

# Contributions to the Reconstruction of the Break-up History of Gondwana from a Northern Victoria Land Perspective: The GANOVEX IX Campaign 2005/06

by Detlef Damaske<sup>1</sup> and Andreas L. Läufer<sup>1</sup>

**Abstract:** The reconstruction of the Early Mesozoic to Recent geodynamic evolution of the northern Victoria Land sector of Antarctica and in particular processes leading to the break-up and continuing fragmentation of the Gondwana supercontinent were the primary goals of this multidisciplinary geoscientific project. It comprised (i) a comprehensive geological programme performed mainly along the Ross Sea coast between the Prince Albert Mountains to Cape Hallett and inland up to the Deep Freeze Range and (ii) an aeromagnetic survey flown in the offshore region north of Cape Adare. Geology included different disciplines such as structural geology, thermochronology, sedimentology, volcanology, and palaeontology. The aeromagnetic survey combined with structural-geological and thermochronological investigations was intended to examine a possible correlation of offshore magnetic lineaments with onshore major fault systems that define the present structural architecture of northern Victoria Land. The study was performed within the frame of the ninth German Antarctic North Victoria Land Expedition (GANOVEX IX) of the German Federal Institute for Geosciences and Natural Resources (BGR) during the austral summer 2005/06.

**Zusammenfassung:** Die Rekonstruktion der frühmesozoischen bis quartären geodynamischen Entwicklung des nördlichen Viktorialandes der Antarktis war übergeordnetes Ziel dieses multidisziplinär ausgelegten geowissenschaftlichen Projekts. Im Fokus der Untersuchungen lagen insbesondere die zum initialen Auseinanderbrechen und zur Fragmentierung des Superkontinentes Gondwana führenden Prozesse. Das Projekt ist Teil eines umfassenden geologischen Forschungsprogramms im Küstenbereich des Rossmeeres zwischen den Prince Albert Mountains und der Cape Hallett Region sowie im Landesinneren bis zur Deep Freeze Range. Ein aeromagnetisches Messprogramm wurde im Seebereich nördlich von Cape Adare geflogen. Der multidisziplinäre Ansatz basierte hauptsächlich auf der kombinierten Anwendung strukturgeologischer, thermochronologischer, sedimentologischer, vulkanologischer und paläontologischer Methoden. Die aerogeophysikalische Befliegung in Kombination mit strukturgeologischen und thermochronologischen Untersuchungen hatte zum Ziel, mögliche Verbindungen zwischen magnetischen Lineamenten im marinen Bereich und den großen Störungssystemen an Land, die den jetzigen strukturellen geologischen Bau des nördlichen Viktorialandes kontrollieren, zu untersuchen. Die Arbeiten erfolgten im Rahmen der neunten Expedition der Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) in das nördliche Viktorialand (GANOVEX IX) im Südsommer 2005/06.

## INTRODUCTION

The timing of the break-up history of the supercontinent Gondwana, particularly in the sector between Australia and Antarctica, is of great importance for fundamental changes in the global system, because it seems to mark the beginning of glaciations leading to a considerable climate shift on the whole planet.

Since 1979, the Federal Institute for Geosciences and Natural Resources (BGR) in collaboration with German university colleagues and foreign scientific institutions has studied the structure and geological evolution of northern Victoria Land and the Ross Sea sector of Antarctica within the frame of the GANOVEX programme (German Antarctic North Victoria Land Expedition). Common target of these activities is the investigation of the Antarctic continental lithosphere and its margins in order to gain a better knowledge of the formation of the supercontinent Gondwana and its fragmentation eventually leading to the modern Antarctic continent with its shelf margins. The activities of BGR are a major contribution to the targets of German Antarctic research.

