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Recent Thermochronological Research in Northern Victoria Land, Antarctica

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Abstract: Northern Victoria Land forms a segment of the Transantarctic Mountains in the western Ross Sea that is characterized by extreme landscape contrasts. A high Alpine coastal morphology developed in immediate vicinity to high-elevated inland plateaus and deep, structurally defined glacial troughs. Recent thermochronological research during the last five years discovered that the whole region was occupied by a Mesozoic sedimentary basin. This recognition requires future thermochronological research to focus on five main objectives: (1) More and better data, new and complementary techniques, and quantitative modelling, (2) evolution of the Mesozoic Victoria Basin on the continental crust of SE Australia and the western Ross Sea, (3) Passive margin formation versus West Antarctic rifting, (4) timing and amount of the final exhumation and uplift of the Transantarctic Mountains since the Eocene/Oligocene, and (5) Landscape contrasts in northern Victoria Land resulting from the interplay between climate, tectonics and lithology. This paper also gives an overview of thermochronological field work during expedition GANOVEX X und reviews subsequent research in the Terra Nova Bay region, were up to 1.1 km thick post-Ferrar sediments were deposited between ~180 and ~35 Ma.

Zusammenfassung: Das nördliche Victoria Land bildet ein Segment des Transantarktischen Gebirges im westlichen Ross-Meer das durch extreme Landschaftskontraste gekennzeichnet ist. Einer hochalpinen Küstenmorphologie stehen landeinwärts in unmittelbarer Nähe tief eingeschnittene Hochlandplateaus mit tiefen, strukturell kontrollierten glazialen Trögen gegenüber. Thermochronologische Studien der letzten fünf Jahre belegen dass die gesamte Region von einem mesozoischen Sedimentbecken bedeckt war. Diese Erkenntnis erfordert weitere thermochronologische Untersuchungen mit besonderem Fokus auf fünf Schwerpunkten: (1) Mehr und bessere Daten, Einsatz neuer und komplementärer Techniken und quantitative Modellierungen, (2) Bildung des mesozoischen Victoriabeckens auf der kontinentalen Kruste SE Australiens und des westlichen Ross-Meers, (3) Entwicklung des passiven Kontinentalrands versus Rifting des Westantarktischen Riftsystems, (4) zeitlicher Verlauf und Betrag von finaler Exhumierung und Hebung des Transantarktischen Gebirges seit dem Eozän/Oligozän und (5) Landschaftskontraste im nördlichen Victoria Land resultierend aus der Wechselwirkung von Klima, Tektonik und Lithologie. Der Artikel gibt auch einen Überblick über die thermochronologische Feldarbeit während der Expedition GANOVEX X und die anschließende Erforschung der Terra Nova Bucht, in der zwischen ~180 und ~35 Ma bis zu 1.1 km mächtige post-Ferrar-Sedimente abgelagert wurden.

INTRODUCTION

Northern Victoria Land forms the northernmost segment of the Transantarctic Mountains in the Ross Sea sector of Antarctica (Fig. 1A). The region occupies a crucial position in the context of both the Gondwana breakup between Antarctica and Australia and the subsequent uplift of the Transantarctic Mountains since it is located at the intersection of two continental-scale crustal structures: the passive continental margin in the north and the Cenozoic West Antarctic Rift System in the east (Fig. 1A). Its basement comprises lithological units of different rheological and erosional competence (Wilson Terrane versus Bowers and Robertson Bay terranes). It exposes the transition between two contrasting landscape styles: high-standing plateaus towards the continental interior versus coastal Alpine geomorphology, and a broad spectrum of thermal indications has been recognized here (Fig. 2).

This constellation has placed the region in the focus of numerous uplift and exhumation studies during the last two decades. Since the post-Jurassic tectonic history of the Transantarctic Mountains is not recorded by petrological or stratigraphic evidence, this research chiefly relies on thermochronological, structural and geophysical data, geomorphological observation and on the sedimentary record of adjacent offshore basins and troughs. Two decades of thermochronological investigation produced large apatite fission track (FT) datasets obtained from vertical profiles and single samples from various parts of northern Victoria Land by FITZGERALD & GLEADOW (1988), BALESTRIERI et al. (1994, 1997, 1999), LISKER (1996), SCHÄFER (1998), BALESTRIERI & BIGAZZI (2001), ROSSETTI et al. (2003, 2006), LISKER et al. (2006), and STORTI et al. (2008). The range of both apatite FT ages (~30 to ~250 Ma) and proxies (mean track lengths usually <14 μm, with standard deviations >1.5 μm) coincides with the general FT data pattern throughout the Transantarctic Mountains.

Accordingly, the established uplift concept of the Transantarctic Mountains (summarized by FITZGERALD 2002 and LISKER 2002) was also applied to northern Victoria Land. It comprises three cooling stages due to exhumation (denudation) and associated uplift during the Early Cretaceous, Late Cretaceous, and Cenozoic (Fig. 1B). The exhumation episodes have been related to regional rifting events: (I) the initial breakup between Australia and Antarctica, (II) the main extension phase between East and West Antarctica along low-angle extensional faults; and (III) southward propagation of seafloor spreading from the Adare Trough into continental crust underlying the western Ross Sea in the early Cenozoic (cf. FITZGERALD 2002). This traditional interpretation of regionally consistent stepwise exhumation since the Early Cretaceous appears well in agreement with present structural and geophysical data, and seems to be consistent for the majority of the sampled apatite FT locations when considered separately.

