones in deep troughs are most likely warm-based for much of their lengths, the smaller ones in shallower troughs may be cold-based). The flux of ice through these glaciers and how it has changed since the LGM is an important connection between the East and West Antarctic Ice Sheets and may help constrain the speed of retreat for the grounded ice in the Ross Embayment. Recent work on the Reedy Glacier by Hall, Stone, and Conway has focused on reconstructing glacier ice thickness as a constraint on the speed of retreat of WAIS.

On a longer timescale, the glaciers of the TransAntarctic Mountains have affected the evolution of the Mountain Range. The process of "fjordification" of a range involves a positive feedback mechanism that focuses erosion in troughs occupied by warm-based glaciers, while cold-based surrounding ice at higher elevations and in shallower troughs erodes more slowly (Robert Anderson, personal communication, 2006). The process is a positive feedback mechanism in that once an ice-filled trough becomes warm-based, its erosion rate increases and the trough deepens, which draws more ice flux through the trough away from nearby cold-based glaciers in shallow troughs. This maintains the warm bed and further increasing erosion rates. In many places worldwide, we see the results of this fjordification process; for example, Baffin Island and Norway, both of which formed when an ice sheet was held back by a mountain range (Laurentide Ice sheet and Fenoscandian Ice Sheet, respectively). The process is ongoing in the TransAntarctic Mountains and can provide insights into this process.

Both of these questions can be approached with similar glaciological field data, combined with other geological data sets. A first step would be to measure modern surface velocity profiles across both large and small glaciers of the TAM, coupled with radar profiles to get trough depths and shapes. These measurements would provide the ice flux flowing through each trough from EAIS to RIS. An ice and heat flow model would provide insight into which glaciers are warm-based, which are cold-based, and which may have regions of both warm- and cold-based ice. From there, different modeling approaches and further data collection would allow focused research into each of the two timescales of interest. The timescales and processes I presented here are two of potentially many interesting questions.

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Landscape Evolution in the Dry Valleys of Antarctica

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The Dry Valleys of Antarctica have proven to be a critical location for understanding past ice sheet dynamics, landscape stability and climate history. In large part the existing understanding of their geologic history is based on dating, mapping, and stratigraphic relations of glacial deposits, colluvial sediment, and in situ volcanic ashes. In many cases, however, these age constraints provide only limiting ages for glacial advances, or loose limits to rates of erosion or sediment transport. Existing cosmogenic-nuclide surface exposure ages from many parts of the Dry Valleys are in general younger than the age of surface deposits inferred from stratigraphic relations, presumably due to some combination of surface erosion or past ice cover, both of which would serve to reduce the apparent exposure age. Here we report both measurements of multiple cosmogenic nuclides from surface deposits, which help to detect long periods of past ice cover, and measurements of the changes in nuclide concentration with depth below the surface of the deposit, which help to understand rates of soil mixing, soil transport, and landscape evolution. For example, beryllium-10 and aluminium-26 measurements from the surface of an avalanche deposit that contains 11.3 Ma volcanic ash (cf. Marchant et al., 1993) yield an apparent exposure age of only 0.4 Ma. However, measurements of the subsurface nuclide concentrations, when taken together with the stratigraphic and geomorphic situation of the site, show that the age of the ash does not conflict with the apparent exposure age when slow erosion of the deposit (ca. 2 m/Ma) since deposition is taken into account. Similar examples from other sites allow us to shed light on the apparent conflict between the stratigraphic evidence for great antiquity of the landscape and the relatively young apparent exposure ages for some surfaces, as well as to better understand rates of erosion, sediment transport, and landscape evolution.

An Approach to Tectonic Correlation at High South Latitude in Antarctica

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At high southern latitude in Antarctica, the convergence of meridians of longitude toward the South Pole causes unique problems for geometrical comparison of structural geological and geophysical datasets. Vector data (strike, trend) are ordinarily measured with respect to geographic North; however, the true North reference direction varies rapidly with longitude position around the Antarctic continent. For example, the angular difference in North direction between Amundsen and Reedy Glaciers at 86°S is 40° over a distance of 240 km. The drastic angular variation in reference direction will be of consequence for regional tectonic interpretations that compare faults, dike arrays, or geophysical lineaments in sectors of the southern Transantarctic Mountains that will be accessed by the overland route to South Pole.

A simple modular arithmetic conversion, of a type commonly used in number theory, offers the means to normalize geological orientation data to a single reference direction. In spreadsheet format, the function is $SC \equiv MOD\,[(S + \Delta L), 360]$, where SC = converted strike; S = measured strike; ΔL = angle in degrees longitude between reference site and study site; and 360 = the divisor. The function can be used to convert vector data to the coordinates of the Antarctic Navigational Grid (ANG), the system used for air navigation in Antarctica; or alternatively to perform a conversion that rotates data to the longitude reference direction for a research site under study. For example, a comparison of dike orientations in Marie Byrd Land (145°W longitude) with those in south Victoria Land (160°E longitude) requires a rotation of >55° counterclockwise, which can be carried out as a spreadsheet calculation using the general modular arithmetic expression introduced here. If implemented by the international geological community, this approach may form the basis for a protocol that will allow direct comparison of structural/geophysical data between geographically separated study regions in Antarctica. Opportunities to apply this normalization technique will increase as new structural investigations are carried out in the southern TAM and geophysical coverage of central East Antarctica improves, providing a means to correlate bedrock structures and geophysical lineaments.

ROSETTA: A Program for ROSs Embayment Aerogeophysics: Tectonic/Trend Analysis

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In order to explore tectonic linkages between the West Antarctic rift system and Transantarctic Mountains, we plan to develop a proposal to acquire a unifying aerogeophysical data set over the Ross Ice Shelf. Detailed geophysical transects border the Ice Shelf on all sides, but the basin geometry and bedrock character beneath the thick tabular floating ice is very poorly known. The aim of the **ROSETTA [ROS**s **E**mbayment Aerogeophysics: **T**ectonics/**T**rend **A**nalysis] project is to determine basin geometries, fault trends, distribution of volcanic and sedimentary rocks, and volcano-magmatic trends over the RIS "keystone" region in order to unify findings from geological research in the TAM and Marie Byrd Land; geophysical airborne and marine studies; reflection seismic lines; and Ross Sea drilling. The new acquisition will replace the 1970s' Ross Ice Shelf Geophysical and Glaciological Survey (RIGGS/RISP), with surface measurements 55 km spacing, that are unusable for systematic structural interpretation and regional tectonic correlation at the level of detail of geophysical data covering neighboring sectors.

Recent combined geophysical-geological transects of the TAM clearly show that integrative studies of the Ross Sea rift/West Antarctic rift, rift flanks, Interior Ross Embayment, and interior East Antarctica are critical for achieving a full understanding of Transantarctic Mountains evolution. ROSETTA aims to define the distribution and geometry of late Cretaceous sedimentary basins and Cenozoic volcanics within the West Antarctic rift system, and to delimit tectonic trends that may be used to correlate geophysical data sets from West Antarctica and TAM with outcrop-based studies of the rift flanks in the TAM. The ROSETTA survey will span the area between geophysical surveys (TAM transects I & II, CWA-CASERTZ, NVL [Ganovex-ItaliAntartide], and MBL) and ground-based geology studies of the TAM and MBL. Planned with a flight line spacing of 10.6 km and tie lines every 31.8 km, the survey will acquire 65,000 line km of data over an area the size of France. The shape of the area in map view resembles that of the Rosetta Stone, emblematic of the potential of the area to unify scientific perspectives developed in the TAM, West Antarctica, and Ross Sea.