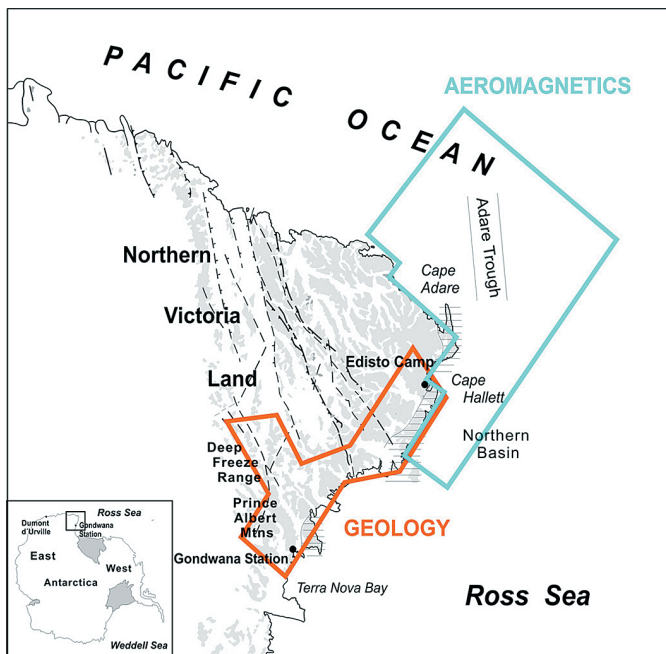
The reconstruction of the initial break-up history of Gondwana in this sector of Antarctica and the subsequent opening of the Tasman oceanic gateway between Australia and Antarctica, as well as the analysis of processes controlling uplift and denudation of the Transantarctic Mountains and long-term landscape evolution of Antarctica were the main targets of GANOVEX IX. Another major goal of the expedition was to investigate factors controlling the present structural architecture of northern Victoria Land, particularly the relationship between large-scale onshore fault systems and oceanic fracture zones in the southern Pacific Ocean between Australia and Antarctica.

These targets required the coordination and close cooperation of different research programmes developed by scientists of the BGR, the universities of Bremen, Jena and Münster and the Technical University of Freiberg. The participating scientists covered different disciplines such as geophysics, structural geology, geo- and thermochronology, geochemistry, sedimentology, stratigraphy, palaeontology and palynology. The scientific projects of this campaign (for working areas see Fig. 1) were defined based on results of preceding expeditions of BGR's GANOVEX programme (e.g. ESTRADA et al. 2009), in particular GANOVEX VIII (1999/2000) (DAMASKE & BOZZO 2003, 2004).

## SCIENTIFIC BACKGROUND

In its geological past, Antarctica was not always an isolated continent, but represented the centrepiece of the supercontinent Gondwana that formed as a result of the collision of several continental fragments and accretionary processes approximately 600-500 Ma ago and included all modern continents of the southern hemisphere. Gondwana existed until c.

<sup>1</sup> Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Stilleweg 2, D-30655 Hannover, Germany.



**Fig. 1:** Areas of fieldwork during GANOVEX IX in the region of northern Victoria Land and offshore Cape Adare.

**Abb.1:** Arbeitsgebiete während GANOVEX IX im Bereich des nördlichen Viktorialandes und im Meeresgebiet vor Cape Adare.

180 Ma before present, when it began to break-up, indicated by voluminous basaltic eruptions. Africa, India, Australia and finally South America drifted away from Antarctica, eventually leading to today's isolated position of the continent in the South Polar Region and the establishment of the modern global ocean circulation system and today's climatic conditions.

In early Gondwana history, a high-elevation mountain range existed in northern Victoria Land, which is geologically comparable to the modern Andes in many ways. Like the Andes, this mountain range formed because the Pacific plate was continuously subducted under the much lighter continental plate of Gondwana. This ancient, about 500 Ma old mountain range is generally referred to as the Ross Orogen (e.g., BORG & STUMP 1987, KLEINSCHMIDT & TESSENHORN 1987). Some of its most characteristic structural elements are large-scale, high-strain thrust zones, which show opposite-directed kinematics towards the East (or the Palaeo-Pacific Ocean) on its eastern flank and towards the West (or the East Antarctic Craton) on its western flank (e.g., KLEINSCHMIDT et al. 2003). A segment of the eastern branch of this bi-vergent thrust system is described by LÄUFER et al. (2011 this vol.).