However, the paradigm fails to explain the substantial variation of timing and amount of exhumation between the different segments of the Transantarctic Mountains despite the uniform distribution of marker horizons (stratigraphic units,

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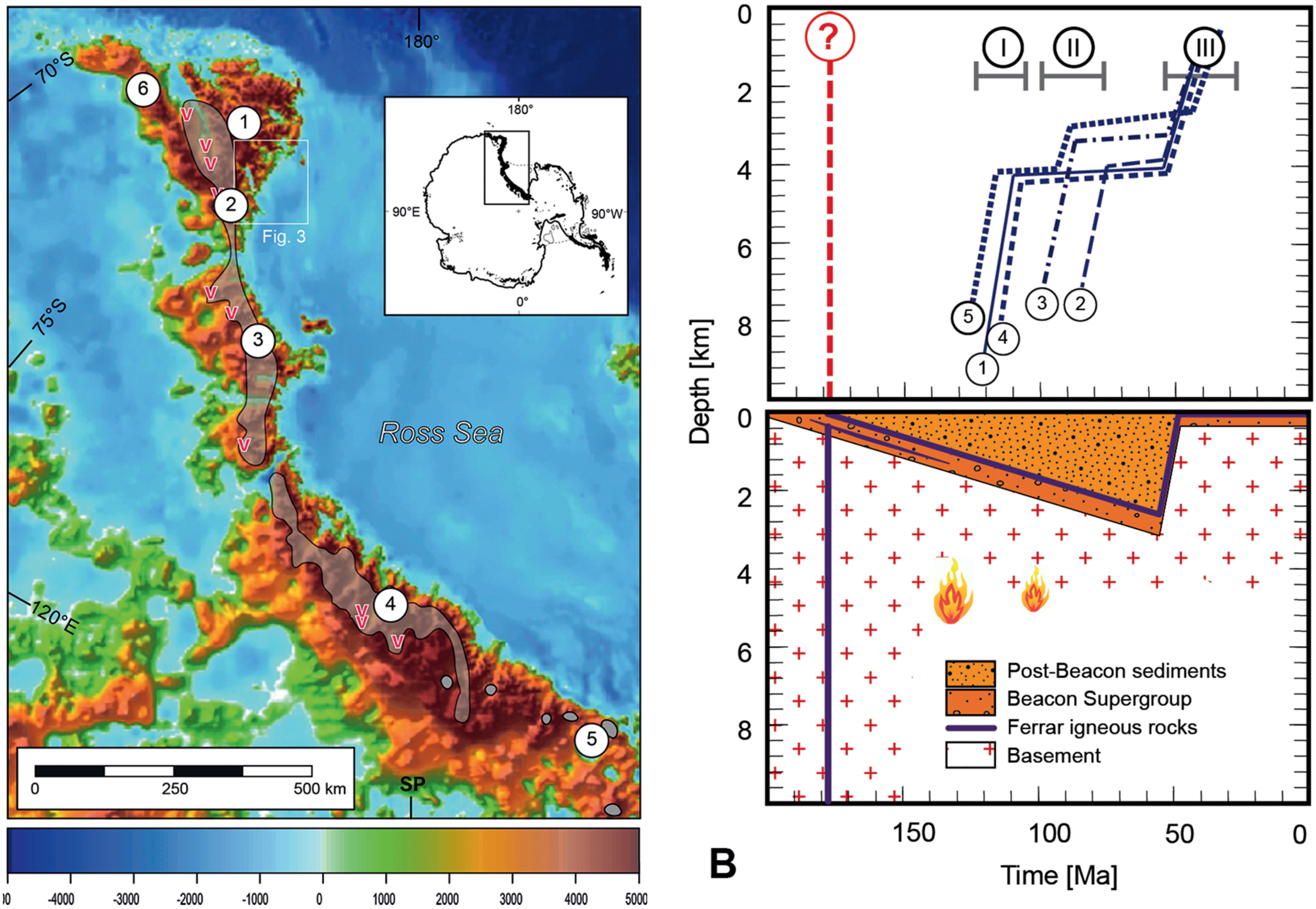

Fig. 1: A: Topographic and bathymetric map of part of Transantarctic Mountains and Ross Sea (from Lisker & Läufer 2013). The transparent grey overlay shows the distribution of Beacon Supergroup and Jurassic Ferrar igneous rocks, with the red symbol "v" indicating the occurrence of Ferrar lava flows and volcanoclastics (after Elliot & Fleming 2008). Both Beacon sediments and volcanic rocks are crucial paleosurface indicators. Numbered circles mark the target areas of exhumation studies based on apatite fission track (FT) data: (1) Fitzgerald & Gleadow (1988), (2) Balestrieri et al. (1994, 1997), (3) Gleadow & Fitzgerald (1987), (4) Fitzgerald (1994), (5) Fitzgerald & Stump (1997), (6) Lisker et al. (2006). The Inset shows the location of the region within Antarctica. **B:** Schematic diagram showing the contrasting burial and exhumation scenarios for the Transantarctic Mountains. Numbers in the figure refer to locations in map. Top = traditional scenario of monotonous cooling/exhumation in three episodes since the Jurassic (modified after Fitzgerald 2002). The question mark at 180 Ma indicates that this concept does not consider the age crossover between Ferrar emplacement and early Cenozoic cooling/exhumation. Note also the diachronous course and the missing structural trend of the "exhumation" paths. Bottom = formation of the Mesozoic Victoria Basin and Cenozoic cooling/exhumation based on the relationship between timing of Ferrar effusion (red stippled line) and apatite fission track data (Lisker & Läufer 2013). Maximum burial depth, heatflow, and timing of exhumation may vary along the Victoria Basin.

