

# The Electronic Geophysical Year 2007–2008

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A worldwide revolution is taking place in the way we store, access, and analyze data and information. For the geosciences, our ability to gather data about the Earth and its space environment is unprecedented. Data acquisition rates of a petabytes per day no longer cause surprise and real-time access to data is becoming widespread. We can obtain data and services via the internet and grid systems from anywhere in the world, we can store and serve data with true interoperability, we can deal with real-time data applications, assimilate data into models, build virtual observatories, and more.

The challenges of organizing, providing ready access to, and using data effectively expand as data volumes, data complexity, and interoperability requirements increase. Meeting these challenges demands investment of time and resources as well as new skills. The onset of these demands has been rapid and novel.

The Electronic Geophysical Year of 2007–2008 (eGY – see [www.egy.org](http://www.egy.org)) has served to build an international foundation for capitalizing on the new opportunities, The objective is to raise awareness of, and promote informatics capabilities in Earth and space science research; to advance towards the goal of a geoscience information commons in the spirit of the International Geophysical Year fifty years ago; to accelerate the development and adoption of virtual observatories and similar cyber-based systems for dealing with the large, diverse data and information requirements of modern research, and to promote better data management policies and practices. The formal themes of eGY are data access, data discovery, data release, data preservation & rescue, reducing the Digital Divide, and education and outreach.

The central outcome of eGY, which ends in December 2008, has been a heightened awareness among scientists and their professional bodies such as ICSU, IUGG, IUGS, COSPAR, AGU, GSA, and EGU, of the role of informatics in science.

# Microbialites of Hamelin Pool and Lake Clifton, Western Australia

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The Hamelin Pool stromatolites show great morphological variation and extend from the high intertidal zone to subtidal depths of about 2 metres. Analysis of variation in stromatolite height shows that the tallest structures occur in the shallow subtidal zone, and that stromatolite relief decreases toward both the upper intertidal zone and toward the deeper subtidal limit of occurrence. Stromatolites at similar depths all have similar relief. The shape of the stromatolites also varies consistently depending on the position relative to present sea-level. Flat forms dominate the high intertidal zone, cauliflower-shaped stromatolites are found in the lower intertidal zone, columnar-shapes dominate in shallow subtidal environments and the deepest examples are all small domes.

Several authors have related variation in stromatolite shape to the occurrence of different types of microbial communities at different elevations. Burne (1991-1992) suggested that stromatolite growth was initiated in subtidal environments, and the present distribution is the result of falling sea levels and modification by intertidal microbial communities.

We have now (a) precisely surveyed the distribution of stromatolites in Hamelin Pool, and (b) modelled stromatolite growth variation by stipulating depth limits for stromatolite growth; suggested stromatolite growth rates; likely rate and direction of sea-level change; and period of time of that conditions for stromatolite growth have existed. We conclude that the morphological variation of stromatolites in Hamelin Pool can be accounted for by a model in which principal growth occurs only between mean low sea level and a depth of 2 metres, growth rate is 5 mm/decade, conditions suitable for stromatolite growth commenced 1,500 years ago, and relative sea level has fallen by 2 metres in the past 4000 years.

In 2007 research on Lake Clifton, a RAMSAR wetland south of Perth was resumed. Despite the recognised significance and importance of Lake Clifton and its protection as part of a National Park (Burne and Moore 1987, Moore and Burne 1994), there has been very serious environmental degradation over the past 15 years. There appear to have been three major causes of environmental degradation –

**Nutrient levels in the Lake** – The naturally low nutrient levels of Lake Clifton were essential for the health of the thrombolite-based ecosystem. Despite the importance of monitoring of nutrient levels and limiting nutrient input to the Lake being emphasised by the Scientific Advisors in the Management Plan for the Lake, no monitoring appears to have been undertaken and nutrient levels appear to have risen considerably, possibly as a consequence of sub-division of the Lake's eastern border.

**Introduction of Black Bream into Lake Clifton** – The introduction of Black Bream into Lake Clifton by a Mandurah resident has had a devastating impact on the water quality, biota and microbial communities of the Lake. Research is being undertaken on the nature of possible remedial action that might be implemented.

Freshwater aquifer depletion - It appears that the construction of the Dawesville Cut involved pumping of the groundwater aquifer and discharge of the fresh groundwaters into the sea. This channel was constructed as an ecologically questionable engineering solution aimed at dealing with the environmental degradation of the Peel Harvey Estuary. The coincidence between the excavation of the Dawesville Cut and elevated salinity of Lake Clifton lake water suggests that this groundwater pumping severely impacted the fresh groundwater aquifer running along the eastern boundary of Yalgorup Lakes. This may account for the salinisation of the aquifer, the reduction in carbonate and fresh water input into Lake Clifton, and the death of stands of Tuart Trees along the eastern Boundary of the Lake System. This may therefore be the result of not properly assessing the environmental impact of Groundwater pumping. Possible remedial action is under consideration.

Burne R.V. (1991-92): Lilliput's Castles: Stromatolites of Hamelin Pool. *Landscape* V.7 No.2 Summer ed. p. 34-40

Burne, R.V., Moore, L.S. (1987) Zircons from Syros, - Microbialites: Organosedimentary deposits of benthic microbial communities. *Palaios*, 2:241 - 254

Moore, L.S., Burne, R.V. (1994):-The modern thrombolites of Lake Clifton, Western Australia. in *Phanerozoic Stromatolites II* .(Bertrand Sarfati, J., & Monty C. L., Editors), Kluwer Academic, Pages 3 - 29.



