Exploring under the East Antarctic Ice Sheet with new aerogeophysical surveys over the Wilkes Subglacial Basin, the Transantarctic Mountains and Dome C

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Summary As we enter the IPY geological boundary conditions for the stability of the East Antarctic Ice Sheet (EAIS) remain largely unknown. During the 2005/06 field season a major new aerogeophysical survey was performed over the Wilkes Subglacial Basin, the Transantarctic Mountains and Dome C. Over 60,000 km of new airborne radar, aeromagnetic and aerogravity data were collected. We will describe the survey layout and methodologies and present new geophysical images as a tool to address the highly contentious stability of the EAIS during warmer than present palaeoclimates, the underlying crustal structure, and to study subglacial lakes.

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New aerogeophysical survey

An extensive aerogeophysical investigation was flown over East Antarctica during the 2005/06 Antarctic field-campaign as part of two collaborative UK-Italian projects: *ISODYN* (*I*cehouse Earth: *S*tability *O*r *DYN*amism?) and *WISE* (Wilkes *WI*lkes Basin/Transantarctic Mountains *S*ystem *E*xploration). The *Programma Nazionale di Ricerche in Antartide* (PNRA) and the *British Antarctic Survey* (BAS) jointly supported the ISODYN/WISE survey. Our new survey area is shown in Figure 1. It covers part of the Wilkes Subglacial Basin (Drewry, 1976; Steed, 1983; ten Brink et al., 1997; Ferraccioli et al., 2001; Studinger et al., 2004) and several tectonic blocks over the adjacent Transantarctic Mountains (e.g. Van der Wateren and Cloetingh, 1999). It also extends to the western Ross Sea Rift (e.g Davey and Brancolini, 1995) and to Dome C.

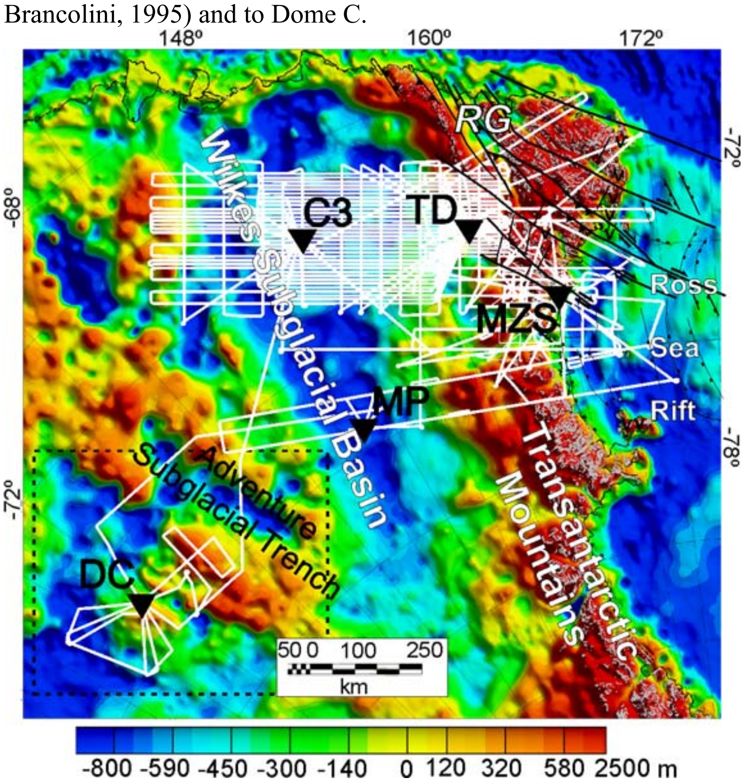

Figure 1. Location of the new ISODYN/WISE aerogeophysical survey superimposed upon BEDMAP topography for the Wilkes Subglacial Basin and Transantarctic Mountains. Dashed box shows extent of Figure 3.