Abb. 1: A: Ausschnitt aus topographischer und bathymetrischer Karte von Transantarktischem Gebirge und Rossmeer (aus Lisker & Läufer 2013). Der transparent grau schattierte Bereich zeigt die Verteilung von Beacon Supergruppe und jurassichen Ferrar-Magmatiten, das rote „v"-Symbol steht für Ferrar-Laven und Vulkanoklastiten (nach Elliot & Fleming 2008). Beacon-Sedimente und -Vulkanite sind nachdrückliche Beweise von Paläo-Oberflächen. Die nummerierten Kreise markieren die Untersuchungsgebiete früherer Exhumierungsstudien auf der Grundlage von Apatit-Spaltspurendaten (FT): (1) Fitzgerald & Gleadow (1988), (2) Balestrieri et al. (1994, 1997), (3) Gleadow & Fitzgerald (1987), (4) Fitzgerald (1994), (5) Fitzgerald & Stump (1997), (6) Lisker et al. (2006). Das Inset zeigt die Lage der Region innerhalb der Antarktis. **B:** Übersichtsdiagramm der kontrastierenden Versenkungs- und Exhumierungsszenarien für das Transantarktische Gebirge. Die Ziffern in der Abbildung beziehen sich auf die Lokationen der nebenstehenden Karte. Oben = traditionelles Szenario monotoner Abkühlung/Exhumierung in drei Episoden seit dem Jura (modifiziert nach Fitzgerald 2002). Das Fragezeichen bei 180 Ma unterstreicht dass dieses Konzept die Altersüberschneidung von Ferrar-Vulkanismus und känozoischer Abkühlung/Exhumierung nicht berücksichtigt. Beachtung verdienen auch diachroner Verlauf und fehlender struktureller Trend der „Exhumierungs-Pfade". Unten = Ausbildung eines Mesozoischen Viktoriabeckens und känozoische Abkühlung/Exhumierung basierend auf Zeit der Ferrar-Effusion (rote gestrichelte Linie) und Apatit-Spaltspurendaten (Lisker & Läufer 2013). Maximale Versenkungstiefe, Wärmefluss und Exhumierungszeiten können innerhalb des Viktoriabeckens variieren.

erosion surfaces), and the lack of spatial correlation with the loci of tectonic activities (Fig. 1A). It also does not account for thermochronological age data from the Transantarctic Mountains front that are substantially younger than the latest of the postulated cooling/exhumation episodes (e.g., Fitzgerald & Gleadow 1988, Balestrieri et al. 1994, 1997, Fitzgerald et al. 2006). Most importantly, the recent recognition of crossover age relationships between vertical apatite FT age profiles and the effusion age of Ferrar volcanic and volcanoclastic rocks reveals that the postulated uplift/exhumation history bases on a self-contradiction (Lisker & Läufer 2013). Instead, the regional compilation of thermochronological and stratigraphic data, the broad range of Late Jurassic-Cretaceous paleotemperatures between 60 and 340 °C derived from various geochronological, magnetic, mineralogical, and petrographic studies (Fig. 2 and references below), the diachronous timing of the thermal peaks (e.g., Molzahn & Wörner 1999), and the fit of the continental shelfs of Antarctica and Australia can only be explained by varying heat flow within a now vanished "Mesozoic Victoria Basin" during the Cretaceous. Qualitative

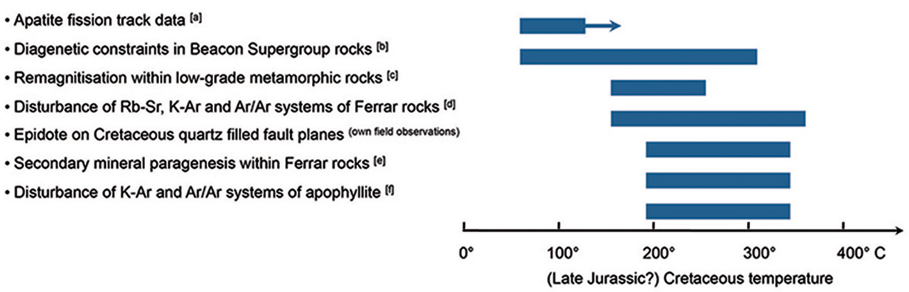

Fig. 2: Compilation of paleotemperatures derived from thermal indicators in Beacon and Ferrar rocks. (a) = Fitzgerald (2002) and Lisker (2002); (b) = Balance & Watters (2002), Bernet & Gaupp (2005); (c) = Faure & Mensing (1993), refs. in Molzahn et al. (1999); (e) = Hornig (1993); (f) = Molzahn et al. (1999).

Abb. 2 : Kompilation von Paläotemperaturen auf der Grundlage thermischer Indikatoren in Beacon- und Ferrar-Gesteinen. (a) = Fitzgerald (2002) und Lisker (2002); (b) = Balance & Waters (2002), Bernet & Gaupp (2005); (c) = Faure & Mensing (1993), refs. in Molzahn et al. (1999); (e) = Hornig (1993); (f) = Molzahn et al. (1999).

interpretation of these constraints suggests that regional exhumation due to the formation of the West Antarctic Rift System and uplift of the Transantarctic Mountains did not commence prior to the Paleocene.

Objectives of thermochronological research in northern Victoria Land

The Antarctic expedition GANOVEX X 2009/10 of the German Federal Institute of Geosciences and Natural Resources (BGR) provided the opportunity to have a fresh look to the regional geological evolution of northern Victoria Land in the context of the Mesozoic Victoria Basin. The evolution before, during and after the breakup of Gondwana needs to be studied in a composite approach of scientists from various disciplines: geophysics, structural geology, petrology, sedimentology, stratigraphy, paleontology, and thermochronology. Within this frame, thermochronological research there focuses on five main topics.