Figure 1. Subtidal Stromatolites, Hamelin Pool

# The significance of the Gogo Fauna

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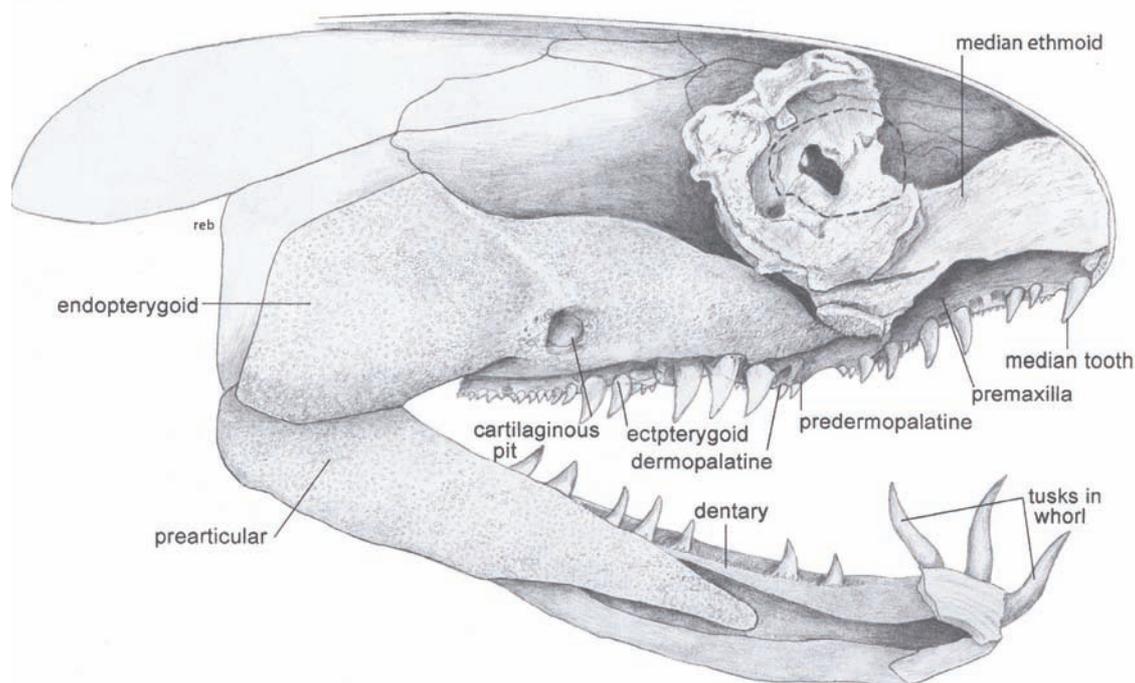
This fauna is of Early Devonian age. It was deposited as a fore-reef carbonate deposit in embayments in the reef system along the Canning Basin edge of the Kimberley Precambrian Massif. Because of the quiet conditions in these embayments, the enclosing sediments frequently covered the bottom dwelling fauna. Many of these organisms were vertebrates, and because some of them after burial were not disturbed by predators, they are preserved in almost three dimensions and their histological structure is preserved in the finest detail. For this reason a large number of organisms have been described. In most other areas the specimens are squashed flat, and the finer details are lost because of alteration. Gogo specimens can be freed from the limestone sediment by etching with acetic acid and such features as the neural system, the vascular systems and the growth patterns of the bones can be displayed. What is more, the techniques developed by Professor Tim Senden and A.J. Lemay in the School of Applied Mathematics, IAS, have enabled us to see details that were not revealed even by etching. This includes internal structures of the braincase and the genital systems.

As examples of the quality of the preservation we refer to four recent discoveries that have hit the headlines.

Andrews, S.M., Long, J.A., Ahlberg, P., Barwick, R.E. & Campbell, K.S.W. 2006. The structure of the sarcopterygian *Onychodus jamdemarrai* n.sp. from Gogo, Western Australia: with a functional interpretation of the skeleton. *Transactions of the Royal Society of Edinburgh; Earth Sciences*: Vol 96: 197-307 Figs 1-75.

Campbell, K.S.W. & Barwick, R.E. 2006. Morphological innovation through gene regulation from Onychodontiform fish. *International Journal of Developmental Biology*, Vol 50: 371-375.

Long, J.A., Trinajstić, K., Young, G.C. & Senden, T., 2008. Live birth in the Devonian Period. *Nature*: Vol 453: 650-652



# Stoichiometry and kinetics of jarosite dissolution in acid sulfate soils

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Jarosite, ideally  $\text{KFe}^{3+}_3(\text{SO}_4)_2(\text{OH})_6$ , is stable under acid oxidising conditions and is an important mineral in acid sulfate soils. It accommodates a wide range of trace cations in solid solution, which can be remobilised if it dissolves. We have found jarosite dissolution to be strongly incongruent: large cations such as  $\text{K}^+$  can be lost or exchanged even when the iron sulfate framework remains largely intact. Rare earth cations display extreme fractionation of LREE into jarosite and exclusion of HREE from it, with the result that dissolution of jarosite produces characteristic MREE enrichment in the associated water. Long-duration kinetic studies show that the dissolution stoichiometry in a closed system evolves in a complex fashion through time, from fast release of sulfate to slower release of Fe to constant in Fe as the system becomes buffered by saturation of Fe-oxyhydroxide phases.

Welch SA, Kirste D, Christy AG, Beavis SG, Beavis F (2007) Jarosite dissolution I - trace cation flux in acid sulfate soils. *Chem. Geol.* **245**: 183-197.

Welch SA, Kirste D, Christy AG, Beavis FR, Beavis SG (2008) Jarosite dissolution II - reaction kinetics, stoichiometry and acid flux. *Chem. Geol.* **254**: 73-84.

Welch SA, Kirste D, Christy AG, Beavis F, Beavis SG (2008) Jarosite reactivity and trace metal geochemistry in acid sulfate soils. Goldschmidt 2008 Geochemistry Conference, Vancouver, Canada, 13 -18 July, 2008. *Geochim. Cosmochim. Acta* **72**: A1013 Suppl. (Refereed conference abstract).