The ROSETTA program will address fundamental questions about the tectonic development of the TAM and West Antarctic rift system that bear on questions of evolution of the interior of East Antarctica. Investigation of the linkages between the tectonic elements will become increasingly feasible with the development of the traverse route to South Pole – an infrastructure backbone for ROSETTA airborne surveys and for future Ross Ice Shelf studies. By determining the continuity of tectonic elements between extended crust beneath the Ross Ice Shelf and the TAM-East Antarctica; and the extent and distribution of Mesozoic vs Cenozoic extension, ROSETTA will provide critical regional context for new research to be carried out in the southern TAM. The new data will allow the solid earth science community to test hypotheses on the kinematics, mechanisms and magnitude of extension and development of mountain relief in the TAM that come principally from marine surveys and drilling in the Ross Sea and field geological investigations along the rift flanks. The ROSETTA geophysical data also will be an asset to the Antarctic geology and geophysics community in planning for future drilling, outcrop and geophysical programs. As the Rosetta Stone provided the means to decipher Egyptian hieroglyphics, the new geophysical coverage of this keystone region will enable us to develop an integrated, comprehensive understanding of the crustal structure, extent of magmatism, basin geometries and linkages between the West Antarctic rift system and TAM. ROSETTA will unify airborne and marine geophysical, seismic and drilling data sets acquired over the past three decades, linking existing geological and geophysical studies and datasets.

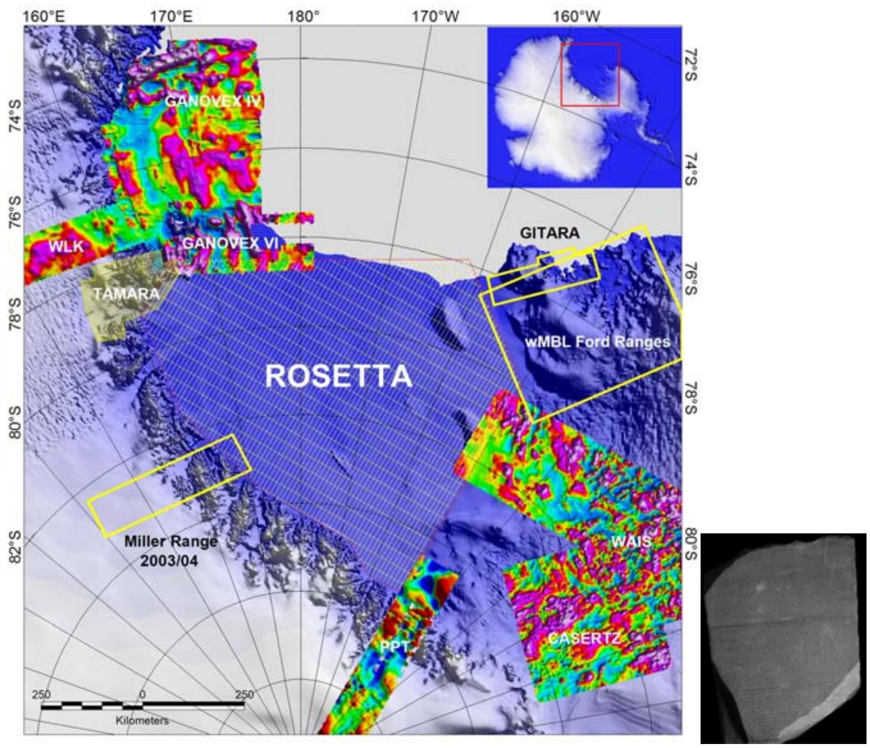

Figure 1. Region of the Ross Ice Shelf to be proposed for the ROSs Embayment Aerogeophysics: Tectonics/Trend Analysis [ROSETTA] program, with areas of existing coverage indicated. The planned flight line grid is shown (spacing at 10.6 km line / 31.8 km tie line). Small image to right offers shape comparison with the Rosetta Stone, which is on display in the British Museum.

Vertebrate Paleontology and the Permo-Triassic Boundary in Antarctica.

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The geologic record of Antarctica has recently been used to address the cause of the Permo-Triassic (PT) mass extinction. At Graphite Peak extinction markers such as a negative δ^{13} C shift, shocked quartz, and a faint iridium anomaly were reported above the highest coal layer in the Buckley Formation. From the same locality, meteorite fragments and extraterrestrial fullerenes with trapped noble gases were suggested to occur, and were interpreted as support for the presence of a PT impact structure located northwest of Australia. However, the lack of directly datable material in the relevant strata has meant that age control is typically accomplished through biostratigraphic correlation, including data from fossil plants, pollen, and vertebrates.

Vertebrate paleontologists have long recognized that the Triassic fauna of Antarctica is similar, but not identical, to that of South Africa. The difference could be attributed to a variety of factors, including biogeographic separation (e.g., due to climatic differences), temporal resolution (e.g., Antarctic and South African rocks record non-overlapping periods of time), or taxonomic practice (e.g., the faunas are really the same, but certain index fossils have been misidentified). Discriminating between these choices requires a careful review of the relevant vertebrate fossils. It also requires revisiting Antarctic localities that were collected in the 1970-90s to verify their stratigraphic position, as well as exploring for new fossils at these and new localities in the central Transantarctic Mountains.

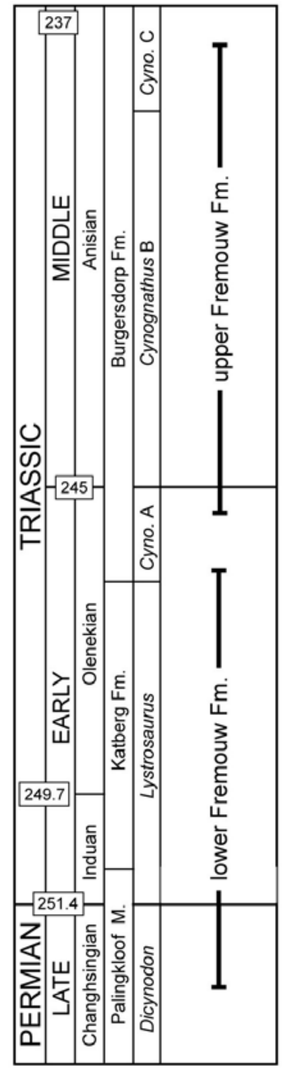

Figure 1. Permo-Triassic stratigraphy of South Africa, with possible biostratigraphic correlations to the Fremouw Formation of Antarctica.