The Ross Orogen was subsequently levelled to an extensive peneplain by intense erosion within geologically relatively short time. The common landscape of Gondwana was then characterized by wide basins with braided river systems for a period of almost 300 Ma. Smaller and larger freshwater lakes repeatedly formed within these basins. The sediments that were deposited in the basins are generally referred to as the Beacon Supergroup in Victoria Land. Deposition terminated when huge volumes of flood basalts of the Ferrar volcanic event started to erupt around 180 Ma ago indicating the initial break-up of the Gondwana supercontinent. During

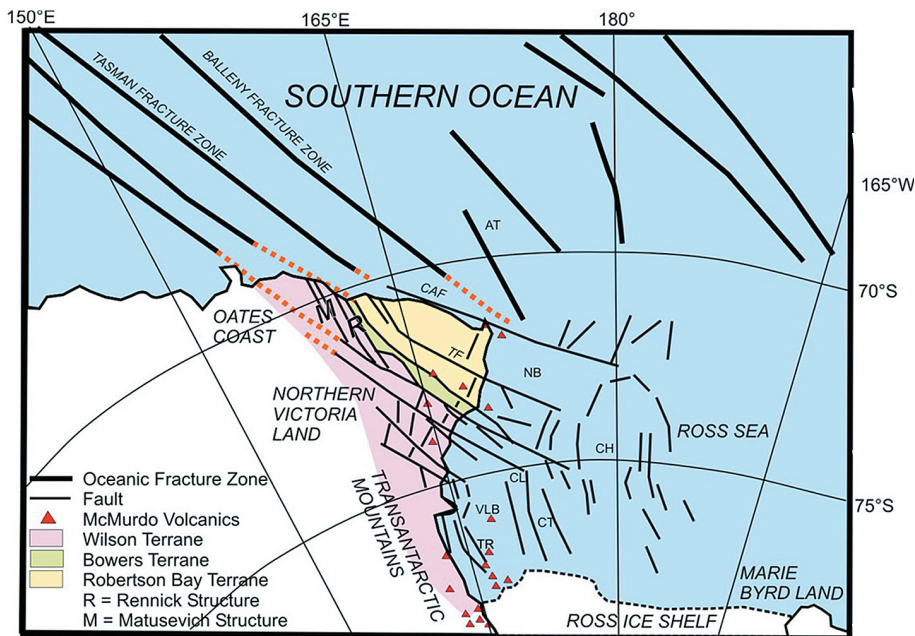
GANOVEX IX, an approximately 200 km long section of Beacon sedimentary and Ferrar volcanic rocks was studied with regards to their volcanology, sedimentology and palaeontology. A large number of stratigraphic sections were analyzed in great detail on the centimetre and decimetre scale, including several sections of ancient lake-sediments. It could be demonstrated that chaotically brecciated rocks formed by explosive eruptions before the onset of the actual Ferrar lava flows. Sandstones interspersed with numerous volcanic fragments occur at the base of these breccias. Intercalations of slack water horizons contain a rich flora and fauna yielding an age for this succession, thus leading to a rather new view of the geological evolution of the region at the end of Triassic and in early Jurassic times (BOMFLEUR et al. 2011 this vol., SCHÖNER et al. 2011 this vol.).

In order to gain a better understanding of the processes involved in the Cretaceous and Cenozoic development of northern Victoria Land and the formation of the West Antarctic Rift System, which eventually led to the modern plate configuration between Australia, Antarctica and New Zealand, an interlocking application of different geoscientific methods is necessary. Geophysics and structural geology play a key role in these reconstructions. Structural geology is an important tool to outline differences or similarities in the geodynamic evolution of continental fragments. While structural geology is largely dependent on rocks exposed at the surface, geophysical methods (and particularly aeromagnetics as used during GANOVEX IX) can provide important information on the crustal structure hidden under the ice or in off-shore areas. With the aid of geo- and thermochronological methods, the evolutionary steps of the geodynamic evolution of the region identified by structural geology can be calibrated in time by isotopic ages.

Thus, the main target of the structural geology/ thermochronology team was the late Mesozoic and Cenozoic tectonic and uplift/denudation history of northern Victoria Land (see LISKER & LÄUFER 2011 this vol. and LÄUFER et al. 2011 this vol.).