Over 60,000 line km of new data were collected during 68 survey flights over an area of 767,300 km^2. The survey included transects and a more detailed grid with line spacing of 8.8 km and tie line interval of 44 km (Fig. 1). This represents the largest aerogeophysical survey ever flown by BAS over Antarctica. PNRA provided all the logistic support and fuel at Mario Zucchelli Station (MZS in Fig. 1), at two remote field camps over the EAIS, namely Talos Dome (TD) and Sitry (C3), and at Mid-Point (MP). Additional support and fuel was provided by PNRA and the French Antarctic Programme at Dome Concordia (DC). This survey leg was part of a separate trilateral UK/Italian and French agreement to characterise some of the subglacial lakes of the Dome C region (Seigert et al., 2005). The airborne survey platform was a BAS Twin Otter, fully equipped with airborne radar, aeromagnetic and airborne gravity sensors.

Survey aims

The UK component of the aerogeophysical survey aims to provide new boundary conditions to input into coupled ice sheet and palaeoclimate models, as part of the interdisciplinary BAS GEACEP (*Greenhouse to Ice-house Evolution of the Antarctic Cryosphere & Palaeoenvironment*) research Programme. We aim to utilise combined data assimilation, validation and modelling approaches to: 1) offer a new angle to the debate on the contentious stability or dynamism of the EAIS during warm periods in the Neogene (Miller and Mabin, 1998 and references therein) and 2) to investigate the mechanisms, which led to the transition between greenhouse and icehouse conditions at the Eocene/Oligocene boundary (e.g. DeConto and Pollard, 2003). The Italian component aims to investigate the controversial crustal architecture and tectonic evolution for the Transantarctic Mountains and Wilkes Subglacial Basin. The collaborative UK-Italian and French effort over Dome C will utilise the new and previous aerogeophysics to study the geological and glaciological setting of a major Antarctic subglacial lake district (Tabacco et al., 2006).

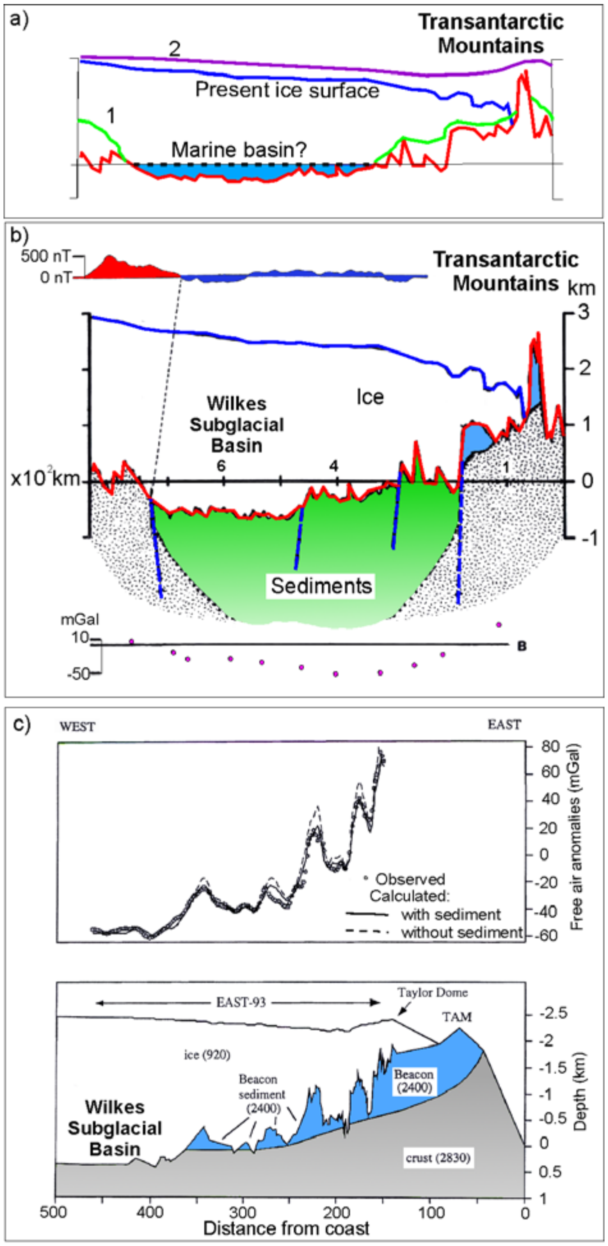

Figure 2. a) Dynamists for the EAIS predict that Pliocene(?) marine diatoms of the Transantarctic Mountains were glacially transported from their source region, the deglaciated Wilkes Subglacial Basin (e.g. Webb et al., 1984). This would imply a significant collapse (1) and re-advance of the EAIS (2), but this has been strongly contested by the so called stabilists for the EAIS (e.g. Sugden et al., 1995); b-c) Two contrasting geophysical models for the Wilkes Subglacial Basin predicting that the basin is indeed a major sedimentary basin (Drewry, 1976) or a glaciated flexural depression with no sedimentary infill (ten Brink et al., 1997).