The past decade of work on the PT boundary in South Africa has generated a rich paleobiological, geochemical, and paleomagnetic context making the Karoo internationally recognized as the standard to which other Gondwanan PT records should be compared. By comparison, PT extinction work done in Antarctica is hampered by the less precise correlation afforded by our current understanding of its Triassic vertebrate fauna. For example, vertebrates of the lower Fremouw currently imply a wide range of possible ages for this formation (Fig. 1); some Antarctic localities may contain Permian rocks because of the presence of appropriate indicator vertebrates (e.g., *Lystrosaurus maccaigi* at Collinson Ridge), whereas others are likely to lack PT boundary rocks because their vertebrate fossils suggest a stratigraphically higher, Katberg-equivalency (e.g., *Procolophon trigoniceps* at Kitching Ridge).

Our understanding of Antarctica's paleobiological history is still in its infancy. Simple correlations of the lower Fremouw Formation to the *Lystrosaurus* Assemblage Zone of South Africa —as originally advocated by Kitching et al. (1972) and repeated until today— ignore years of progress. Future vertebrate paleontology field and laboratory work should (1) refine the taxonomy of biostratigraphically important index fossils, (2) enhance our understanding of life on Antarctica in the early Mesozoic, and (3) establish better age control on the rocks of the Fremouw Formation. Accomplishing these three goals will enable Antarctica geology to more fully contribute to studies of the Permo-Triassic extinction.

**Microbially-Mediated Weathering in a Cold Polar Desert.
Is Nitrogen the Key?**

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There are three broad environmental settings in the Transantarctic Mountains. Surficial glacial environments, glacial ice and ice-free terrain. Liquid water is present in each environment in varying quantities and over varying timeframes. Hence, a spatially and temporally changeable mosaic of microbial life can potentially exist throughout these environments. Key to the viability of these ecosystems is primary productivity. Primary productivity and carbon fixation is possible via photosynthesis in all surficial environments, given the abundance of daylight during the austral summer. Comminuted glacial sediment is a source of bioavailable phosphorus. Thus, nitrogen may be the primary limiting nutrient. The availability of nitrogen (and carbon) in these environments and their flowpaths within the system as a whole, in turn, will determine the intensity of microbial activity and thus the magnitude of microbially-mediated mineral weathering. The latter is a longer-term control on the Eh and pH of the ecosystems, which potentially impacts their biodiversity.

The Transantarctic Mountains

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The Gravity Recovery and Climate Experiment (GRACE) was launched by NASA in 2002 to create a detailed global mapping of the Earth's gravity field. Although much of the work done by NASA scientists has focused on the time variable signal of GRACE, these data also provide a unique opportunity to create a high resolution (35-100km wavelength) static gravity field over the most inaccessible regions of the Antarctic interior.

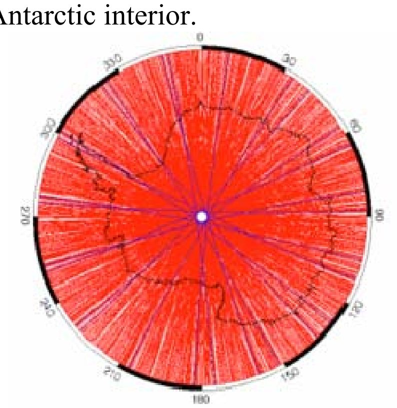

Figure 1. GRACE satellite gravity coverage. Blue lines show one day of data. Red lines show coverage for 64 days.

Through inversion and interpolation techniques, the subglacial topography of the continent will be estimated using detailed aero-geophysical surveys as constraints as well as a means to determine the resolution of the GRACE-derived gravity field.

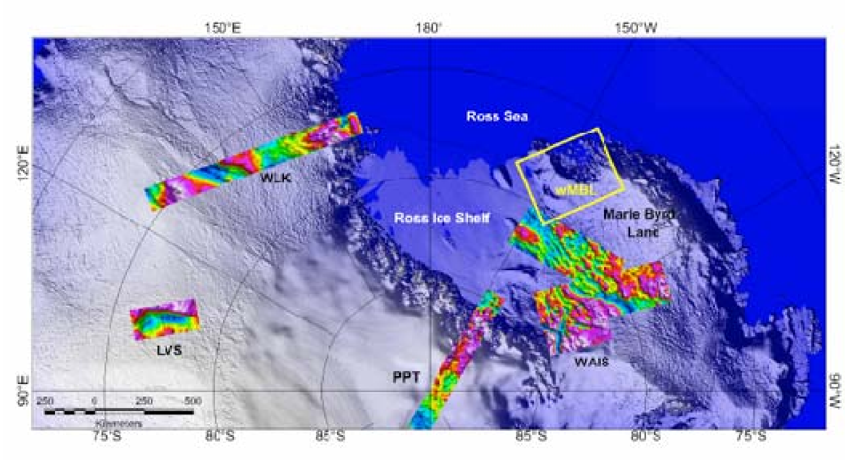

Figure 2. Existing aerogravity data coverage available to constrain GRACE-derived topography estimates.

Through the continued collection and processing of GRACE data, we will be able to study the gravity signal of the Transantarctic Mountain Range as a whole rather than along isolated tracks.

This enables us to better approach questions such as:

- How far into the interior of East Antarctic is there elevated topography associated with the Transantartic Mountains?
- Is the gravity signal of the TAM consistent along the length of the range?

By addressing these questions we can improve our understanding of the TAM's extent as well as its compensation mechanism and status. Also, through the integration of the results of our GRACE objectives with seismic studies, we can develop a better understanding of the lithospheric structure in the TAM and the East Antarctic interior.

Vertebrate Faunas of the Central Transantarctic Mountains: Implications for the Evolution and Biogeography of Dinosaurs and the Triassic-Jurassic Faunal Transition

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As one of the five major mass extinctions in earth history, the Triassic-Jurassic faunal transition remains one of the most intensely debated and actively researched areas in the earth sciences. This period records a major faunal transition among terrestrial vertebrates, one that saw the rise to dominance of the dinosaurs. While the early history of the Dinosauria has always fascinated researchers, this period has received considerably less attention than the later Mesozoic, when dinosaurs were at their zenith. Much of what we know about Late Triassic and Early Jurassic vertebrates comes with a heavy geographical bias, with faunas in North America and Europe having received more study than Gondwanan faunas. The Central Transantarctic Mountains preserve a sedimentary sequence containing an Early Jurassic vertebrate fauna from the Hanson Formation that has yielded considerable insight into the early evolution of several important dinosaur groups. Reconnaissance done in the 2002-2003 field season suggests incredible potential for more discoveries in the Hanson Formation, and possibly in the underlying Late Triassic Falla Formation. The geographic and temporal importance of such vertebrate assemblages cannot be overstated, and given the information emerging from studies of material collected to date, the vertebrate faunas of Antarctica will be critical to understanding the evolutionary dynamics of the Triassic-Jurassic faunal transition, and also to deciphering the early evolution and biogeography of many major dinosaurian groups.