The Pacific sector of Antarctica and its counterpart in southern Australia assumingly have shared a very similar geological evolution after the eruption of the Ferrar volcanic rocks, which is at least since the late Jurassic and through most of the Cretaceous (LISKER & LÄUFER 2007). Once the two continents were separated and Antarctica assumed its isolated position in the South Polar Region, a new tectonic setting involving large-scale crustal extension in the form of West Antarctic rifting, mountain uplift and denudation, and dominantly right-lateral fault movements has been established in Cenozoic times since ca. 55-50 Ma (DAVEY & BRANCOLINI 1995, VAN DER WATEREN & CLOETINGH 1999, ROSSETTI et al. 2006). This geodynamic setting (Fig. 2) is very likely still active today and shows the continuing destruction of the Gondwana fragment Antarctica. A possible link of (i) onshore dextral strike-slip faults and oceanic fracture zones and (ii) the Adare Trough with extinct spreading between 43 and 27 Ma and the Northern Basin of the Ross Sea Rift has been discussed. In order to trace offshore tectonic structures and their possible link with onshore structures in northern Victoria Land and major rift basins in the Ross Sea, an aeromagnetic survey was thus flown over the offshore areas north and north-





**Fig. 2:** Tectonic sketch map of the Ross Sea and Transantarctic Mountains region modified after SALVINI et al. (1997) showing the main offshore fracture zones between Australia and Antarctica and their possible continuation into northern Victoria Land and the Ross Sea (cf. STORTI et al. 2007). AT = Adare Trough, CAF = Cape Adare Fault, TF = Tucker Fault, NB = Northern Basin, CH = Central High, CL = Coulman High, VLB = Victoria Land Basin, TR = Terror Rift, CT = Central Trough.

**Abb. 2:** Tektonische Skizze des Bereichs Ross Sea und Transantarctic Mountains verändert nach SALVINI et al. (1997), welche die wichtigsten intraozeanischen Bruchzonen zwischen Australien und der Antarktis und deren mögliche Fortsetzung ins nördliche Viktorialand und in das Rossmeer zeigt (vgl. STORTI et al. 2007).

east of Cape Adare up to the Adare Trough.

### FIELD WORK DURING GANOVEX IX

Fieldwork during this campaign had a rather complicated logistic set-up receiving support by the Italian and French Antarctic Programmes. Some equipment had already been brought in by the Italian support vessel M/V "Italica" in the season 2004/05. In addition, a fuel depot at Edisto Inlet (Fig. 3) had been set up for the aeromagnetic survey.



**Fig. 3:** Fuel depot at Salmon Cliff, Edisto Inlet, Cape Hallett region. The fuel depot was set up by the Italian Antarctic programme during austral summer 2004/05 one year before the actual GANOVEX IX expedition. At the beginning of the expedition, it had to be moved by helicopter to Edisto Glacier, because due to logistic reasons the aerogeophysics base camp had to be set up on Edisto Glacier instead of at Salmon Cliff.

**Abb. 3:** Treibstoffdepot bei Salmon Cliff, Edisto Inlet, Region Cape Hallett. Das Treibstoffdepot wurde im Südsommer 2004/05, ein Jahr vor der GANOVEX-IX-Expedition, durch das Italienische Antarktisprogramm errichtet. Es musste zu Beginn der Expedition per Hubschrauber auf den Edisto Glacier umgesetzt werden, da das Basislager der Aerogeophysik dort errichtet werden musste und nicht wie ursprünglich geplant am Salmon Cliff.

The expedition was then carried out in austral summer 2005/06 between mid-October until early March with a peak of field activities between mid-November and mid-January. The expedition team consisted of eight geoscientists, two technicians, two logistic personnel, two mountain guides, six helicopter crew, three twin otter crew, and two media crew. Personnel was transported to the ice by an Italian Hercules C-130 from Christchurch, New Zealand, in late October and early November 2005 (Fig. 4).

Main logistic base in the field was BGR's Gondwana Station (Fig. 5) at the Gerlache Inlet of Terra Nova Bay in the Ross Sea.

From mid-November 2005 to mid-January 2006 a base field camp was set up at Edisto Glacier (Fig. 6). From there, the aeromagnetic survey was flown using a Twin Otter as platform (Fig. 7). A small geology team participated in this campaign during December.



**Fig. 4:** SAFAIR Hercules aircraft landing on sea-ice in Gerlache Inlet, Terra Nova Bay. The aircraft was chartered to transport personnel and equipment to Gondwana Station. Mt. Melbourne volcano is visible in the background.

**Abb. 4:** Landung eines Flugzeuges der SAFAIR vom Typ Hercules auf dem Meereis des Gerlache Inlet, Terra Nova Bay. Das Flugzeug wurde für den Personen- und Materialtransport zur Gondwana-Station gechartert. Im Hintergrund ist der Vulkan Mt. Melbourne sichtbar.