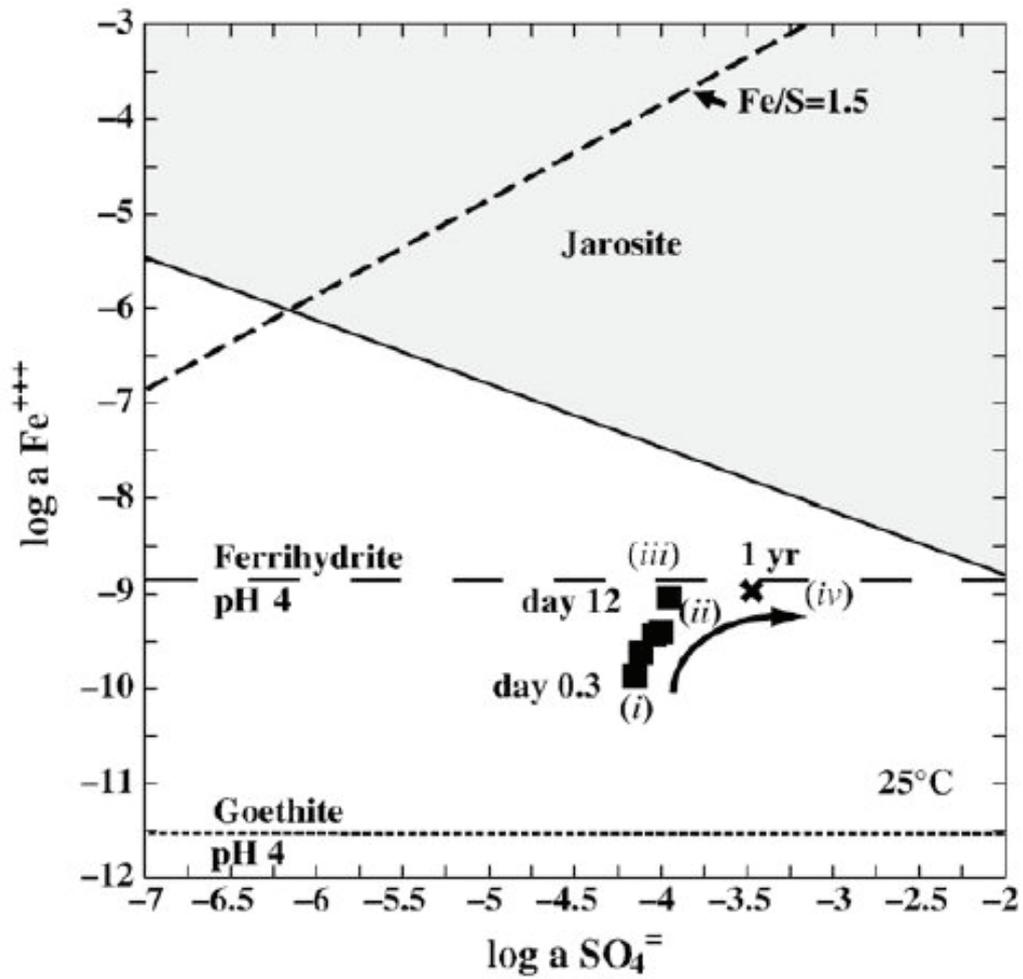


Figure 1. Time evolution of ferric iron and sulfate concentrations in water associated with dissolving jarosite. Stoichiometric dissolution indicated by Fe/S = 1.5 dashed line. Earliest measurements show substantial release of sulfate, followed by slower release of Fe (steep part of curve) until ferrihydrite becomes saturated (flat part of curve). Jarosite saturation ultimately achieved at far right of activity-activity diagram.

# Enhanced detection capability at infrasound stations in the global CTBT verification network

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A 60-station global infrasound monitoring network is being constructed as part of the verification regime for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Nearly 70% of this network has been established and it is anticipated that the network will be completed in the next few years. The network, which is far larger and much more sensitive than any previous infrasound monitoring network, consists of state-of-the-art infrasonic array stations distributed as uniformly as possible over the face of the globe. Current studies indicate that the final global network will reliably detect signals from a 1-kiloton atmospheric nuclear explosion at two or more monitoring stations.

Research at the ANU during the past few years has focused on the development of techniques that can lower detection thresholds, improve location capability and enhance the overall reliability of the network. This has resulted in the development of an optimal infrasonic array design that eliminates problems with spatial aliasing of high frequency signals and problems with signal coherence between array elements. Substantial work has also been carried out on the development of a new and effective technique for reducing wind-generated background noise.

Wind-generated background noise is still the most significant problem at many stations in the global infrasound monitoring network. Wind-generated noise may seriously limit detection capability at stations located in high wind environments with little shelter from the ambient winds. A wind-noise-reducing pipe array is currently used at all infrasound stations in the CTBTO verification network. While these devices provide significant noise reduction, the level of background noise at some stations remains unacceptably high, especially during the daytime. It is generally recognized that further improvements in pipe array design will not resolve this problem. Work at the ANU on infrasound background noise reduction has therefore been concerned with a new approach to the wind-noise problem that appears to have the potential to effectively eliminate wind noise at most monitoring stations.

This technique is based on the use of a turbulence-reducing enclosure constructed from a series of screens positioned around the sensor inlet ports. A large variety of enclosures have been constructed and tested near one of the standard International Monitoring System (IMS) array elements at IS07, Warramunga. A larger than usual 20-m diameter enclosure (version 6) with three concentric porous walls was tested during the year in an attempt to improve the longer period performance of the device. Rather surprising, the performance of this large diameter device was found to be almost identical to a smaller 14-m diameter enclosure (version 5B) with two concentric walls. Both of these enclosures suppress wind-generated noise by up to four orders of magnitude at higher frequencies, even when the sensor is connected to only a single inlet port located at the center of the enclosure.

We conclude that version 5B shown in Figure 1 is the most effective practical design for a turbulence-reducing enclosure.

The performance of version 5B has also been compared directly with the performance of a standard IMS 96-port 18-m diameter pipe array at site H1 at IS07 Warramunga. This comparison shows that the degree of noise reduction provided by the turbulence reducing enclosure with only a single inlet port is more than two orders of magnitude better than the standard 96-port pipe array at higher frequencies. The performance of the pipe array is, however, slightly better at low frequencies.

This suggests that the performance of existing pipe arrays at IMS infrasound stations can be improved very substantially by enclosing the pipe array inside a turbulence-reducing enclosure similar to version 5B. It is recommended that all new IMS stations should be constructed with wind-noise-reducing pipe arrays located inside a turbulence-reducing enclosure.

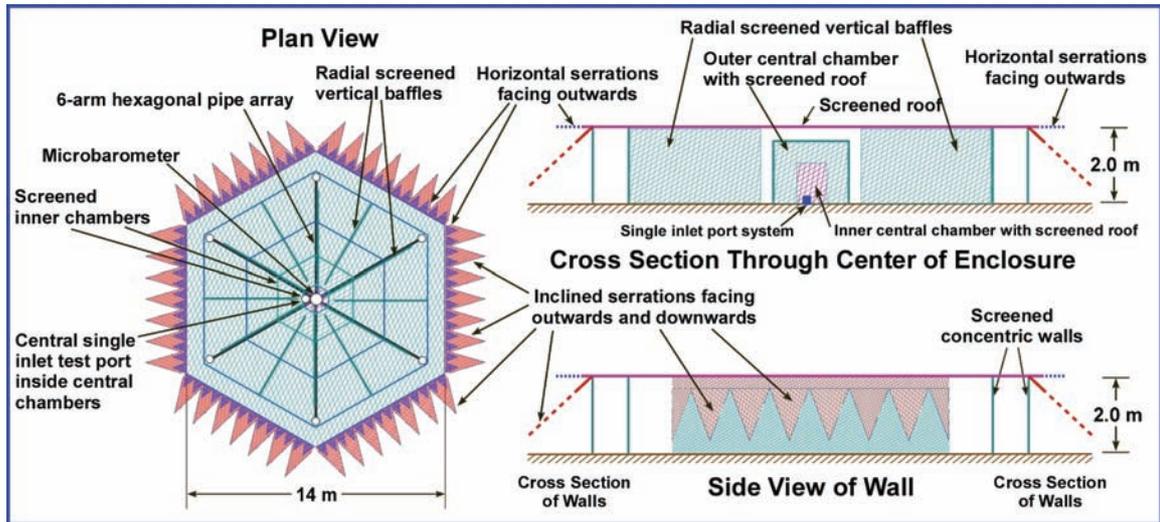


Figure 1. Version 5B of the infrasonic wind-noise-reducing enclosure.