In recent years, increased interest has been focused on understanding the evolutionary relationships of the earliest dinosaurs. This is due to a variety of reasons, including a desire to **(1)** determine the interrelationships of the major dinosaurian groups, **(2)** decipher patterns of character evolution throughout the history of these groups (such as changes along the lineage leading to birds), **(3)** evaluate biogeographic patterns within the Dinosauria, and **(4)** understand the dynamics of major evolutionary trends within the Dinosauria, such as the evolution of gigantism, herbivory, and quadrupedalism. Not surprisingly, fossils from the Late Triassic and Early Jurassic are critical to understanding these patterns, as these fossils often represent the earliest members of their respective evolutionary groups. Dinosaurs from the Central Transantarctic Mountains are yielding much information regarding these questions. For example, a recent study of *Cryolophosaurus elliott*, a carnivorous dinosaur from the Hanson Formation, found that most of the morphological changes in the lineage leading to birds first occurred in the cranial skeleton, with modifications to the post-cranium occurring later in the group's history. This study also suggests that the earliest members of many carnivorous dinosaur groups may have been larger-bodied than previously supposed. Recent work on a primitive sauropodomorph dinosaur (the group that includes the enormous, long-necked sauropods) from the Hanson Formation has contributed to resolving the systematic relationships of these animals, and coupled with the evidence of a possible 'true' sauropod discovered in 2002-2003, provides intriguing paleoecological support for an emerging hypothesis that many of the earliest sauropod dinosaurs evolved in sympatry with these early sauropodomorphs, and coexisted with their primitive cousins for millions of years. Interestingly, this hypothesis also has important implications for understanding the evolution of gigantism among the sauropodomorph dinosaurs. Both of the above examples demonstrate how fossil dinosaurs from the Central Transantarctic Mountains are causing us to reevaluate many long-standing views on early dinosaur evolution.

Terrestrial vertebrate faunas from the Central Transantarctic Mountains are also critical to understanding biogeographic patterns associated with the Triassic-Jurassic faunal transition, and with the early evolution and radiation of the dinosaurs. Recent research on Late Triassic and Early Jurassic faunas has revealed important geographic differences associated with the evolution of several major dinosaur groups, and is suggesting that terrestrial vertebrate faunas during this time were not as uniform and cosmopolitan as traditionally hypothesized. In addition to increasing the known geographic range of several groups, fossils from the Hanson Formation have also yielded interesting geographic information associated with the early dinosaur radiations. For example, a phylogenetic study of carnivorous dinosaurs that included *Cryolophosaurus elliott* suggests that several major carnivorous dinosaur groups may have Gondwanan origins. As more interest is focused on Mesozoic continental-level biogeography, the role of fossils such as *Cryolophosaurus* will be critical, as well as the need for further collection in the Central Transantarctic Mountains. These fossils not only aid in understanding biogeographic patterns within major vertebrate groups, but also are valuable in establishing the patterns of biotic interchange and connection for the Antarctic continent during the Mesozoic.

Dating East Antarctic – West Antarctic Ice Sheet Interactions in the Southern Transantarctic Mountains

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In their present interglacial state, the East and West Antarctic Ice Sheets merge and flow together along the margin of the Weddell Sea Basin, but only interact in the southernmost corner of the Ross Sea drainage – along the escarpment formed by the Thiel Mountains and Ohio Range. Under glacial conditions, the southern Transantarctic Mountains (TAMS) form the interface between the ice sheets in the Ross Sea Basin. East Antarctic ice delivered by thickened outlet glaciers flowing across the range merges with the expanded West Antarctic Ice Sheet in the western Ross Sea. Many generations of till, scattered erratics, and lateral and terminal moraines above the present level of these glaciers record former ice surface elevations, and provide clues to the climatic and geomorphic evolution of Antarctica. Pioneering work by John Mercer on Reedy Glacier, and subsequent studies further north along the range, showed that TAMS glaciers respond strongly to the thickening of West Antarctic ice grounded in the Ross Sea during glacial periods. Glacial deposits at the range front stand up to a thousand meters above the Ross Ice Shelf. Upstream on the same glaciers, these deposits converge towards the present-day ice surface, typically indicating only tens of meters of thickening in East Antarctica at these times.

Until recently, only the relative ages of these deposits could be inferred, from geomorphic data, weathering contrasts and soil development. Exposure dating methods based on cosmic-ray-produced nuclides now provide numerical ages for comparison with other paleoclimatic records. Cosmogenic nuclide techniques, based on the accumulation of rare isotopes such as ^{10}Be, ^{36}Cl and ^{3}He in freshly exposed rock surfaces, are well suited to dating Antarctic glacial deposits, which commonly lack material for radiocarbon and luminescence dating. Their application in Antarctica can be complicated by low weathering rates and weakly erosive glaciation, leading to problems of recycling and prior sample exposure, but these can generally be addressed by careful sampling and tight integration of geomorphic and cosmogenic nuclide data.

Use of these methods in the southern Transantarctic Mountains can provide: (i) Numerical ages for the last glacial maximum from the major glaciers which cut the range. There is growing evidence that maximum ice build-up in Antarctica post-dated the global glacial maximum by thousands of years, with important implications for sea-level reconstructions and the marine oxygen isotope record. (ii) Numerical ages for older deposits which underlie LGM moraines. These may relate to more extensive ice advances early in the last glacial cycle, as inferred from marine deposits on the Antarctic continental shelf. (iii) Detailed reconstruction of glacier profiles since the LGM; these can be used to constrain flowline models and monitor postglacial thinning of the the East and West Antarctic Ice Sheets. (iv) The history of grounding-line retreat in the Ross Sea since the LGM. Ice retreat from the northern Ross Sea is well constrained by marine records and coastal deposits in Victoria Land, but the timing and pattern of grounding line retreat south of Hatherton Glacier remains largely unknown. Exposure dating of glacial deposits along the range front would constrain this history, providing important information about late-Holocene sea-level change and the recent mass-balance of the West Antarctic Ice Sheet. Results from recent field seasons on Scott and Reedy Glaciers, which begin to address these questions, will be presented at the meeting.

Crustal Architecture of the Southern and Central Transantarctic Mountains from Aerogeophysical Data

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The Transantarctic Mountains and associated West Antarctic rift system are among the most enigmatic tectonic regions on Earth and the mechanism of their formation remain controversial or poorly understood. Difficulties in resolving the formation of the Transantarctic Mountains arise from 1) a poor understanding of the age and distribution of basins within the West Antarctic rift system, largely due to the ice cover of the Ross Ice Shelf and the West Antarctic Ice Sheet, 2) the uncertain nature of the boundary between the West Antarctic rift system and the Transantarctic Mountains (East Antarctica), including crustal thickness/structure and contrasts in the mantle structure, 3) the gap in the geologic record between the extrusion of Jurassic tholeiitic magmatism (Ferrar Dolerite and Kirkpatrick Basalt, ~180 Ma) and the latest Eocene glacial sediments (~34 Ma) cored in the Ross Embayment, 4) a lack of delineation of the inland structure of the Transantarctic Mountains. In order to better understand the tectonic and geologic framework, geophysical remote sensing is a crucial step forward. We use aerogeophysical data collected along two transects that cross the Transantarctic Mountains and continue into East Antarctica (Fig. 1) to illustrate how such data is used to constrain the sub-ice topography, the sub-ice geology and the inland structure of the Transantarctic Mountains.