(1) More and better data, new and complementary techniques, and quantitative modelling. A large set of more than 500 apatite FT ages and associated proxies, most of them obtained from vertical profiles, has been compiled during the last two decades from the Pacific termination of the Transantarctic Mountains by various workers (compiled by Lisker & Läufer 2011). However, these data were only interpreted quantitatively in the past while Prenzel et al. (2013) demonstrated that reliable thermal histories depend on quantitative modelling. Unfortunately, the bulk of the available data is not suitable for modelling since they were either generated by population method or they lack information about the chemical composition (and therefore the annealing properties) of apatites (cf. Lisker & Läufer 2011, Prenzel et al. 2013). Moreover, some areas, especially in the morphologically diverse Robertson Bay Terrane, were not sampled and studied representatively. Consequently, most published apatite FT data need to be either supplemented with essential annealing proxies (e.g., Dpar) or substituted completely by new data obtained via external detector method, and should be complemented by new data from so far underexplored areas. Furthermore, the thermal sensitivity should be extended to temperatures as low as ~40 °C by application of (U-Th-Sm)/He analysis on apatites. Then, vertical sample profiles distributed representatively throughout the region will provide a general frame for thermal history modelling and should be connected via horizontal sample arrays. Eventually, numerical modelling of the extensive thermochronological dataset of northern Victoria Land using PECUBE may be applied to quantify rates of crustal heat transport, landscape evolution and tectonic processes (see below).

(2) Evolution of the Mesozoic Victoria Basin on the continental crust of SE Australia and the western Ross Sea. A main goal of the thermochronological work within the region is to reconstruct extension, depth and geometry of the Victoria Basin. The comparison of the brittle fabrics from basement, Beacon and Ferrar rocks provides information on the finite strain field during extension and the relative sequence of regional tectonic events. This work has to be complemented by further search for remnants and additional indirect evidence of Late Jurassic Cretaceous sediments on the continent and especially on shelf and Ross Sea sequences, for example in the context of Antarctic drilling campaigns (ANDRILL). The according dataset will be correlated with existing data from northern Victoria Land and Australia since a consistent basin formation model has to take into account the common early rifting history of Antarctica and Australia. Current breakup models largely ignore the discrepancy between the extensive shelf of Australia that contains up to 15 km of post-mid Jurassic sediments, and the short shelf in front of northern Victoria Land with only a thin sedimentary cover.

(3) Passive margin formation versus West Antarctic rifting. Isotherm patterns derived from thermal history modelling of apatite FT and (U-Th-Sm)/He analyses may be used to determine basic parameters for the understanding of continental rifting and margin evolution. This includes timing, distribution and depth of exhumation, geometry and segmentation of the passive/sheared margin, the isostatic compensation of exhumation, and the classification of the margin type. The topic also comprises a quantification of potential denudational interferences between Gondwana margin evolution and Cenozoic Ross Sea rifting. The lithospheric rigidity (variable already along the continental margin alone), and the flexural wavelengths of passive continental margin and West Antarctic Rift System may divert considerably, and flexural warping and denudational rebound of the crust will likely show maximum interference at the locus of the NE Robertson Bay Terrane. Alternatively, the maximum overlap could be located at the Rennick Graben that forms the continuation of the Victoria Land Basin of the West Antarctic Rift System into Terra Nova Bay and northern Victoria Land (Cooper et al. 1987). Our understanding of the regional landscape evolution can be improved, and a respective long-term model established

only by evaluation, quantification and modelling of amounts and rates of exhumation of the diachronous continental and rift margins, the distances between the two eroding escarpment fronts, the age difference between both escarpments, and the initial pre-rift shape of the land surface for each of the rifted margins evolved. Eventually, these constraints need to be linked quantitatively with the respective morphological parameters, with special consideration of the decreasing topographic altitude of the Transantarctic Mountains and their increasing asymmetry towards the north.

(4) Timing and amount of final exhumation and surface uplift of the Transantarctic Mountains. The thermochronological research of the last decades usually referred – mainly due to the limited resolution of apatite FT data – to the Cretaceous to Paleocene cooling/exhumation history of the Transantarctic Mountains. However, recent thermochronological data from the Rennick Graben and southern Victoria Land (Balestrieri et al. 1994, Rossetti et al. 2003, Fitzgerald et al. 2006, Storti et al. 2008, Lisker unpubl. data) and dating of tectonic events in the Terra Nova Bay region (Di Vicenzo et al. 2004) indicate a significant Eocene/Oligocene exhumation stage that is also supported by the sedimentary record of the adjacent Ross Sea troughs (e.g., Florindo et al. 2005). Though, post-Oligocene cooling is only detected qualitatively by apatite FT data, not resolved. (U-Th-Sm)/He analysis on apatites from the rapidly uplifted/eroded massifs at the Transantarctic Mountains front will provide insight in timing and amount of exhumation since the Oligocene: (a) Did exhumation occur in response to a single major uplift stage at the Eocene-Oligocene boundary; (b) are there several discrete uplift/exhumation stages, or (c) are the Transantarctic Mountains the result of a more gradual uplift process? The variation of low-temperature isotherms in time and space in the context of the geological record will allow to conclude on the influence of lithology of the now vanished rock column and of climate change and permanent glaciation on uplift and exhumation of the Transantarctic Mountains. A high-resolution exhumation pattern will also contribute to test existing uplift models of the Transantarctic Mountains, which are still discussed controversially by either a simple shear model (Fitzgerald et al. 1986, modified by Salvini et al. 1997), a flexural uplift model (Stern & ten Brink 1989), or a delayed phase changing model (Smith & Drewry 1984). Other models, such as the plateau collapse model of Bialas et al. (2007) are ruled out by the crossover relationships shown by Lisker & Läufer (2013).