# Effects of Archaean to early Proterozoic asteroid impact clusters on crustal evolution

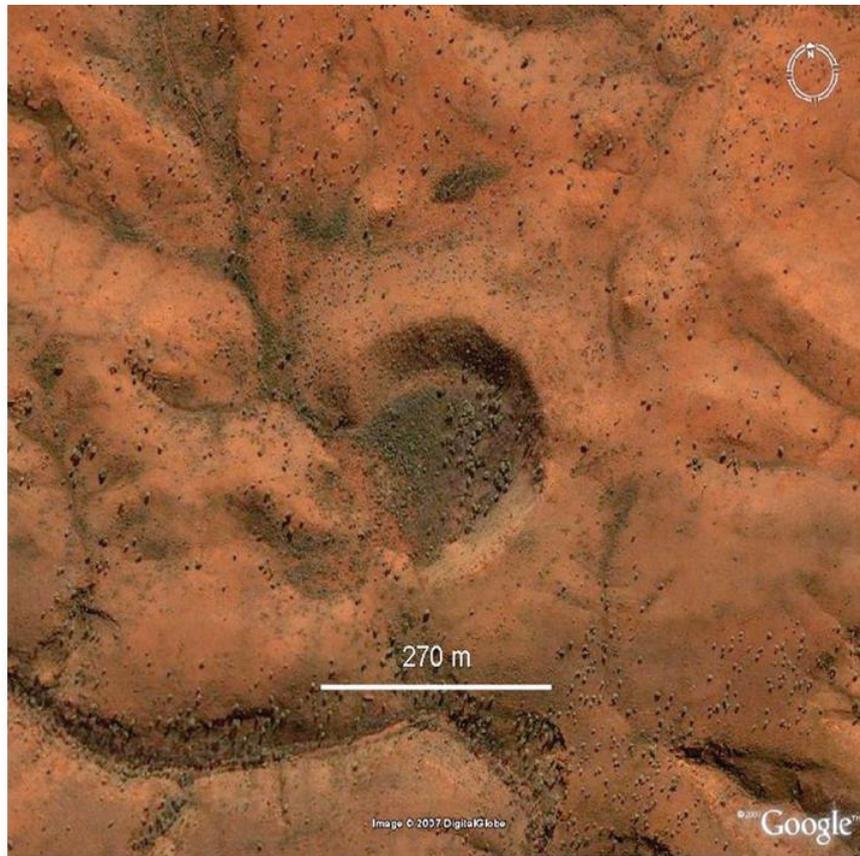
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(joint with, and logistically assisted by, the Pilbara project of the Geological Survey of Western  
Australia).*

The role of asteroid and comet impacts as triggers of mantle–crust processes poses one of the fundamental questions in Earth science. Evidence has been documented for close association between impact ejecta/fallout units with major unconformities and lithostratigraphic boundaries in early Precambrian terrains, including abrupt changes in the nature of volcanic and sedimentary environments across stratigraphic impact boundaries, with implications for the composition of provenance. In the Barberton Greenstone Belt, eastern Kaapvaal Craton, South Africa, 3.26–3.24 Ga asteroid mega-impact units are juxtaposed with abrupt break between mafic-ultramafic volcanic crust and an overlying association of turbidites, banded iron formations, felsic tuff and conglomerates.

Contemporaneous stratigraphic relationships are identified in the Pilbara Craton, Western Australia. Evidence for enrichment of seawater in ferrous iron in the wake of major asteroid impacts reflects emergence of new source terrains, likely dominated by mafic compositions, attributed to impact triggered oceanic volcanic activity. Relationships between Impact and volcanic activity are supported by the onset of major mafic dyke systems associated with ~2.48 Ga and possibly the 2.56 Ga mega-impact events. Abrupt breaks at 3.26–3.24 Ga between ~12 km-thick mafic-ultramafic volcanic sequences of Archaean greenstone belts and overlying felsic volcanic-turbidite-banded iron formation assemblages in the Transvaal and the Pilbara cratons are accompanied by 4 asteroid ejecta units. Mass balance calculations based on Ni/Cr, PGE and <sup>52/53</sup>Cr isotope data indicate mafic-ultramafic target crust and parent asteroid on a scale of 20 – 50 km diameter. Kinematic models of impact by such asteroids on thin geothermally active Archaean crust and lithosphere suggest consequent reorganization of mantle convection cell systems, accounting for contemporaneous peak igneous activity.

The onset of ferruginous sedimentation immediately following the impacts, indicated by occurrence of BIF above ejecta units, indicates increased supply rates of soluble ferrous iron to the oceans under the low Eh conditions of the Archaean hydrosphere, indirectly suggesting the erosion of mafic volcanics possibly triggered by the impacts. A new impact crater discovered by Dr A.H. Hickman and documented by the author is reported in the current issue to the Australian Journal of Earth Science (see Figure 1). The results of this study are reported in 16 papers in international and national scientific journals and in books during 2004 – 2008.



**Figure. 1.** The newly found Hickman Crater, Ophthalmia Range, Western Australia, reported in Glikson et al., *Australian Journal of Earth Science*, December, 2008.

# Clarification of the Influence of Water on Mantle Wedge Melting

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Water is a significant component in primitive island arc magmas and its ubiquitous presence is attributed to release of water from dehydration reactions in subducted oceanic crust and lithosphere. Water released from the subducted slab is inferred to be transferred as aqueous vapour or water-rich melt into the overlying peridotite of the mantle wedge. Because of the inverted temperature gradient inferred for the mantle wedge immediately above the subducted slab, access of aqueous vapour or water-rich melt will initiate melting close to the water-saturated peridotite solidus. The location of a region of water-saturated mantle melting, if it exists, can be predicted if we know the P,T dependence of the water-saturated peridotite solidus and can model the temperature distribution in a particular subduction setting. We have confirmed the results of a number of experimental studies in the 1970's which defined the P,T conditions for the water-saturated solidus of lherzolite up to 3GPa..

We conducted 60 experiments from 1.5 GPa to 6 GPa using different water contents and several bulk compositions. Electron microprobe analyses of 4-7 phases in each experiment document systematic compositional changes in co-existing phases. In addition Fourier Transform Infra-Red (FTIR) spectroscopy was used to measure the water contents of nominally anhydrous minerals (commonly abbreviated NAMS) in 25 of the experiments. The solidus decreases rapidly from  $\sim 1100^{\circ}\text{C}$  at atmospheric pressure to 0.5 GPa,  $1000^{\circ}\text{C}$ , and continues to decrease slightly to a minimum of  $970^{\circ}\text{C}$  at 1.5 to 2 GPa. We demonstrate that for hydrous silicate melt, the fluid-saturated solidus of lherzolite model mantle composition with small (0.2-2%) water contents and very small carbon content, is  $\sim 1010^{\circ}\text{C}$  at 2.5 GPa,  $\sim 1210^{\circ}\text{C}$  at 4GPa. and at least  $1375^{\circ}\text{C}$  at 6GPa.. The melt composition at the water-saturated solidus at 2.5GPa is a very silica-undersaturated olivine nephelinite and is extremely silica-undersaturated at higher pressure.

We also used olivine single crystal discs and either olivine aggregates or carbon sphere aggregates as melt and fluid traps forming interstitial films or inclusions within olivine. For several experiments with high water contents, the capsule was pierced under high vacuum at room temperature and the vapour released was analysed by gas chromatography. We have conducted layered experiments for the purpose of measuring the water content of nominally anhydrous minerals under conditions where we were simultaneously observing melting, water-rich vapour, pargasite or phlogopite in fertile lherzolite. We obtained data using the layered capsules with 'sensor' layers of olivine, low-Al and high-Al orthopyroxene and clinopyroxene, at pressures of 1.5, 2.5, 4, and 6 GPa..