Imaging subglacial topography for the Wilkes Subglacial Basin

There are several requirements for coupled ice sheet/palaeoclimate models addressing the contentious stability of the EAIS during warm periods in the Cenozoic (Haywood et al., 2002). First, it is necessary to have accurate subglacial topography to run reliable predictive ice sheet/palaeoclimate models. Second, we need to know more about the basal geological boundary conditions, which may influence ice flow and stability (Bamber et al., 2006). Third, the model predictions need to be validated against geological evidence.

Bedrock topography for Antarctica has been compiled within BEDMAP (Lythe et al., 2001). The data over the Wilkes Sublglacial Basin and Transantarctic Mountains were mainly derived from two reconnaissance surveys flown in the 70's utilising a long-range aircraft, which covered a huge area of 900,000 km^2 (Steed and Drewry, 1982). The line spacing was coarse, typically 50 to 100 km. The BEDMAP compilation depicts the Wilkes Subglacial Basin as a broad depression running in the hinterland of the Transantarctic Mountains from George V Land, where the basin appears to be about 400 km wide, and gradually narrowing to less than 100 km at 85ºS (Fig. 1). More recent airborne radar data across the Wilkes Subglacial Basin have been collected as part of the US/Italian aerogeophysical traverse (AEROTAM) from McMurdo to Dome C (Studinger et al., 2004). A major basin is not clearly defined from these more recent data. Does the Wilkes Subglacial Basin even exist? Recent BAS airborne radar data over Coats Land (East Antarctica) have shown that in regions where data coverage is sparse subglacial topography may differ significantly from continental-scale data gap interpolations (Bamber et al., 2006). We are currently processing 7 Tera-Bytes of new ISODYN/WISE radar data over the Wilkes Subglacial Basin and Transantarctic Mountains to image subglacial topography over the region to an unprecedented accuracy and resolution. We also aim to merge our higher resolution data with BEDMAP and the AEROTAM dataset to allow new, coupled EAIS/climate models to be run.

Are there sediments in the Wilkes Subglacial Basin?

Establishing if thick sediments are likely or unlikely to occur in the Wilkes Subglacial Basin is key to assess whether there were significant deglaciations of the EAIS and marine incursions (Fig. 2a) during the Late Miocene and warm mid-Pliocene, as proposed by the dynamists (e.g. Webb et al., 1984), or vice versa, if the ice sheet was stable (e.g. Sugden et al., 1995). This is an essential geological boundary condition for models addressing the stability of the ice sheet during warms periods in the Neogene, and by analogy in the warmer that present future (Haywood et al., 2002). Aeromagnetic data provide a tool to estimate depth to magnetic basement, which is a proxy for the thickness of sedimentary infill within basins. This technique has successfully imaged major sedimentary basins beneath both the West and the East Antarctic Ice Sheet (Bell et al., 2006; Bamber et al., 2006). Although aeromagnetics alone cannot provide the ages for the sediments, there are clear magnetic signatures associated to Jurassic sills over both the Transantarctic Mountains and Wilkes Subglacial Basin (Ferraccioli and Bozzo, 1999; Studinger et al., 2004). Hence thick post-Jurassic sedimentary infill can be inferred, if it exists. We will use a combination of aeromagnetic, airborne gravity and airborne radar data to assess if the Wilkes Subglacial Basin is indeed a sedimentary basin (Fig. 2b), as first proposed by Drewry (1976), or if it is instead a glaciated flexural depression (Fig. 2c) with little to no sedimentary infill (ten Brink et al., 1997). Independent seismological, magnetotelluric and Geomagnetic Depth Sounding data were also acquired and may assist in determining whether or not the Wilkes Subglacial Basin is a major sedimentary basin.