(5) Landscape contrasts and climatic implications resulting from the interplay between climate, tectonics and lithology. Perhaps the most unique feature of northern Victoria Land is the distinctive landscape contrast across the termination of the Transantarctic Mountains. Although described repeatedly by geologists and geomorphologists (e.g., Tessensohn 1994, Van der Wateren et al. 1994, Baroni et al. 2005), contrasting uplift and exhumation in northern Victoria Land could not be quantified and profoundly interpreted yet since apatite FT ages of usually >30 Ma did not allow to dating the onset of the youngest exhumation phase(s). A few Neogene thermochronological age data have been reported only by Fitzgerald & Gleadow (1988) and Balestrieri et al. (1997) so far. The low resolution of existing cooling/exhumation data hampered tight constraints on time, temperature and spatial patterns. Moreover, earlier workers often ignored the intimate link between geological and geomorphological indications. A compilation of topographic and thermochronological data reveals that lithological differences between igneous and high-grade metamorphic basement units on the one side and low-grade metasedimentary terranes on the other side produce profound differences in both geomorphology and intensity of exhumation. Moreover, this relationship is superimposed by tight interaction between erosion behaviour and climate change. For example, hypothetical Cretaceous uplift of the Transantarctic Mountains had the potential to trigger long-term glaciation of polar Gondwana, while global cooling since the Eocene/Oligocene has produced different glacial systems (wet, dry) of extremely varying erosion efficiency. Recognition and quantification of these relationships will provide a deeper insight in the long-term climate evolution on the margin of the East Antarctic Craton.

Thermochronological field work during GANOVEX X

Field work during GANOVEX X focussed on mapping, measurements and sampling of the brittle kinematic inventory, and sample collection of horizontal and vertical profiles for FT and (U-Th-Sm)/He analyses. Particular attention was paid to morphologically exposed outcrops (escarpments, glacial valleys, erosion surfaces), unconformities, Phanerozoic deposits (Beacon Supergroup), superficial or shallow igneous bodies (Black Prince volcanics, Ferrar sills and volcanoclastics, Meander intrusives), regional faults, and dyke occurrences. We observed and sampled thermal features associated with tectonic structures, such as fault coatings and mineralization (e.g., epidote), secondarily grown white mica, bleaching horizons and aureols, pseudotachilytes, dykes and veins, secondary zeolithes within volcanic rocks etc.

Thermochronological fieldwork and sampling was carried out in two general areas: in the vicinity of Mariner Glacier and in the Terra Nova Bay region (Fig. 3). This separation was related to the logistic division of the expedition into two legs, but also follows the rheological and geomorphological properties of the basement units building up northern Victoria Land. Here, the Alpine topography cut in the meta-sedimentary rocks of the Bowers and Robertson Bay Terranes (Mariner Glacier area: Admiralty Block of Tessensohn 1994) contrasts with the plateau landscape dominating the Wilson Terrane (Terra Nova Bay region: Outback Shoulder of Tessensohn 1994).

Fieldwork during the first leg of GANOVEX X in the vicinity of Mariner Glacier was performed via helicopter support (Helicopters New Zealand) from the vessel MS "Italica" on 29 outcrops (Tab. 1 & Fig. 3) in three target areas, with varying sampling rationale. Sampling in front and at the flanks of the Mariner Glacier (17 outcrops/samples) and in the southern Victory Mountains (vertical profile of 5 samples) concentrated on the lithological contrast between Wilson metamorphics or Admiralty Intrusives and Robertson Bay/Leap Year/Sledgers groups, and on the control of erosion levels by volcanics and near-surface intrusions. A different approach was chosen for Mount Murchison where a vertical profile of seven specimens was sampled to complete an existing profile of very young apatite FT age (Fitzgerald & Gleadow 1988: 25-36 Ma), and to complement it with (U-Th-Sm)/He data to conclude