The Bouguer gravity anomaly of both transects is very similar. Both transects display a steep gradient towards the Ross Sea side and a gentle gradient in the hinterland. Forward modeling of gravity data suggests slight crustal thickening of 5 km beneath the mountain front suggesting partial isostatic compensation by thickened crust. A comparison of structural trends in the magnetic data on the inland flank of the Transantarctic Mountains from the two aerogeophysical transects reveals remarkable differences. In southern Victoria Land, the main structural trends are parallel to the Adventure Subglacial Trench and Resolution Subglacial Highlands at a 45° angle to the Transantarctic Mountains front. In contrast, within the South Pole segment of the southern transect, the dominant trend in the magnetic anomalies is oriented 60° to the Transantarctic Mountains, and lies at a high angle to the trend in southern Victoria Land. These contrasting trends are interpreted to most likely represent tectonic features, perhaps of different origins. A pronounced magnetic lineament beneath the South Pole (the South Pole Lineament; Studinger et al., in press), parallel to the 0°/180° longitudinal meridian defines a previously unknown tectonic trend of the East Antarctic craton. The lineament suggests the presence of a lithospheric-scale structure beneath South Pole. This lineament projects along a fault, mapped from ice-penetrating radar data, that extends to the Shackleton Glacier, the site of a major geological boundary across the Transantarctic Mountains. Potentially, the lineament is the expression of the edge of the undeformed craton, an inherited structure created during assembly or breakup of Rodinia and Gondwana supercontinents; or an intracontinental transform.

Acquistion of aerogeophysical transects over the exposed Transantarctic Mountains and reaching deep into the interior of the ice-covered East Antarctic shield is a powerful tool for advancing our understanding of the margin of the shield and its relation to younger tectonic events.

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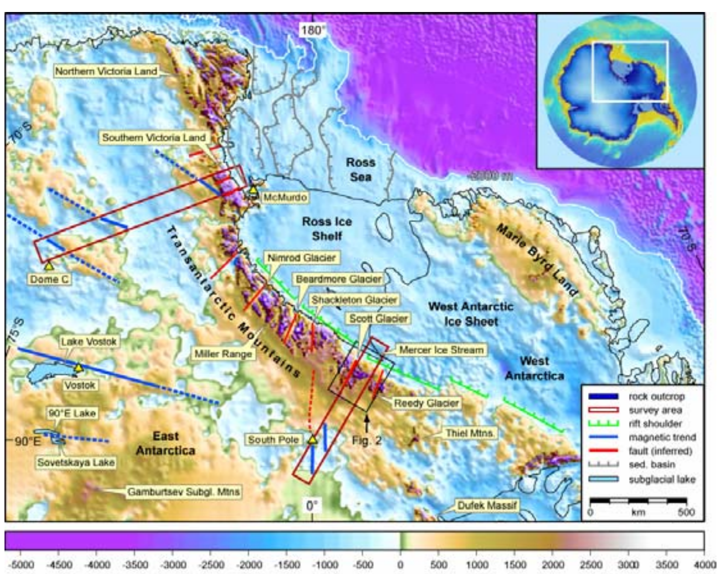

Outstanding Problems in the Ross Orogen South of Darwin Glacier

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The general tectonic patterns of the Ross orogen have long been known: a Neoproterozoic/Cambrian sequence of sediments and volcanics, deformed, metamorphosed and intruded during a major orogenic episode. In recent decades distinct histories have been recognized within the major regions of the Transantarctic Mountains: northern Victoria Land (NVL), southern Victoria Land (SVL), the central Transantarctic Mountains (CTM) and the Queen Maud Mountains (QMM). Advances have been made in particular through precise U-Pb dating of zircons from magmatic rocks and detrital suites, allowing the correlation of fossil-dated sedimentary sequences with volcanic and plutonic rocks throughout the orogen. As we come to understand better the history of individual regions within the Ross orogen, the need to understand the relationships between these areas becomes imperative for a comprehensive understanding of the evolution of the orogen as a whole.

South of Darwin Glacier one may recognize three regions with distinct geological histories: 1) the southernmost portion of SVL, characterized by the little-studied Horney Formation; 2) the CTM, characterized by the Beardmore Group and Early-Middle Cambrian Byrd Group; and 3) the QMM, characterized by the Liv Group.

The discontinuity along Byrd Glacier marks distinct differences to the north and south in 1) lithology (major occurrences of limestone south of Byrd Glacier, only minor calc-schists to the north), 2) metamorphic grade (mainly lower greenschist to the south and upper amphibolite to the north), and 3) timing of plutonism (as old as 545 Ma in the Britannia Range and Darwin Glacier area to the north while Shackleton Limestone was being deposited to the south.)

Does the Byrd Glacier discontinuity represent a terrane boundary? Did the boundary develop as a subduction zone? Did it develop as a strike-slip fault? Were both modes of displacement active? Why was the pre-Beacon exhumation of the Britannia Range north of Byrd Glacier so much deeper than the Byrd Group to the south? Was crust doubly thickened to the north? What are the geophysical signatures across this boundary?

The relationship between the Byrd Group of the CTM and the Liv Group of the QMM awaits a more precise correlation of events in the two areas, and in particular a more precise chronology of deposition and volcanism of the Liv Group. What we know from fossils is that Shackleton Limestone was deposited in the Early Cambrian, while Liv Group spanned the Early to Middle Cambrian. Volcanism is all but absent in the Byrd Group (an ash in the upper Shackleton Limestone, a pillow basalt at the boundary with the overlying clastic Starshot Formation and Douglas Conglomerate), whereas the Liv Group contains abundant rhyolite and a measure of basalt, with most of the dated rhyolites falling in the range of 525-505 Ma, but with one outlier at 550 Ma, similar to the age of the oldest magmatic rocks in SVL. The area between carbonate outcrops of Byrd and Liv Group (essentially between Robb and Ramsey Glaciers) is blanketed by a sequence of clastic sediments mapped as Neoproterozoic Beardmore Group, but likely to be in part or entirely Cambrian sediment correlative with Starshot Formation around Nimrod Glacier. The relationship of these sedimentary rocks to Duncan, Party and La Gorce Formations of the QMM also remains to be determined.

How do the chronologies of deposition (both carbonate and clastic) and volcanism in the two regions match? What does this tell us about whether the Byrd Group and the Liv Group belong to two separate terranes or are different manifestations of the same broader tectonic unit?
What is the temporal span of magmatism in the QMM? Are there magmatic differences over time that may shed light on evolving tectonism?

A broad range of disciplines may contribute to the resolution of these questions, including but not limited to: stratigraphy, paleontology, structural geology, geochronology, igneous and metamorphic petrology, isotope geochemistry, paleomagnetism, and airborne geophysics.

Fossil Floras of the Central Transantarctic Mountains

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The terrestrial rocks of the central Transantarctic Mountains have been a source of outstanding fossil discoveries, including both floras and faunas, for more than 30 years. Discoveries have ranged from in situ petrified forests to the first Jurassic dinosaur from the continent. The rare juxtaposition of sites that include many different types of plant preservation, the exceptional quality of the plant fossils, and the biodiversity at the sites makes this area unique in the world. Our laboratory has concentrated on the examination of fossil floras from the CTM, both because of this unique preservation and because of the age of the well-exposed rocks in this area. The Paleozoic/Mesozoic transition is an important time in the evolution of several groups, but was a particularly critical time in seed plant evolution, and some of the gymnosperm groups from this time have been suggested as angiosperm (flowering plant) ancestors. In addition, there was a massive floral turnover in Gondwana at the end of the Permian, paving the way for new groups to appear in the earliest Triassic. Fossil floras in the CTM are preserved primarily as compression remains, but there are sites that include permineralized peat deposits of Permian, Triassic and Jurassic age; petrified wood is also fairly common. Using data from these different preservational modes, we have contributed new information on seed plant evolution, including reconstructions of the major plant groups present in Antarctica during the Permian and Triassic. This work has been widely cited and has been utilized in building seed plant phylogenies.