Allowing for the uncertainty in calibrations in the quantification of IR spectra, our results show that if water contents in fertile mantle lherzolite (i.e. HZ1 lherzolite, MORB Pyrolite, MM3 lherzolite ) are as low as 100-250 ppm  $\text{H}_2\text{O}$ , then pargasite is stable at 2.5 GPa and melting begins at the 'fluid-absent lherzolite+  $\text{H}_2\text{O}$  dehydration solidus' which is close to  $1100^{\circ}\text{C}$  for these compositions. With increasing water content the proportion of pargasite at the solidus increases to  $\sim 10-15\%$  (i.e. with 1500-2000 ppm  $\text{H}_2\text{O}$  in the lherzolite) but the water content of NAMS remains unchanged. At higher water contents a water-rich vapour is present and melting begins at the vapour-saturated solidus with pargasite stable at and slightly above the solidus. Our data on the water content in olivine in the sequence from the first appearance of a water-rich vapour (e.g. between 0.073% and 0.145%  $\text{H}_2\text{O}$  at 2.5Gpa,  $1000^{\circ}\text{C}$ ) to 'leached' experiments with 14.5%  $\text{H}_2\text{O}$  show little change with increasing

bulk water content, suggesting that water activity is effectively buffered by the pargasite-bearing assemblage.

At >3GPa, pargasite is unstable and with water contents of 100-250 ppm or more, melting begins at the vapour-saturated solidus which for a water-rich vapour and fertile lherzolite composition is at ~1225 °C at 4Gpa and ~1375°C at 6GPa. The data also show that if a melt is formed at the vapour-saturated solidus at >3GPa ('incipient melting regime') and migrates out of the vicinity, then the water content retained in the residual but still fertile lherzolite (in nominally anhydrous minerals) is 100-250ppm H<sub>2</sub>O. Decompression melting of such residual lherzolite at temperatures in the 'major melting regime' i.e. slightly above the anhydrous solidus, will produce magmas at ~10% or ~20% melting containing 0.1-0.25% or 0.05-0.13% H<sub>2</sub>O respectively, i.e. controlled by the residual water contents retained in NAMS. Such magmas would have incompatible element contents reflecting the history of their source including the loss of very small melt fraction(s) in the garnet lherzolite stability field. These characteristics match those of N-MORB or D-MORB, whereas E-MORB characteristics reflect source lherzolite to which a migrating incipient melt has been added.

# The preservation of microbial lipids in saline and acid-saline environments

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We are currently working on a pair of separate, but related, lipid biomarker analyses on samples from Lake Tyrrell, VIC, Australia, in order to ascertain the timescales and extent of biomarker preservation within a hypersaline lacustrine system. In the context of the primary project, we have obtained a ~13m drill core (see Fig. 1) from the northern end of the lake during field work in July 2008; from this core we are extracting lipids to construct a temporal sequence. Prof S. George and his PhD student, Mr. P.S. Bray, both from Macquarie University, will perform compound specific radiocarbon dating on archaeol extracted from the core and optically stimulated luminescence dating (in collaboration with Dr Kathryn Fitzsimmons, RSES) on quartz lenses within the core to ascertain the timescales over which environmental change occurred. To determine the magnitude and nature of this change, we are examining suites of lipids from each sub-sampled depth to reconstruct the microbial community that was present in the lake at the time the compounds were deposited. The objectives of this work are to 1. Determine the potential for Australian salt lakes to be used as data sources for paleo-environmental reconstruction; 2. Refine estimates of past aridity for the Tyrrell Basin; and 3. Investigate the extent of community restructuring by micro-organisms in response to salinity changes.

The secondary project examines biomarker preservation at pH 4 acidic seeps found at the southern end of Lake Tyrrell. Anoxic, iron-rich ground waters flowing from these seeps oxidize near the surface and result in ferricrete deposition. The ferricretes are composed of quartz-rich lake sediments cemented into meter-scale rocks by iron oxides (magnetite) and oxyhydroxides (goethite). These ferricretes are underlain by typical acid-saline depositional facies, very similar to that encountered at Meridiani Planum on Mars by the rover Opportunity. To determine whether molecular markers for life can coexist with oxidized mineral deposits, we extracted samples of ferricrete and underlying sediments to establish the presence and provenance of free and bound lipid biomarkers.

In order to assess the effects of oxic lithification on redox sensitive lipids, we monitored the concentration of phytanol and its oxidation product, phytanic acid, in ferricretes and surrounding sediment samples. Results indicate that the jarosite-rich ( $\text{KFe}_3+3[(\text{OH})_3\text{SO}_4]_2$ ) sediment directly underlying the concretion is a poor matrix for lipid preservation: only small concentrations of phytanol were evident, and phytanic acid was below detection limits. By contrast, both the goethite-rich layer of the concretion and the reduced sulfide-rich sediments surrounding it showed greater concentrations of each compound (20x and 250x, respectively). Interestingly, the ratio of phytanol to phytanic acid is approximately equal within the oxic concretion and the reduced sediment, indicating that abiotic oxidation is not likely to be a relevant diagenetic pathway for phytanol in this setting.

Differences in compound concentrations between samples demonstrate the differential preservation of lipids within the ferricrete and the underlying sediment. While the concentrations of lipids are ~10 times lower in ferricrete than in sediment, their presence indicates that biomarker molecules may survive the oxidizing conditions of ferricrete formation broadly analogous to those that existed on the Martian surface.

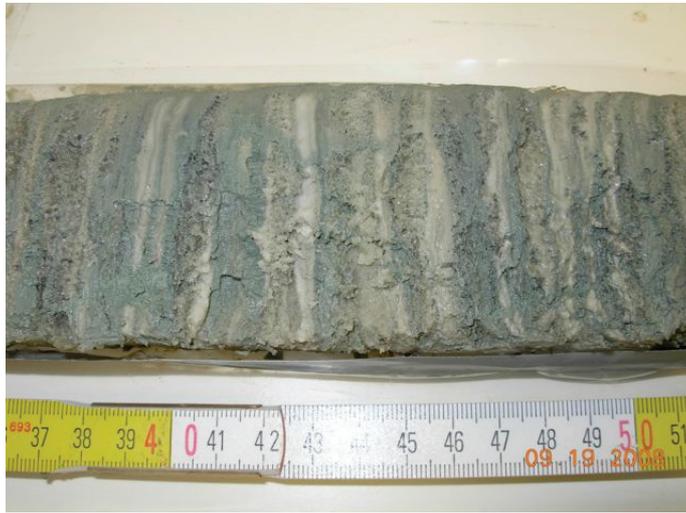


Figure 1. Section of drill core from Site 12 at Lake Tyrrell, ~5m depth

# Oxygen isotope values from Permian high latitudes: clues for palaeolatitudinal sea-surface temperature gradients and Late Palaeozoic deglaciation.

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Institut für Geologie, Mineralogie Korte, C., Jones, P.J., Brand, U., Mertmann, D. & Veizer, J. (2008) Oxygen isotope values from Permian high latitudes: clues for palaeolatitudinal sea-surface temperature gradients and Late Palaeozoic deglaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology* 269, 1-16.