Sample	Location	Latitude South	Longitude East	Elevation (m a.s.l.)	Lithology
Leg I Mariner Glacier area					
4001	No Ridge	73°29.863	167°01.709	928	Granite (Meander Intrusives)
4002	Apostrophe Island	73°31.140	167°26.038	38	Gabbro (Granite Harbour Intrusives)
4003	Spatulate Ridge	73°29.176	167°15.461	530	Gabbro (Granite Harbour Intrusives)
4004	Eagles Bluff	73°15.631	167°10.096	391	Granite (Meander Intrusives)
4005	W Cape Crossfire	73°09.072	168°10.353	199	Granite (Admiralty Intrusives)
4006	Cloudy Ridge	73°20.210	168°43.911	4	Graywacke (Robertson Bay Group)
4007	Mt. Murchison	73°23.073	166°53.551	1300	Granite (Granite Harbour Intrusives)
4008	Mt. Murchison	73°25.492	166°18.721	3200	Granite (Granite Harbour Intrusives)
4009	Mt. Murchison	73°25.152	166°18.406	3414	Gneiss (Wilson Metamorphics)
4010	Mt. Murchison	73°24.851	166°25.015	2176	Gneiss (Wilson Metamorphics)
4011	Mt. Murchison	73°26.733	166°29.609	1577	Gneiss (Wilson Metamorphics)
4012	Mt. Murchison	73°20.739	166°00.112	661	Gneiss (Wilson Metamorphics)
4013	Cape King	73°36.000	166°33.470	74	Granite (Admiralty Intrusives)
4014	Emerging Island	73°23.117	168°01.838	76	Granite (Admiralty Intrusives)
4015	Retreat Hills	72°55.644	165°09.543	2694	Amphibolite (Wilson Metamorphics)
4017	Between Navigator Nunatak and Deception Plateau	73°12.261	164°26.763	2322	Granite (Granite Harbour Intrusives)
4018	Mt Kinet	73°17.437	165°52.361	1740	Granite (Granite Harbour Intrusives)
4019	Nunatak N Husky Ridge	73°18.326	166°02.757	1140	Mica schist (Wilson Metamorphics)
4020	Frank's Point	73°16.221	166°18.428	385	Descent Unit
4021	Cape Crossfire	73°05.149	168°16.665	985	Rhyolithe (Hallet Volcanics)
4023	S Victory Mts	72°50.637	167°57103	2494	Graywacke (Robertson Bay Group)
4024	S Victory Mts	72°49.018	167°55.512	3089	Graywacke (Robertson Bay Group)
4025	S Victory Mts	72°49.872	167°58.957	2164	Graywacke (Robertson Bay Group)
4026	S Victory Mts	72°50.041	168°00.424	1824	Graywacke (Robertson Bay Group)
4027	S Victory Mts	72°43.279	167°52.283	2559	Granite (Admiralty Intrusives)
4028	Husky Ridge	73°18.757	166°20.478	409	Granite (Granite Harbour Intrusives)
4029	Husky Ridge	73°24.448	166°25.957	2196	Granite (Granite Harbour Intrusives)
Leg II Terra Nova Bay					
4030	Mount Frustrum	73°21.244	162°56.807	2465	Kirkpatrick Basalt
4031	Mount Frustrum	73°31.851	162°40.790	2500	Kirkpatrick Basalt
4032	Lichen Hills N	73°15.984	162°00.858	2285	Granite (Granite Harbour Intrusives)
4033	Lichen Hills S	73°20.885	162.16.848	2161	Granite (Granite Harbour Intrusives)
4034	Mount Frustrum	73°22.863	162°55.631	3096	Kirkpatrick Basalt
4035	Mount Frustrum	73°22.235	162°51.741	2139	Kirkpatrick Basalt
4036	Mount Baxter	73°22.256	162°51.817	2442	Granite (Granite Harbour Intrusives)
4039	Mount Crummer	75°03.152	162°38.532	485	Granite (Granite Harbour Intrusives)
4040	Mount Crummer	75°03.085	162°39.340	370	Granite (Granite Harbour Intrusives)
4041	Mount Crummer	75°02.506	162°40.363	32	Granite (Granite Harbour Intrusives)
4042	Ridge N Bier Point	74°08.167	164°07.985	1466	Granite (Granite Harbour Intrusives)
4043	Inexpressible Island	74°56.056	163°42.940	25	Granite (Granite Harbour Intrusives)
4044	Cape Phillipi	75°13.955	162°32.708	363	Granite (Granite Harbour Intrusives)
4045	Starr Nunatak	75°53.908	162°35.605	109	Granite (Granite Harbour Intrusives)
4046	McDaniel Nunatak	75°48.302	161°46.895	854	Granite (Granite Harbour Intrusives)
4047	Evans Height	75°05.674	161°32.418	739	Granite (Granite Harbour Intrusives)
4048	Mount Larson	74°50.874	162°12.395	1520	Granite (Granite Harbour Intrusives)
4049	Mount Monteagle	73°45.594	165°22.762	2091	Granite (Granite Harbour Intrusives)
4050	Mount Monteagle	73°43.597	166°00.597	1200	Granite (Granite Harbour Intrusives)
4051	Mount Monteagle	73°41.502	165°56.573	1415	Granite (Granite Harbour Intrusives)
4052	Mount Monteagle	73°41.478	166°03.870	1042	Granite (Granite Harbour Intrusives)
4053	Mount Monteagle	73°39.709	166°07.975	367	Granite (Granite Harbour Intrusives)
4054	Harrow Peak	74°04.730	164°51.711	37	Granite (Granite Harbour Intrusives)
4055	Mount Crummer Top	75°02.992	162°34.597	881	Granite (Granite Harbour Intrusives)
4056	Mount Gaberlein	75°03.450	162°04.051	1154	Granite (Granite Harbour Intrusives)
4057	Mount Stierer	75°05.072	162°08.174	900	Granite (Granite Harbour Intrusives)
4058	Mount Bellinghausen	75°06.778	162°06.617	1222	Granite (Granite Harbour Intrusives)
4059	Mount Bellinghausen	75°06.433	162°06.954	1065	Granite (Granite Harbour Intrusives)
4060	SE Mt. Bellinghausen	75°09.076	162°14.049	736	Granite (Granite Harbour Intrusives)
4061	Fleming Head	75°09.531	162°38.655	213	Conglomerate (Bowers Group)
4062	Fleming Head	75°13.396	162°36.216	1	Granite (Granite Harbour Intrusives)
4063	E Mount Stierer	75°04.819	162°20.486	508	Granite (Granite Harbour Intrusives)

Tab. 1: List of samples collected during GANOVEX X. **Tab. 1:** Verzeichnis der während GANOVEX X genommenen Proben.