Origin of the Wilkes Subglacial Basin and its relationship with the Transantarctic Mountains

Several hypothesis have recently been forward for the tectonic origin of the Wilkes Subglacial Basin: 1) a glaciated depression induced by flexural uplift of the Transantarctic Mountains (ten Brink et al., 1997); 2) a fault-bounded "extended terrane" (Ferraccioli et al., 2001); 3) a transtensional basin, linked to Cenozoic strike-slip motion between East and West Antarctica (Ferraccioli and Bozzo, 2003); 4) a Cretaceous(?) en-echelon tectonic structure of the Rennick Graben (RG) of Northern Victoria Land (Fitzgerald, 2002); 5) a compressional feature (Studinger et al., 2004). A combination of aerogravity and aeromagnetic data analysis will be used to validate or refute these previous hypotheses, or to propose new models.

Tectonic segmentation of the Transantarctic Mountains

Major faults have been inferred to separate tectonic blocks of the Transantarctic Mountains (Fig. 1). Most of these faults are buried beneath glaciers. Our new aeromagnetic imaging will trace faults from their exposed segments to ice-covered regions (e.g. Ferraccioli and Bozzo, 1999; Ferraccioli and Bozzo, 2003). Airborne gravity and airborne radar data will be a tool to develop new models addressing differential uplift for the Transantarctic Mountains (e.g. Stern et al., 2005). Our aeromagnetic data interpretation will target the role of inheritance in mountain uplift and tectonic segmentation (e.g. Salvini et al., 1997; Ferraccioli and Bozzo, 1999). This will enhance our understanding of the tectonic development, and will provide more quantitative constraints to investigate forcing and feedbacks mechanisms between mountain uplift, EAIS dynamics and Cenozoic paleoclimate (e.g. Van der Wateren and Cloetingh, 1999; Haywood et al., 2002).

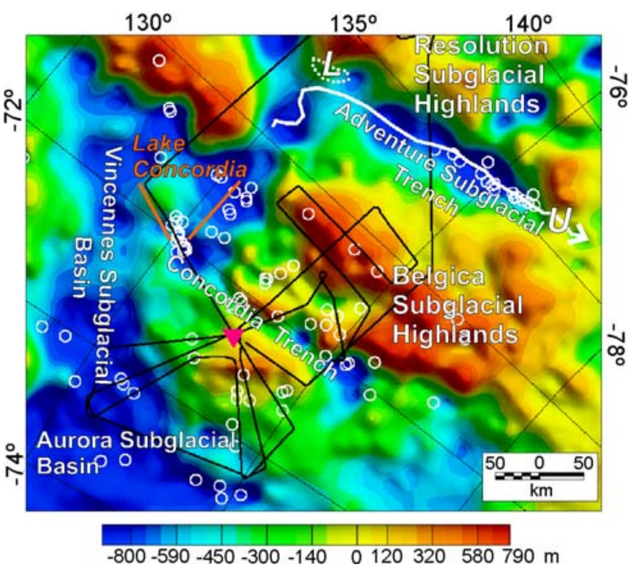

Figure 3. ISODYN/WISE flight lines (black) superimposed on bedrock topography for the Dome C subglacial lake district. Note the lakes (white circles) and the cluster of lake-like reflectors over Lake Concordia (Tikku et al., 2005). Red triangle marks Dome C. Solid white line shows the direction of water flow, connecting subglacial lakes within the Adventure Subglacial Trench (Wingham et al., 2006).

Geological boundary conditions for subglacial lakes

The Dome C survey leg (Fig. 3) was flown to provide a new aerogeophysical window on geological boundary conditions for the Dome C subglacial lake district (Tabacco et al., 2006). For example, what are the interplays between geology and tectonics, and the different types of lakes recently identified (Tabacco et al., 2006; Carter et al., 2007), if any? And what are the possible controls on the subglacial hydrology, which appears to connect some of these subglacial lakes, e.g. in the Adventure Subglacial Trench region (Wingham et al., 2006)? Contrasting tectonic origins (extensional vs. compressional) have been suggested for the Adventure trench and the adjacent Wilkes Subglacial Basin (Ferraccioli et al., 2001; Studinger et al., 2004). Catastrophic floods from subglacial lakes could have reached the margin of the East Antarctic Ice Sheet in the mid-Miocene, as indicated by geomorphical features over the Transantarctic Mountains (Lewis et al., 2006). These huge floods may have released such large volumes of meltwater into the Ross Embayment, to impact the stability of the Antarctic cryosphere and paleoclimate evolution (Lewis et al., 2006). Hence gaining an improved understanding of the links between subglacial lake systems, geology, tectonics and palaeoclimate is highly timely.