In addition to studies on the evolution and diversity of fossil floras from the CTM, we have also been utilizing fossil plants as proxies for paleoclimate in the Permian and Triassic. The plants that thrived in Antarctica during these time periods were living at polar latitudes at a time of relative global warmth and high CO_2, an environment which does not exist today, but which is predicted for the future with continued global warming. Our studies of fossil tree rings from Permian and Triassic rocks in the CTM have raised a number of interesting questions about the standard paleoclimate models for these time periods, and more recent modeling has incorporated data from Antarctic fossil floras. In order to reconstruct past environments and the biota from these environments, it is important to include data from as many areas as possible. Thus, the data from fossil floras need to be placed in a detailed sedimentologic and paleoecologic framework, as well as integrated with data from fossil faunas and from trace fossils. The CTM is an ideal area in which to undertake this type of interdisciplinary work, as there are a number of researchers actively examining various aspects of past life and its environment. The Antarctic fossil plants represent a unique window into the biology of organisms that lived at high polar latitudes and an ecosystem that does not exist elsewhere on the Earth today.

State-of-the-art 4D Geospatial Technology to Support Geoscience Research in Antarctica

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High-accuracy and resolution remotely-sensed geospatial data are crucial to several mainstream international Antarctic research objectives, such as determining the tectonic evolution of Antarctica, rifting, and orogenesis, understanding how unique geologic processes occur, reconstructing the history of the ice sheets, understanding complex interactions within the biosphere and geosphere, and better comprehension of marine, terrestrial and freshwater ecosystems. Remote sensing techniques, repeated observations accumulated over long time periods, and modeling are appropriate tools to enhance this area of research. The primary objective of the proposed project is to introduce state-of-the-art geospatial infrastructure in Antarctica for supporting geoscience research activities, and to acquire authoritative information that documents its efficiency, accuracy, reliability and applicability in geospatial data collection and in near-real-time processing in the Antarctic environment. Our main thrust is to use airborne LiDAR (light detection and ranging), digital optical and multispectral sensors to snap the extraordinarily detailed 4D geospatial image that is necessary to capture the required level of time-space resolution that effectively addresses the research problems listed above. The 4th dimension is provided by the repeated time series of 3D data. This airborne sensor suite will be supported by a GPS/INS georeferencing module (Global Positioning System/Inertial Navigation System), and optimized to meet the needs of geoscience research in Antarctica. We could thereby record, e.g., the displacement fields, or other bio- or geosphere change in unprecedented detail, in hope of providing new insights into fundamental geophysical and environmental problems in Antarctica. Our primary goal is to provide the research community with leading-edge near real-time geospatial data products that will expand fundamental knowledge of the region, and foster research on global and regional problems of current scientific importance.

Antarctic Microbial Biogeography

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A perception exists that Antarctic terrestrial life is species poor and living on the edge. However, molecular diversity surveys of McMurdo dry valley sediments and soil indicate that these microbial communities are as species rich and dynamic as their temperate counterparts. Very little is known about the microbiota of Antarctic inland systems and presumably habitable regions are less widespread compared to the McMurdo dry valleys. In regions where water exists, even fleetingly, the Transantarctic Mountains may contain representatives of truly endemic Antarctic microorganisms. By comparing the genetic divergence and diversity of microbial communities at these inland oases to data from other Antarctic microbial surveys, the extent of habitability, dispersal, and diversification will emerge that will aid in defining the Antarctic microbial province.

Searching the Transantarctic Mountains for Late Permian Impact Evidence

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Several studies have proposed a large meteorite impact in Gondwana for the source of the greatest known extinction of life near the end of the Permian. However, remarkably few geological sections are complete enough to document events leading up to and across the extinction. Thus, the complete P-Tr terrestrial sections in the Beardmore Glacier region of the Transantarctic Mountains are critical to improving our understanding of this extinction event. Detailed stratigraphic studies of isolated Asian sections suggest that the P-Tr extinction involved two distinct events (e.g., Isozaki, et al., 2004). The Guadalupian-Lopingian extinction occurred first at roughly 260 Ma where up to 58% of marine genera disappeared (Stanley and Yang, 1994). About 5-10 million years later, the main extinction followed with the disappearance of up to 90% of marine life and about 75% of the terrestrial vertebrates, and plant life reduced mostly to the fungal stage. Thus, the search for meteorite evidence should consider the older rocks from near the beginning of the Guadalupian-Lopingian event (~ 260 Ma) and not simply focus on the younger stratigraphy of the maximum extinction (~ 250 Ma). Impact ejecta may masquerade as mudstone or tuff units so that available sections that span both extinction events need to be analyzed stratigraphically and chemically for shocked minerals, spherules and other signatures of impact. We review the P-Tr sections of the Transantarctic Mountains and related rock specimens maintained by the Antarctic Rock Repository at the Byrd Polar Research Center for hosting evidence of meteorite impact.

The Transantarctic Mountains

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Antarctica is considered a pristine environment and has low terrestrial species diversity and trophic complexity, and yet while scientifically possible, we still do not know the number of species in ice free regions, where they are, or how their influence on ecosystem processes (e.g., nutrient cycling, carbon flux, decomposition, feedbacks to climate, hydrology) will be affected by multiple global changes. Knowledge from ice-free coastal regions and the Dry Valleys show the biodiversity is undergoing rapid change, similar to changes occurring world-wide. Ecological communities of invertebrates to microbes exist in numerous microhabitats due to variation in geologic and climatic history. The scarce available evidence indicates habitats of rocky moraines, soils and cyroconite holes of glaciers in the continental interior may host not only microbes, but also complex algal and invertebrate communities.

To capture a true picture of how terrestrial Antarctic ecosystems function requires we clarify misconceptions about the lack of animals and cryptogamic plants and their habitats closer to the South Pole. We must not continue to perpetuate the notion that the interior of Antarctica has no animals, no plant forms and only microbes, when evidence is beginning to show otherwise. Antarctic terrestrial ecosystems are more than physiological objects of study, and the biodiversity of Antarctic lands, ice and seas is not isolated from the rest of the globe. They interact, influence and are influenced by other organisms, climate, atmosphere and geologic legacy. Changes to, and feedbacks from, terrestrial biodiversity and ecosystem functioning and their geologic habitats need to be, and can be, quantified in Antarctica more than any other continent, using combinations of techniques and models based on interdisciplinary research.