An additional five-member three-week satellite camp was located at Mt. Carson in the Deep Freeze Range during December to support sedimentological, geochemical and palaeontological fieldwork.

After completion of fieldwork, the expedition team was transported back to Hobart, Australia, via the French Dumont d'Urville base onboard of M/V "l'Astrolabe" in three legs in late January, late February, and early March 2006.



**Fig. 5:** The Gondwana Station of BGR at Terra Nova Bay. The main container assembly is flanked by the generator shed (left) and storage containers (right). The bright orange bivouac hut, which represented the first Gondwana station erected in 1983, had been moved from its original location to the present position when the new containerized station was built during austral summer 1988/89.

**Abb. 5:** Die Gondwana-Station der BGR an der Terra Nova Bay. Die Container-Station wird flankiert vom Generatorverschlag (links) und Lagercontainern (rechts). Die hell-orangene Biwak-Hütte, errichtet als erste Station 1983, wurde von ihrem ursprünglichen Platz auf diese jetzige Position während des Baus der Container-Station im Südsommer 1988/89 versetzt.



**Fig. 6:** Base camp on the Edisto Glacier during typical fog conditions. The camp served as base for the Twin Otter operations of the aeromagnetic survey and for helicopter supported geological investigations in the northern working areas.

**Abb. 6:** Basislager auf dem Edisto-Gletscher während typischer Nebelwetterlage. Das Lager diente als Basis für die aeromagnetische Befliegung mit einer Twin Otter sowie den Hubschraubergestützten geologischen Untersuchungen in den nördlichen Arbeitsgebieten.

## ACKNOWLEDGMENTS

This paper is a contribution to the results of GANOVEX IX (2005/06) of the Federal Institute of Geosciences and Natural Resources (BGR) in Hannover, Germany. We would like to thank the Italian and French Antarctic Programmes for giving logistic support. Many thanks go to our pilots and engineers of Helicopters New Zealand and Kenn Borek Air and to all other members of the expedition making GANOVEX IX a success (Fig. 8). Last-not-least, we would like to thank Norbert W. Roland for leading the expedition and for discussions in the field and thereafter. The university-based projects were funded through the Programme "Antarctic Research" of the German Research Foundation (DFG). We thank Franz Tessensohn and Georg Kleinschmidt for their engagement in reviewing the manuscript with helpful suggestions and comments.



**Fig. 7:** Installation and ground testing of the aeromagnetic equipment in the survey Twin Otter on the sea-ice in Tethys Bay – the innermost part of Gerlache Inlet – close to the Italian Mario Zucchelli Station.

**Abb. 7:** Einbau und Bodenerprobung der aeromagnetischen Messapparatur im Twin-Otter-Messflugzeug auf dem Meereis der Tethys Bay – dem innersten Teil des Gerlache Inlet – nahe der italienischen Station Mario Zucchelli an der Terra Nova Bay.



**Fig. 8:** The GANOVEX IX expedition team at Gondwana Station: 1 = Jörg Schneider, 2 = Andreas Läufer, 3 = Detlef Damaske, 4 = Norbert Roland, 5 = Frank Lisker, 6 = Jürgen Kothe, 7 = Maurice Conway, 8 = Brian State, 9 = Benjamin Bomfleur, 10 = Felix Goldmann, 11 = Heinz-Dieter Möller, 12 = Lothar Viereck-Götte, 13 = Jan Storp, 14 = Robert Schöner, 15 = Henrik Wagner, 16 = Michael Trapp. Photo by Michael Trapp.