The Permian was a period of waning large-scale continental glaciations in the southern Hemisphere. The waning of these ice sheets during the Early Permian led to discharge of <sup>18</sup>O-depleted ice-melt water into the oceans. This, coupled with rising seawater temperatures, resulted in a concomitant decline of about 2.5 ‰ in the  $\delta^{18}\text{O}$  of seawater, as recorded by brachiopod shells from low-latitude (< 30°) habitats. The transition from ice- to greenhouse conditions is reflected also in the oxygen isotope data of unaltered brachiopods and bivalves from high latitudes. Moreover, the high-latitude specimens have consistently more positive  $\delta^{18}\text{O}$ , by about 2.5 ‰, than their coeval low-latitude counterparts, suggesting a Permian sea-surface temperature (SST) gradient of about 9 to 12°C between tropical-subtropical (<30°) and high southern (55 ± 10°) latitude localities, apparently irrespective of whether in a greenhouse or an icehouse mode. This Permian SST gradient is comparable to the SST gradient of about 14°C. The  $\delta^{18}\text{O}$  seawater records suggest that the global warming that resulted in the waning of the Permo-Carboniferous ice sheets during the Sakmarian was followed by another cooling during the late Kungurian and by renewed warming during the Mid- and Late Permian.

# Australia–Laurasia convergence, Alice Springs Orogeny and tectonic extrusion of the Thomson Orogen

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Most of the year has been spent on fine-tuning the concept by expressing it into figures and finalizing literature searches. The hypothesis has been presented at the Australian Earth Science Convention in Perth. Work is now geared towards publication. Current status of the concept summarizes as follows:

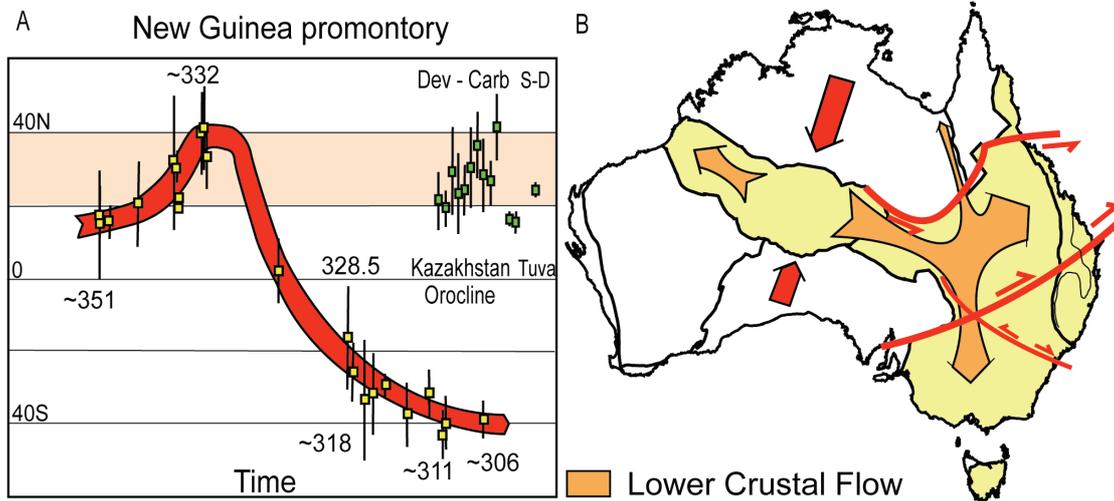
Palaeomagnetic results from the ignimbrite-rich Carboniferous succession of the Tamworth Belt, Southern New England Orogen (SNEO), show a northward excursion over more than 30° of latitude with an apex in middle-late Visean (Figure 1A). The excursion is identifiable also in limited palaeomagnetic data from the Australian craton and the Tasman Orogenic System (TOS) and may have started in the Early Devonian. By middle-late Visean, the promontory of the Australian craton in New Guinea, as part of Gondwanaland, reached 30°–40°N, well within the latitudinal range of the Central Asian Orogenic Belt (CAOB).

Devonian–Carboniferous convergence/collision of northeastern Gondwana (Australia) and southern Laurasia (CAOB) is thought the cause of contemporaneous, Variscan, tectonism in the CAOB and in Australia (Alice Springs Orogeny [ASO], Quilpie and Kanimblan Orogenies). Compressional deformation in Australia was largely confined behind the New Guinean promontory, between the Bintuni, Bonaparte and Ord Basins, Halls Creek Fault Zone and the Lasseter Shear Zone in the west and the Aure Trough, Queensland Basin and Bowen–Gunnedah–Sydney Fault Zone in the east.

Convergence-driven N–S compression, hot crust in the Larapintine Graben and a free oceanic boundary, constituted Variscan Australia–Asia conditions that were comparable to the Cenozoic India–Asia indentation/extrusion. Tectonic extrusion of ductile lower crust (and melt?) from the central Larapintine Graben caused eastward displacement of the Thomson Orogen and the Northern New England Orogen (NNEO) along the Diamantina River Lineament–Clarke River Fault Zone in the north and along the Darling River/Cobar–Inglewood Lineaments and Cato Fracture Zone in the south (Figure 1B). The buttress of the NNEO caused telescoping of an unpinned SNEO during Stephanian reversal of Gondwana's rotation.

Different tectonic grains (ASO, Quilpie, Kanimblan, kinkbanding) represent the integrated effects from convergence/collision on the brittle upper crust (direct N–S compression) and on the ductile, partially molten?, lower crust (hydraulic transmission, fanning out from N–S compression toward alignment with an E–W pressure gradient). A single N–S compressional event can thus lead to contemporaneous deformations with widely different tectonic grains, varying from N–S to E–W.

Seismic tomography shows continental-like velocities in the lower crust/upper mantle of the more internal TOS and E–W fanning of SV azimuthal anisotropy in support of the extrusion model. Large-scale negative magnetic anomalies in the Larapintine Graben and the TOS are likely to represent hematite-residing Kiaman reverse remanence in the lower and upper crust and may trace lower crustal flow throughout the TOS.



**Figure 1** A) Red band shows Carboniferous palaeolatitudes for the New Guinean promontory of the Australian craton according to SNEO results (yellow squares, Klootwijk 2002, 2003, in prep.). Green squares show Devonian-Carboniferous palaeolatitudes for the Kazakhstan Orocline and Tuva terrane of the Central Asian Orogenic Belt. B) Red arrows indicate compression from Australia-Laurasia convergence during the Devonian-Carboniferous. Orange arrows indicate ductile flow of lower crust from the Larapintine Graben into mainly the Thomson and Lachlan Orogens. Major ENE-WSW fault zones guided up to 200 km upper crustal eastward displacement of the Thomson Orogen and the NNEO. The yellow compartments indicate at large the weaker, heated, crust of the Larapintine Graben and the weaker, originally oceanic, crust of the Tasman Orogenic System.