Conclusion

Over 60,000 line km of new airborne geophysical data have been collected in East Antarctica over the Wilkes Subglacial Basin and adjacent Transantarctic Mountains. We will present preliminary geophysical images resulting from these new data as a tool to re-address the stability the EAIS, regional crustal architecture, and geological boundary conditions for subglacial lakes.

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References

Bamber, J.L., F. Ferraccioli, I. Joughin, T. Shepherd, D.M. Rippin, M.J. Siegert, and D.G. Vaughan (2006), East Antarctic ice stream tributary underlain by major sedimentary basin. Geology, 34(1), 33-36; doi: 10.1130/G22160.1.

Bell, R.E., M. Studinger, G. Karner, C.A. Finn, and D.D. Blankenship (2006), Identifying major sedimentary basins beneath the West Antarctic Ice Sheet from aeromagnetic data analysis, in Antarctica: Contributions to Global Earth Sciences, edited by D.K. Fütterer, D.D. Damaske, D. Kleinshmidt, H. Miller, and F. Tessensohn, pp. 117-122, Springer-Verlag, Berlin Heidelberg New York.

Carter, S.P., D.D., Blankenship, M.E., Peters, D.A., Young, J.W., Holte, and D.L., Morse (2007), Radar-based subglacial lake classification in Antarctica. Geochemistry, Geophysics, Geosystems, 8, doi:10.1029/2006GC001408.

Davey, F.J., and G. Brancolini (1995), The Late Mesozoic and Cenozoic structural setting of the Ross Sea region, in Geology and Seismic Stratigraphy of the Antarctic Margin, Antarctic Research Series, 68, edited by A.K., Cooper P.F., Barker, and G. Brancolini, pp 167-182, AGU, Washington D.C.

DeConto, R. M., and D. Pollard (2003), Rapid Cenozoic glaciation of Antarctica induced by declining atmospheric CO_2. Nature, 421, 245-249.

Drewry, D.J. (1976), Sedimentary basins of the East Antarctic Craton from geophysical evidence. Tectonophysics, 36, 301-314.

Ferraccioli, F., and E. Bozzo (1999), Inherited crustal features and tectonic blocks of the Transantarctic Mountains: an aeromagnetic perspective (Victoria Land-Antarctica). J. Geophys. Res., 104, 25,297-25,319.

Ferraccioli F., F. Coren, E.Bozzo, C.Zanolla, S.Gandolfi, I. Tabacco, and M. Frezzotti (2001), Rifted(?) crust at the East Antarctic Craton margin: gravity and magnetic interpretation along a traverse across the Wilkes Subglacial Basin region. Earth. Planet. Sci. Lett., 197, 407-421.

Ferraccioli, F., and E. Bozzo (2003), Cenozoic strike-slip faulting from the eastern margin of the Wilkes Subglacial Basin to the western margin of the Ross Sea Rift: an aeromagnetic connection, in Intraplate strike-slip deformation belts, edited by F. Storti, R.E. Holdsworth, and F. Salvini pp 109-133, Geological Society, London, Special Publications, 210.

Fitzgerald P. (2002), Tectonics and landscape evolution of the Antarctic plate since the breakup of Gondwana, with an emphasis on the West Antarctic Rift System and the Transantarctic Mountains, in Antarctica at the close of a millenium. Proceedings of the 8th International Symposium on Antarctic Earth Sciences, edited by Gamble J.A., D.N.B. Skinner, and S. Henrys pp 453-469, Royal Society of New Zealand Bulletin, 35, SIR publishing.