**Abb. 8:** Die Teilnehmer der GANOVEX IX Expedition an der Gondwana Station. Foto von Michael Trapp.



## References

- Bomfleur, B., Schneider, J.W., Schöner, R., Viereck-Götte, L. & Kerp, H.* (2011): Fossil sites in the continental Victoria and Feraf groups (Triassic–Jurassic) of north Victoria Land, Antarctica.- *Polarforschung* 80:88-99.
- Borg, S.G. & Stump, E.* (1987): Palaeozoic magmatism and associated tectonic problems of Northern Victoria Land, Antarctica.- In: G.D. MCKENZIE (ed.): *Gondwana Six: Structure, Tectonics and Geophysics.*- Geophys. Monogr. Amer. Geophys. Union: 67-75.
- Damaske, D. & Bozzo, E.* (eds) (2003): *Scientific Results from the Joint German-Italian 1999-2000 Antarctic Expedition, First part.*- *Terra Antarctica* 10: 81-256.
- Damaske, D. & Bozzo, E.* (eds) (2004): *Scientific Results from the Joint German-Italian 1999-2000 Antarctic Expedition, Second part.*- *Terra Antarctica* 11: 1-90.
- Davey, F.J. & Brancolini, G.* (1995): The Late Mesozoic and Cenozoic structural setting of the Ross Sea region, in *Geology and Seismic Stratigraphy of the Antarctic Margin.*- In: A.K. COOPER, P.F.BARKER & G.BRANCOLINI (eds), *Antarct. Res. Ser. 68*, American Geophysical Union, Washington, D. C.,167-182 .
- Estrada, S., Damaske, D., Läufer, A. & Piepjohn, K.* (2009): 30 Jahre terrestrische Polarforschung der Bundesanstalt für Geowissenschaften und Rohstoffe - ein Rückblick.- BGR, Hannover, 1-72.
- Kleinschmidt, G. & Tessensohn, F.* (1987): Early Paleozoic westward directed subduction at the Pacific margin of Antarctica.- In: G.D. MCKENZIE (ed), *Gondwana Six: Structure, Tectonics and Geophysics*, Geophys. Monogr., Amer. Geophys. Union, Washington, 40: 89-105.
- Kleinschmidt, G., Läufer, A.L. & Talarico, F.* (2003): Antarktis und Australien, die (fast) Unzertrennlichen: ein Überblick.- *Polarforschung* 71: 97-108.
- Läufer, A.L., Damaske, D. & Lisker, F.* (2011): Neogene tectonics in the Edisto and Tucker Inlet region and its correlation with offshore magnetic anomalies north of Cape Adare, northern Victoria Land, Antarctica.- *Polarforschung* 80: 111-126.
- Läufer, A.L., Lisker, F. & Phillips, G.* (2011): Late Ross-orogenic deformation of basement rocks in the northern Deep Freeze Range, Victoria Land, Antarctica: the Lichen Hills Shear Zone.- *Polarforschung* 80: 60-70.
- Lisker, F. & Läufer, A.L.* (2011): Thermochronological research in northern Victoria Land (Antarctica): a key to the pre-disintegration palaeogeography of Panthalassian Gondwana.- *Polarforschung* 80: 100-110.
- Lisker, F. & Läufer, A.L.* (2007): A Cretaceous Victoria Basin between Australia and Antarctica inferred from volcanoclastic deposits, thermal indications and thermochronological data.- In: A.K. COOPER & C.R. RAYMOND (eds), *Online Proceedings 10th ISAES*, USGS Open-File Report 2007-1047, Extended Abstract 211, 3 p.
- Rossetti, F., Storti, F., Busetti, M., Lisker, F., Di Vincenzo, G., Läufer, A.L., Rocchi, S. & Salvini, F.* (2006): Eocene initiation of Ross Sea dextral faulting and implications for East Antarctic neotectonics.- *J. Geol. Soc.* 163: 119-126.
- Salvini, F., Brancolini, G., Busetti, M., Storti, F., Mazzarini, F., & Coren, F.* (1997): Cenozoic right-lateral strike-slip tectonics in the Ross Sea Region, Antarctica.- In: C.A. RICCI (ed), *The Antarctic Region: Geological Evolution and Processes.*- *Terra Antarctica Publications*, 585-590, Siena.
- Schöner, R., Bomfleur, B., Schneider, J. & Viereck-Götte, L.* (2011): A systematic description of the Triassic to Lower Jurassic Section Peak Formation in north Victoria Land (Antarctica).- *Polarforschung* 80: 71-87.
- Storti, F., Salvini, F., Rossetti, F. & Morgan, J.P.* (2007): Intraplate termination of transform faulting within the Antarctic continent.- *EPSL*, 260: 115-126.
- Van der Wateren, F.M., & Cloetingh, S.* (1999): Feedbacks of lithosphere dynamics and environmental change of the Cenozoic West Antarctic Rift System.- *Global Planet. Change* 23: 1-24.