# Chronological control of Plio–Pleistocene strata in the Omo–Turkana Basin, Ethiopia and Kenya

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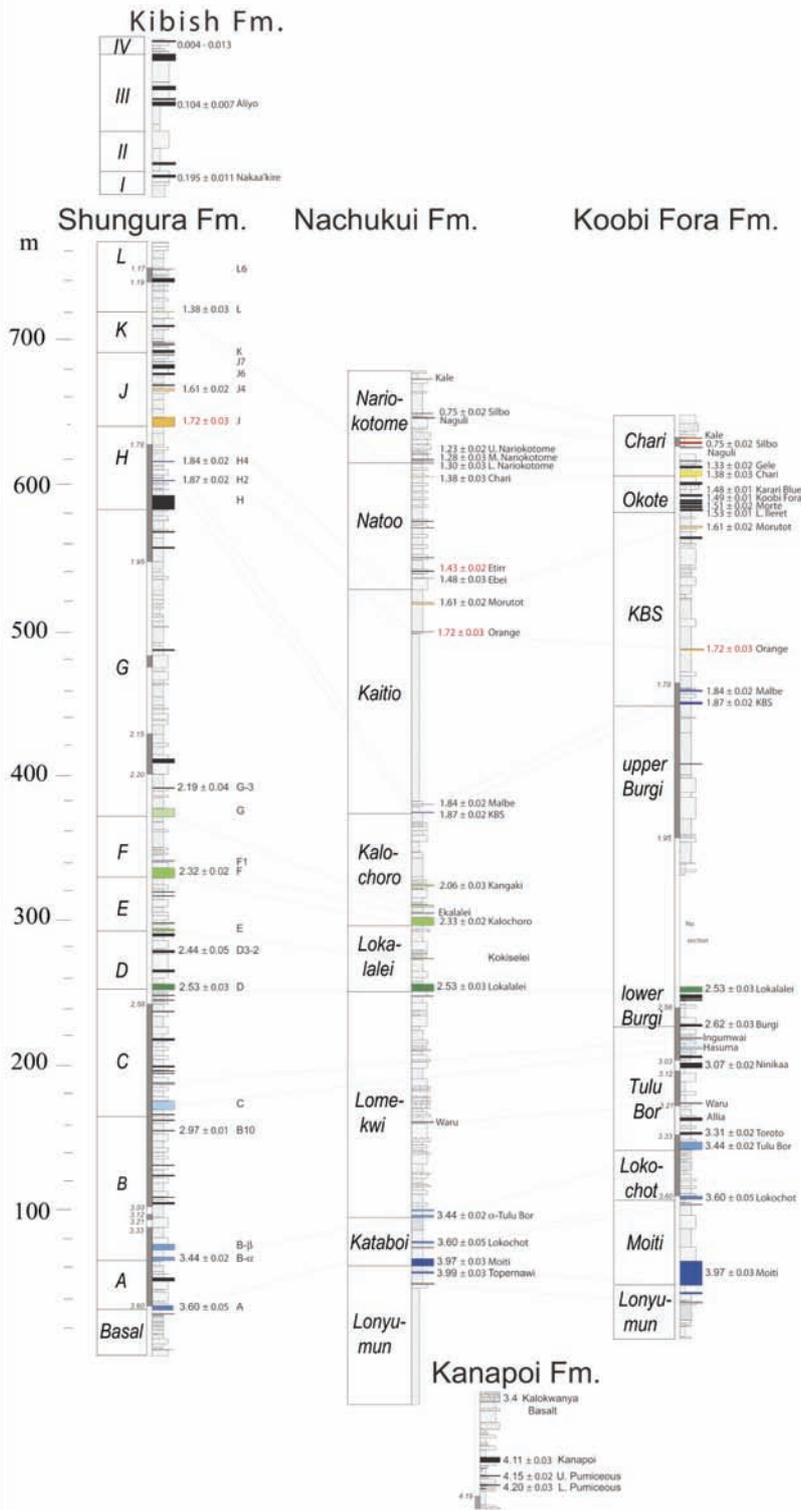
The Omo–Turkana Basin of northern Kenya and southern Ethiopia developed in the northern Kenya Rift about 4.3 Ma ago in the Early Pliocene, with deposition occurring over an area as much as 400 km (N–S) by 70 km (E–W), centred on Lake Turkana. Nearly 800 m of sediments, mainly sands, silts and clays deposited in fluvial, deltaic and lacustrine environments, comprise the Omo Group. Numerous rhyolitic tuffs in the sequence not only have facilitated secure correlations between the formations of the Omo Group but also have provided material for precise <sup>40</sup>Ar/<sup>39</sup>Ar age measurements on single crystals of alkali feldspar separated from pumice clasts within the tuffs.

Ages are now available on over 30 stratigraphic levels, all of which are consistent with their relative stratigraphic order (McDougall & Brown, 2006, 2008). The new ages, which have a precision of the order of 1% (standard deviation of the population), based on pooling of many single crystal ages, are all consistent with the stratigraphic order, providing confidence that they accurately record the timing of the volcanic eruptions, with deposition of the tuffs and pumices occurring shortly thereafter. Thus we now have a robust numerical time framework for the depositional history of the Omo–Turkana Basin.

The majority of the ages lie between 4.2 and 0.75 Ma and have been measured on samples from the three main formations mapped in this large area, with correlations made between sequences on the basis of the distinctive geochemistry of the individual tuffs. The sequence is famous for the very large number of hominin and other vertebrate fossils that have been recovered from it, providing an important record of evolution. It is through the geochronological measurements that we are able to date individual fossils, often to significantly better than 0.1 Ma, through stratigraphic correlations of their position relative to known tuffaceous beds.

This has provided an accurate time scale that is independent of assumptions as to the direction and rate of vertebrate evolution. In some cases we are able to correlate the depositional history in the region with paleoclimatic indicators in deep sea cores, related to Milankovitch cycles and the astronomical time scale. This has been successfully accomplished in relation to the younger Kibish Formation, where correlations have been made with sapropel deposition in the Mediterranean Sea some 3000 km to the northwest (McDougall et al., 2008). With increased precision of the ages, potentially possible using the new generation of multiple collector mass spectrometers for argon isotopic analysis, controls on deposition in the Omo–Turkana Basin related to paleoclimatic factors will become correlateable with the more detailed records in the deep sea cores.

# Principal Pliocene & Pleistocene Formations of the Omo-Turkana Basin



# Early geological investigations of the Pleistocene Tamala Limestone, Western Australia

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**Abstract:** The first geological studies of the Quaternary deposits, which crop out extensively along the coast of Western Australia, were carried out by members of English and French expeditions of discovery, between 1791 and 1836. The exploring parties included scholars with a background in geology, zoology and botany, as well as knowledgeable surgeons and sea captains with a strong interest in the natural sciences. Their collective work established the continuity, over vast distances, of a sequence of sedimentary rocks composed of quartz grains and shell debris, which today form the major part of the Tamala Limestone sequence. Their observations of the internal features of these rocks led some among them to develop views on the nature and origin of the cementing substance that bonds sand grains and shell debris in sedimentary layers and in concretions. There was disagreement among successive parties of visitors on the nature and origin of rhizoliths and other petrified woody matter in calcareous rocks. The finding of well-preserved sea shells in rocks now above sea level provided convincing evidence to investigators that the ocean had, in recent times, retreated from the land. The discovery of species of mollusc, known to be extinct in Europe, raised questions about an assumed world-wide extent of sedimentary sequences.