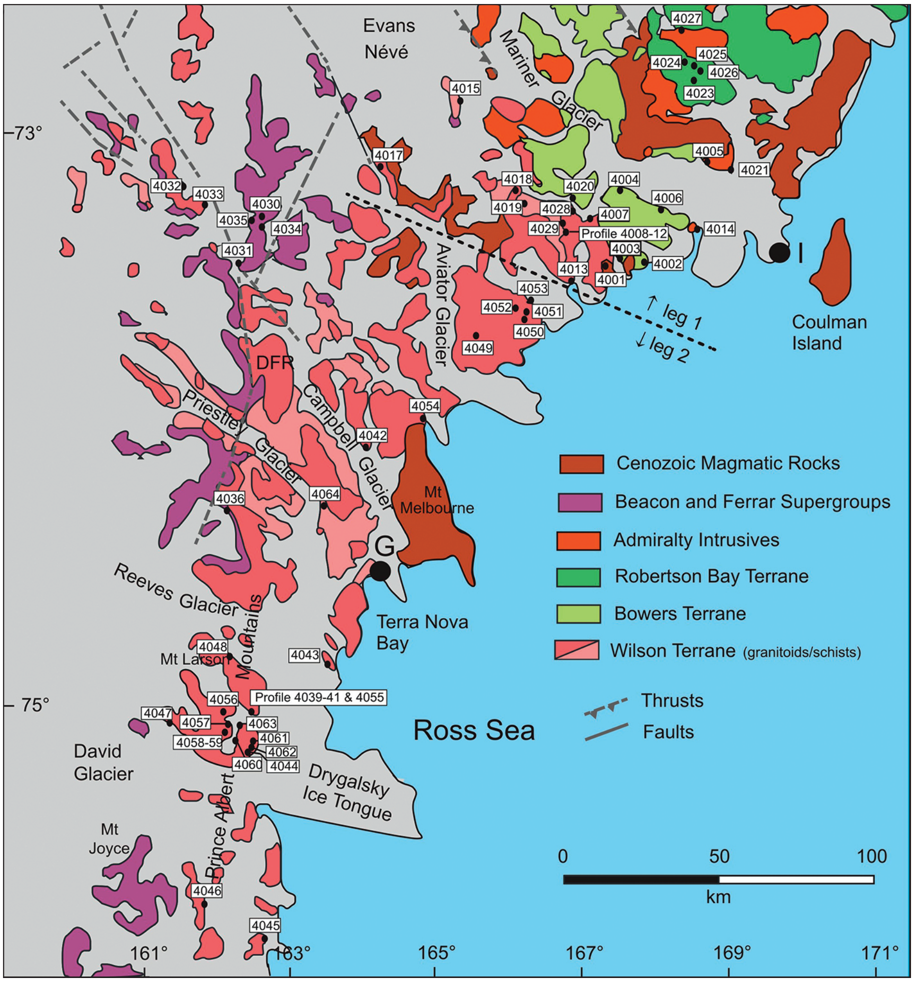

Fig. 3: Sample locations for thermochronological studies of the GANOVEX X campaign in the vicinity of Mariner Glacier (leg 1) and in the Terra Nova Bay region (leg 2). DFR = Deep Freeze Range, EHR = Eisenhower Range, I = position of expedition vessel "Italica" (base for leg 1), G = Gondwana Station (base for leg 2).

Abb. 3: Probenlokationen thermochronologischer Studien der GANOVEX X-Kampagne im Umfeld von Mariner Glacier (Leg 1) und Terra Nova Bay (Leg 2). DFR = Deep Freeze Range, EHR = Eisenhower Range, I = Position des Expeditionsschiffs „Italica" (Basis für Leg 1), G = Gondwana Station (Basis für Leg 2).

on the youngest exhumation phase(s) in coastal northern Victoria Land. Sampled rock types include granitoids (Granite Harbour, Admiralty, and Meander Intrusives: eight locations/samples), mafic rocks (Tiger Gabbro: 2), volcanic rocks (2), high-grade metamorphic rocks (Wilson metamorphics: 11), and low-grade metasedimentary rocks (Robertson Bay, Leap Year, and Sledgers groups: 6).

Fieldwork during the second leg of GANOVEX X in the Terra Nova Bay region was based on helicopter operations from the German Gondwana Station on 33 outcrops (Tab. 1 & Fig. 3). Main target area was the region of the Southern Prince Albert Mountains where 12 outcrops/samples and a vertical profile of four specimens at Mount Crummer were sampled. To the northeast of Gondwana Station, a vertical profile of five specimens was sampled at Mount Monteagle beneath an elevation of 1500 m to complete an existing profile of apatite FT ages above the mentioned altitude (Balestrieri et al. 1997). Furthermore, a vertical profile of four specimens at Mount Frustrum at the GANOVEX X geophysics base camp in the Mesa Range, two samples at Lichen Hills located east of this camp and six samples in an area in the vicinity of Gondwana Station, e.g., Black Ridge, were collected. Sampled rock types include mainly Granite Harbour Intrusives (28 locations/samples) and subordinately volcanic rocks (Kirkpatrick Basalt: 4) and low-grade metasedimentary rocks (Bowers: 1).

New thermochronological research in the Terra Nova Bay area

Some of the general questions listed above were initially addressed during the last couple of years, mainly in the Eisenhower Range/Terra Nova Bay area. The Eisenhower Range constitutes a ~70 km long and up to 3000 m high plateau forming an escarpment along the Priestley Glacier (Fig. 3). The basement consists of Wilson Terrane – late Proterozoic and Early Paleozoic Ross orogenic, low- to medium-grade metamorphic and granitic rocks (e.g., Borg et al. 1987). Post-Ross orogenic erosion formed a low-relief erosion surface overlain by the clastic Triassic to Jurassic Beacon Supergroup deposits. Triassic to Jurassic Beacon sediments with a thickness varying between ~30 m and ~50 m are preserved (e.g., Schöner et al. 2011). Beacon deposition was followed by intrusion and extrusion of magmatic rocks in/on basement and sediments during the Ferrar event at ~180 Ma (e.g., Elliot & Fleming 2008). Two recent thermochronogical studies of Prenzel et al. (2013, 2014) compiled new apatite FT data and apatite (U-Th-Sm)/He (AHe) from vertical profiles in the Eisenhower Range, and merged them with published apatite FT data. These data, supplemented by paleotemperature and pressure estimates derived from Beacon sandstones, provide new quantitative results on regional burial evolution and first regional constraints on basin inversion and exhumation processes.