Among the ice-free areas in the interior of the continent are many geologic features of the Transantarctic Mountain Range, e.g., nunataks, ridges, and slopes, where “soil” is exposed for short times of the summer. Many of these soils and rocks may have structured communities that include lichens, cyanobacteria, invertebrates and microbes. The extent, location and variability of soil habitats needs to be assessed, because if climate warming increases ice melt in remote mountainous areas closer to the South Pole, ancient and new species of invertebrates may be revealed and changes may occur in the foodweb composition, soils and ecosystem processes. Newly exposed sites also will be prime areas for invasive species that may modify the environment in unpredictable ways. The effect of these global changes on biodiversity, range expansion, assembly, and ecosystem functioning can be documented and monitored.

One way to advance is to include scientists examining climatic, geological, geochemical, physical and biotic components that control the distribution and maintenance of ecosystems and their relation to other polar and warmer ecosystems. Scientists might propose to identify, quantify and link the geologic features and age, the soil C:N:P and the source of carbon, algae (net primary production), invertebrate species (their role in the trophic chain is generally known and they are easily identified), and microbes. An overall goal would be to describe the linkages of foodwebs of the interior at a few sites for soils, glaciers and aquatic habitats and through monitoring, models and syntheses determine how global changes impact Antarctic biodiversity and ecosystem function. This effort is urgently needed for understanding how present and future change in Antarctica will have impacts on human life elsewhere.

Thermal Regimes and Architecture of Rift-Platform Transitions
Inferred from Electrical Conductivity Structure

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Deformation of the continents is heterogeneous and reflects the interplay between force and strength. Variations of strength in both brittle and ductile regimes have fluid content and thermal contrasts as primary controls. These physical properties and other geochemical fluxes at crustal and upper mantle scales can be mapped according to their electrical conductivity using magnetotellurics (MT). Constraints on crust/mantle composition and thermal history narrow the possible physical states and fluid compositions inferred from imaged geophysical structure. Geochemical flow paths implied from geophysical structure can provide insight to fluid/magma conduits and ore deposition. Other mechanisms of high conductivity such as graphite can be discriminated according to macro-scale textures and external constraints on temperature and oxidation state. MT wavefields have distinct resolving kernels and provide complementary information about geochemical and geophysical state of the crust and upper mantle.

Two successful deployments of deep conductivity profiling within the Antarctic interior using the MT method took place in the 1990's. Novel developments in electrode preamp design were required to overcome the high contact impedance (up to 2 M-ohm) at the electrode-firn interface for the electric field component. The first profile deployment took place out of the central West Antarctica (CWA) camp in concert with seismic and potential field studies to assess the thermal regime there in extended West Antarctica. High crustal and upper mantle resistivities were imaged which are consistent with extension that is long inactive or amagmatic. The second MT experiment took place across the South Pole Station area to assess crustal structure and thermal regime in this high-standing area of East Antarctica. A conductive sedimentary section, possibly the Beacon Supergroup, immediately under the 3 km ice sheet was inferred, which showed pronounced lateral variations in thickness. The lowermost crust and uppermost mantle also are of high conductivity, which appears uniform over at least the 54 km profile length. This suggests an enhanced thermal regime for the South Pole region that may be influenced by plume processes implied in other studies. A strong, crustal-scale conductor running parallel to the acquired profile, and normal to the trend of the Trans Antarctic Mountains (TAM), also is imaged suggesting a fossil suture zone containing graphitized metasediments.

The West-East Antarctic transition across the TAM has sometimes been compared to the Great Basin-Colorado Plateau extensional transition zone (GCTZ) in the western United States. A recently completed MT transect some 500 km in length across the GCTZ reveals an enhanced thermal state of the Great Basin upper mantle, and active magmatic underplating to the crust under both the Great Basin proper and its transition. Great Basin upper mantle is highly anisotropic possible reflecting hydrated aligned olivine consistent with SKS splitting. Within the GCTZ itself, symmetric nested detachment-like structures are seen to sole into the conductive lower crust. These resemble fault structures developing in the early-middle stages of continental margin formation when the lower crust is weak but the upper mantle has significant strength (jelly sandwich model). Comparative studies of the TAM and GBCP where effective elastic strengths are quite different could illuminate the diversity of controls on dismemberment of continental interiors.

Controls on the Distribution of Productivity and Organic Resources in Antarctic Dry Valley Soils

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The Antarctic Dry Valleys are regarded as one of the harshest terrestrial habitats on Earth because of the extremely cold and dry conditions. Despite the extreme environment and scarcity of conspicuous primary producers, the soils contain organic carbon and heterotrophic micro-organisms and invertebrates. Potential sources of organic compounds to sustain soil organisms include *in situ* primary production by micro-organisms mosses, spatial subsidies from lacustrine and marine-derived detritus, and temporal subsidies from ancient lake deposits. The contributions from these sources at different sites are likely to be influenced by local environmental conditions, especially soil moisture content, position in the landscape in relation to lake level oscillations and legacies from previous geomorphic processes. In this presentation we will report in situ measurements of key biogeochemical processes in the carbon and nitrogen cycle (respiration, denitrification, methanogenesis) and complement these with laboratory investigations of nitrification and enzyme activities linked to the transformations of organic N, P and S containing compounds. We review the abiotic factors that influence biological activity in dry valley soils and present a conceptual model that summarises mechanisms leading to organic resources therein.

NZ Ice Core Programme in the Central Transantarctic Mountains

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The scientific goal of the NZ ice core programme is to improve our understanding of the major Southern Hemisphere climate drivers causing high frequency climate variability. These are in particular the El Niño Southern Oscillation, the Antarctic Oscillation, and the Antarctic Circumpolar Wave, as well as drivers and feedback mechanisms causing abrupt climate change. These climate drivers operate on relatively short time scales (sub-decadal) but also potentially respond to longer term forcing (centennial to millennial). It is therefore important to obtain high resolution (sub-annual) records that can reliably capture the high frequency variability of these drivers from sites that are particularly sensitive to their influence, and at the same time providing a long enough record to investigate superimposed longer-term

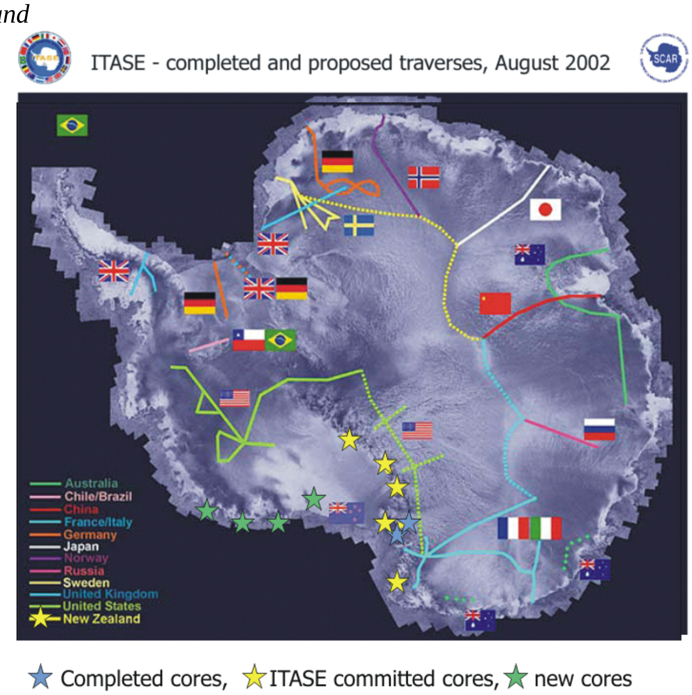
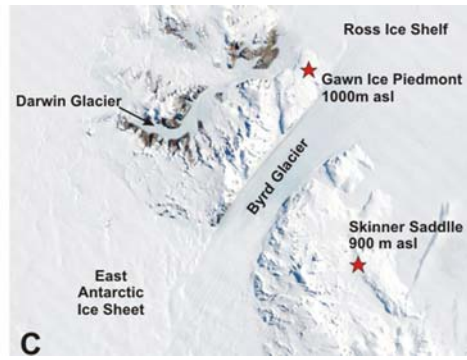