Haywood, A.M., P.J. Valdes, B.W. Sellwood, and J.O. Kaplan (2002), Antarctic climate during the middle Pliocene: model sensitivity to ice sheet variation. Palaeogeography, Palaeoclimatology, Palaeoecology, 182, (1-2), 93-115.

Lewis A. R., D. R. Marchant, D.E. Kowalewski, S.L. Baldwin, and L.E. Webb (2006), The age and origin of the Labyrinth, western Dry Valleys, Antarctica: evidence for extensive middle Miocene subglacial floods, and freshwater discharge to the Southern Ocean. Geology, 34(7), 513-516, doi: 10.1130/G22145.1

Lythe M.B., D.G.Vaughan, and the BEDMAP Consortium (2001), BEDMAP, a new ice thickness and subglacial topographic model of Antarctica. J. Geophys. Res., 106, 11335-11351.

Miller, M. F., and M.C.G. Mabin (1998) and ref. therein, Antarctic Neogene landscapes- In the refrigerator or in the deep freeze?. GSA Today, 8(4), 1-8.

Salvini, F., G. Brancolini, M. Busetti, F. Storti, F. Mazzarini, and F. Coren (1997), Cenozoic geodynamics of the Ross sea region, Antarctica: crustal extension, intraplate strike-slip faulting and tectonic inheritance. J. Geophys. Res., 102, 24,669-24,696.

Siegert M. J., S. Carter, I.E. Tabacco, S. Popov, and D.D. Blankenship (2005), A revised inventory of Antarctic subglacial lakes, Antarctic Science, 17(3), 453−460.

Steed R.H.N., and D.J. Drewry (1982), Radio-echo sounding investigations of Wilkes Land, Antarctica, in Antarctic Geoscience edited by C. Craddock, pp 969-975, The University of Wisconsin Press, Madison.

Steed R.H.N., (1983), Structural interpretation of Wilkes Land, Antarctica, in Antarctic Earth Science, edited by R.I. Oliver, P.R. James, and J.B. Jago pp 567-572, Cambridge University Press, New York.

Stern T.A., A.K. Baxter, and P.J. Barrett (2005), Isostatic rebound due to glacial erosion within the Transantarctic Mountains. Geology, 33(3), 221–224, doi: 10.1130/G21068.1.

Studinger, M., R.E. Bell, W.R. Buck, G.D. Karner, and DD. Blankenship (2004), Sub-ice geology inland of the Transantarctic Mountains in light of new aerogeophysical data. Earth Planet. Sci. Lett., 220, 391–408.

Sugden, D.E., G.H. Denton, and D.R. Marchant (1995), Landscape evolution of the Dry Valleys, Transantarctic Mountains: tectonic implications. J. Geophys. Res., 100, 9949-9967.

Tabacco I.E., P. Cianfarra, A. Forieri, F. Salvini, and A. Zirizotti (2006), Physiography and tectonic setting of the subglacial lake district between Vostok, and Belgica subglacial highlands (Antarctica). Geophys. J. Int., 165, 1029-1040.

ten Brink U.S., R.I. Hackney, S. Bannister, T.A. Stern, and Y. Makovsky (1997), Uplift of the Transantarctic Mountains and the bedrock beneath the East Antarctic ice sheet. J. Geophys. Res.,102, 27 603-27 621.

Tikku A.A., R.E. Bell, M. Studinger, G. K.C. Clarke, I. Tabacco, and F. Ferraccioli (2005), Influx of meltwater to subglacial lake Concordia, East Antarctica. Journal of Glaciology, 51(172), 96-104.

Van der Wateren F.M., and S.A.P.L. Cloetingh (1999), Feedbacks of lithosphere dynamics and environmental change of the Cenozoic West Antarctic Rift System. Global and Planetary Change, 23, 1-24.

Webb, P.N., D.M. Harwood, B.C. McKelvey, J.H. Mercer, and Stott L.D. (1984), Cenozoic marine sedimentation and ice volume variation on the East Antarctic craton. Geology, 12, 287-291.

Wingham D.J., M.J. Siegert, A. Shepherd, and A.S. Muir (2006), Rapid discharge connects Antarctic subglacial lakes. Nature, 440, 1033-1036.