Thirty-four apatite FT ages between 32 ±2 and 259 ±18 Ma and AHe ages from 21 samples between 37 ±3 and 173 ±16 Ma correlate positively with sample elevations between ~200 and ~2600 m. Thermal history modelling of these data and complementary thermal indications detect heating of the paleosurface on the Eisenhower Range to temperatures ≥80 °C subsequent to Ferrar magmatism, and constrain Late Eocene rapid cooling. Regression of modeled paleotemperatures against sample elevations refers to a high Jurassic (~45 °C/km) and a moderate Cretaceous – Eocene (28 ±8 °C/km) geothermal gradient. The texture of Beacon sandstones supports strong mechanical compaction that requires a higher overburden than preserved in the stratigraphic record. Model–led paleotemperatures and pressures suggest basement burial that increases from Late Jurassic (0.7-1.1 km) to Eocene (1.8-2.1 km). The overburden comprises 0.7-1.1 km cumulative Beacon/Ferrar rocks and 0.7-1.4 km of post-Ferrar sediments. Rapid cooling of the whole sample suite between ~35 and 30 Ma implies fast erosion of the post-Ferrar sediments and (re) exposure of underlying magmatic rocks. Subsequent differential sample cooling to present-day surface temperature infers ongoing exhumation by glacial incision enhanced by isostatic response to basin inversion. Decreasing amounts of exhumation from the coast (>3 km) towards the interior (1.5-2.2 km) point to backstepping incision along the fault controlled Priestley Glacier. Substantial exhumation of the Eisenhower Range since the Late Eocene is hence triggered by both tectonic and climatic factors, superimposed by considerable lithological influence during the initial exhumation stage.

The new findings from the Eisenhower Range and their interpretation are supported by new data from adjacent areas, the Deep Freeze Range and the northern Prince Albert Mountains. New thermochronological ages (28 ±3 to 274 ±17 Ma) from Deep Freeze Range positively correlate with elevations (1060-3120 m) with AHe ages being usually 10-20 Ma younger than corresponding apatite FT ages (Prenzel et al. submitted). For the Terra Nova Bay region, thermal history modelling detects common Mesozoic to Eocene heating/burial of the Jurassic surface and constrains rapid Late Eocene cooling/exhumation. The correlation of sample paleotemperatures versus elevation indicates an increased Jurassic (44 ±15 °C/km) and a moderate Cretaceous to Eocene (24 ±7 °C/km) geothermal gradient. Paleotemperatures and gradients used in tandem infer basement burial varying from ~2 km in Deep Freeze and Eisenhower Ranges to ~3.4 km in the Prince Albert Mountains. This vanished rock column consisted of Beacon and Ferrar rocks and 0.6-1 km of post-Ferrar deposits. Burial variation is apparently attributed to a higher thickness of Beacon and Ferrar rocks in the southern Terra Nova Bay and may represent the pre-Ferrar topography. The relative homogeneous post-Ferrar sediment thickness throughout the entire region indicates a continuous, uniform Mesozoic to Eocene sedimentary basin. Mid-Jurassic basin formation and subsequent sediment accumulation until the Late Eocene is explained by initiation of extension within the West Antarctic Rift System at ~180 Ma with a continuous stable stress field of low E-W extension during Ross Sea opening until ~35 Ma. Late Eocene/Early Oligocene basin inversion is linked with right lateral strike-slip and transtensional faulting attributed to major Eocene tectonic reorganization in the Ross Sea region from Cretaceous orthogonal to Cenozoic oblique rifting. Subsequent final exhumation with deepest incision at the coast is explained by a change of exhumation style from downwearing to backstepping incision from the coast towards the interior obviously caused by a combination of glacial incision, climate cooling, and isostatic surface rebound in response to sediment removal at ~30 Ma.

CONCLUSIONS

Recent thermochronological research in northern Victoria Land demonstrated that the region occupied a central position in a long-lasting Mesozoic Victoria Basin between Antarctica and Australia, and opened new perspectives for the formation of the Transantarctic Mountains and the Gondwana breakup. It also concluded that the bulk of published thermochronological data from the region is not suitable for reliable thermal history modelling, and therefore new, better and more data obtained with different thermochronological methods are required. A particular obvious gap in the sample record has been closed during the field campaign GANOVEX X in the Mariner Glacier area, NE Robertson Bay Terrane and in the Terra Nova Bay region.

Thermal history modelling of new thermochronological data from the Eisenhower Range and adjacent areas postdated exhumation and uplift of the high-standing plateaus of the Transantarctic Mountains in the northern Ross Sea to the Eocene/Oligocene boundary and reconstructed pre-Oligocene basin deposits in the order of 0.6-1.1 km for the Terra Nova Bay region. No qualitative constraints were obtained yet from Alpine ranges of the Robertson Bay Terrane. Depth, geometry and timing of basin evolution in this part of the Mesozoic Victoria Basin as well as the origin of the landscape contrast across northern Victoria Land and the influence of climate, tectonics and lithology on geomorphology need to be studied in the future.

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