Figure 1: Overview of completed, committed and proposed NZ ice core sites

trends. ITASE focuses on the last 200 years and where possible longer. In addition, the International Partnership of Ice Coring Sciences (IPICS) has identified an array of 2000-year long records from especially coastal sites as one of four priorities for ice core research in the next 20 years.

In the Ross Sea region, we have identified key locations at low elevation, coastal sites that are particularly climate sensitive, as they capture tropospheric climate variability and in general have a higher snow accumulation rate than sites from the Antarctic interior. This makes these sites ideal when investigating decadal climate behaviour over millennial timescales. Drilling this season will recover 200-m cores from Erebus Saddle and near Cape Hallett to be analysed in our new ice core research facility.



In the next 2 years we plan to build an ice core drill capable of coring to ~700m with design support from our international collaborators for sampling future sites. This will be used for sites in the vicinity of Byrd Glacier (Skinner Saddle and Gawn Ice Piedmont), and near Beardmore Glacier (Giovinco Ice Piedmont, The Cloudmaker, and Haynes Table). All sites are expected to deliver records that meet the ≥200 year ITASE target and most are also likely to satisfy the IPICS target ≥ 2000 year records.

Cenozoic Landscape History of the Central Transantarctic Mountains

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The most significant phase in the formation of the Transantarctic Mountains most likely began around 50-55 Ma, judging from apatite fission-track age data. These indicate that relatively rapid denudation of the mountains dated from that time, with highest denudation rates on the eastern side of the range (Fitzgerald, 1994, 2002). Stern et al. (2005) have proposed that the unusually high relief found in the TAM (50% of peak elevation) compared with mountain ranges of similar elevation in lower latitudes (25% of elevation) is a consequence of a cold polar regime in late Neogene times during which mountains tops were frozen but the valley floors were continually eroded by wet-based outlet glaciers. This history does not sit easily with the Neogene sub-polar climate history implied by a floor of Beardmore Valley exposed in the Dominion Range at ~1800 m asl as indicated by the hardy vegetation, paleosols and fluvio-glacial sediments (Francis & Hill, 1996; Webb et al., 1996; Retallack et al., 2001).

Direct evidence of the age of rock surfaces in the Dominion Range suggests that these sediments are significantly older (Ackert & Kurz, 2004). Plainly further work is needed to establish the age of these deposits and the climatic regime they represent. This might include dating using the accumulation of ^{10}Be (see, for example, Graham et al., 2002) or using authigenic minerals in the sediments (eg. Dickinson & Rosen, 1997), currently being investigated. Cements in breccias beneath toreva blocks in the region (Elliot, 2002) might also be dated to establish the timing of these episodes of valley wall collapse in the region. These varied lines of geological evidence should be tested with modeling of ice flow through the central TAM under different temperature regimes as outlined by Barrett & Payne (2004).

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Terrestrial Biodiversity of the Trans Antarctic Mountains (Ross Dependency)

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Terrestrial biodiversity studies have, in recent years, been concentrated in the vicinity of Ross Island. Although this was a consequence of the location of transport logistics it has had a somewhat unfortunate consequence in that the Ross Island and Dry Valley areas have become accepted as being the norm for Victoria Land. In fact, the Dry Valleys are one of the driest places in the world and, as a result, have a much reduced biota, especially the lichen and moss flora. At present about 16 species of lichens are known from the Dry Valleys but over 30 at Granite Harbour, just to the north. It has been accepted that there is a major cline in biodiversity in Antarctica with numbers of mosses and lichens falling from about 80/300, respectively, in the northern Peninsula to 7/31 at Granite Harbour and 4/16 in the Dry Valleys. The low number of species in the Ross Island vicinity has led to a general belief that only very low biodiversity exists further south, a zone that remains relatively unreported for lichens, mosses and invertebrates.

It now appears that this might be a false assumption. In the 1960s several areas were visited as far south as 86^{o} along the Ross Ice Shelf margin in Southern Victoria Land. These visits often reported considerable amounts of lichen, moss and invertebrates, although the latter were much harder to find (e.g. Cawley and Tyndale-Biscoe 1960). In January 2003, a party from Waikato University visited Mt. Kyffin, Beardmore Glacier. At 83^{o} 45' S this site is well south of expected rich plant communities. However, the results were surprising with considerably more species of lichen being found than previously expected. In total, 26 species were found and of these species only 7 were already known from that far south. Of the remainder, 5 species were known from Northern Victoria Land, 4 from the Antarctic Peninsula and 6 were new to Antarctica (another 4 remain to be identified). This is an exceptional result that has lead to the generation of several new hypotheses. The previously reported invertebrates (mites, springtails) were also found as well as *Scottnema lindsayae* (Nematoda) not previously known to have a distribution so far to the south (Adams et al. submitted ms). Analyses of genetic variability for all species are ongoing, although it is expected that these too will reveal higher than expected levels of diversity.

These southern locations are obviously very suitable for lichens and invertebrates and the concept of a continuous, large-scale cline in climate and biodiversity along the Ross Sea coast may be questionable. Instead, microclimates may dominate and that the local occurrence of water controls productivity of these organisms. However, similar warm microhabitats occur further north and, apparently, do not support this biodiversity. Accordingly, we hypothesise that the biota at these extreme southern sites, are relict communities that have remained since the polar glaciers started to form the Ross Ice Shelf. If this is so then estimates of genetic divergence relative to other taxa may reveal the actual period that these species have been isolated. Regardless, the specimens will be valuable additions to molecular inventories.

Our current proposal (approved by Antarctica New Zealand) is to visit sites to the south of Mt Kyffin including Barrett Glacier (south of Shackleton Glacier). However, the area to the north of Mt Kyffin is virtually unexplored biologically and would benefit from immediate biological survey. Several discontinuities in plant and invertebrate species distributions between the "deep" south (e.g. Shackleton and Beardmore Glacier vicinities) and sites to the north (e.g. McMurdo Dry Valleys) will only be resolved by further sampling. The existence of previously unrecorded and/or unknown plant and animal life in this region is extremely likely. Multidisciplinary approaches (e.g. including biologists, earth scientists etc.), will be extremely valuable to elucidate patterns and processes responsible for the present-day distribution of species and evolution of the Antarctic landscape. Existing international collaborators include Diana Wall (US), Rod Seppelt (Australia), Roman Tuerk (Austria), Leo Sancho (Spain) and Paul Hebert (Canada).

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