# Evolution of the Svecofennian orogenic province

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In several areas of the Svecofennian Province, a major discontinuity has been recognized between Svionian complexes, strongly deformed and metamorphosed at ~1.92 Ga, and overlying post-1.92 Ga Bothnian volcano-sedimentary sequences (Annual reports, 2005, 2006, Skiöld and Rutland, 2008). In Ostrobothnia, Finland (Williams et al., 2008), a similar discontinuity has now been identified within the mostly metasedimentary Western Pohjanmaa Belt and separates two distinct stratigraphic groups. The western Lappfors group, interpreted as a Svionian basement complex, has strong W-trending folding and aeromagnetic signatures that contrast with the unconformably overlying eastern Evijärvi group, interpreted as lower Bothnian, which has more open N-trending folding and magnetic patterns. Several lines of evidence date the unconformity at ~1.92 Ga. Detrital zircons from two samples of Lappfors group metasediment, and a sample of the basal Nivala gneisses in the Eastern Pohjanmaa Belt, have 1.92–1.91 Ga post-depositional low-Th/U metamorphic overgrowths.

The maximum deposition age of the Lappfors sedimentary protoliths, based on detrital zircon ages, is between ~1.97 and ~1.94 Ga. Three samples of Bothnian sediments lack pervasive ~1.91 Ga overgrowths, instead having a variety of detrital zircons as young as ~1.95–1.91 Ga, reflecting recycling of the underlying basement complex. The maximum deposition age of the lower Bothnian sedimentary protoliths is inferred to be ~1.91 Ga. The Niska granite, which intrudes the Evijärvi group and is deformed only by the younger tectonic episode affecting that sequence, has a zircon age of  $1896 \pm 6$  Ma. That episode, which established the present relationships between basement and cover, is dated by ~1.88 Ga metamorphic zircon overgrowths in both the Svionian and Bothnian samples, and by  $1878 \pm 4$  Ma metamorphic monazite from a metasediment from the Savo Belt, east of the Nivala district.

Part of the FIRE 3A reflection seismic profile (Kukkonen et al., 2006; Sorjonen-Ward, 2006) ran NW from the western part of the Central Finland Granitoid Complex (CFGC) across the boundary with the Evijärvi group and into the Lappfors group. Our preliminary interpretation of this section (Kousa et al., 2008) suggests that the Svionian Lappfors group is the surface expression of a middle crustal unit that displays a widespread system of E- to SE-dipping reflectors with listric-type geometry, identified by Kukkonen et al. (2006, pp.29-30). This crustal unit may therefore correspond to the accreted Svionian marginal basin, buried to the east beneath the younger, Bothnian, volcano-plutonic complex. As a corollary, the widespread vertical change in reflectivity between upper and middle crust, (op. cit. p.21), and which is present beneath the western CFGC, may be closely related to the change from the overlying Bothnian complexes to underlying Svionian metamorphic complexes.

We now interpret the observed stratigraphic and structural relationships in Ostrobothnia in terms of an extended orogenic evolution, viz.

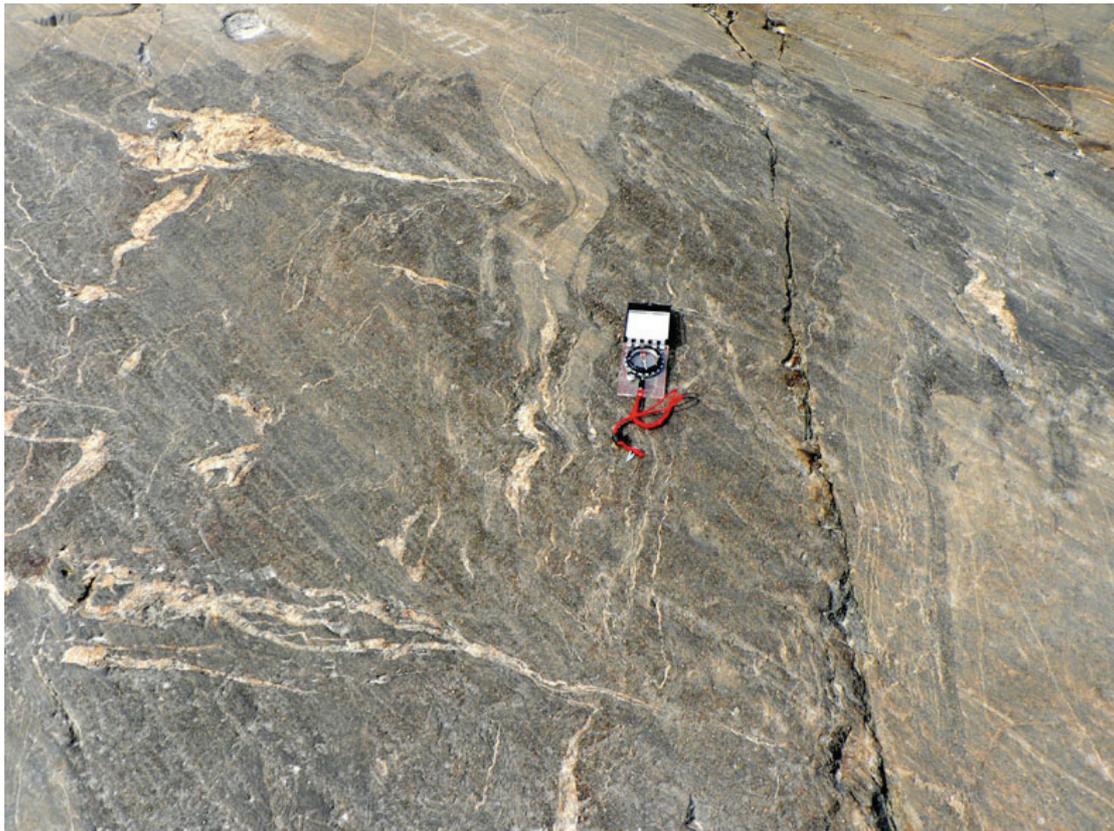
- (1) Deposition of the Lappfors group, with local maximum deposition ages between ~1.97 and ~1.94 Ga as part of an extensive Svionian marginal basin.
- (2) Early Svecofennian (D<sub>1</sub>) closure of the Svionian Basin at ~1.92 Ga involving possible subduction zones.

- (3) An extensional episode during which the Svionian complex was eroded and the lower Bothnian Evijärvi group with its submarine mafic volcanism was deposited at ~1.91–1.90 Ga in a successor marginal basin.
- (4) Transition from marine to terrestrial deposition at ~1.90–1.89 Ga as bimodal calc-alkaline volcanism developed, the upper Bothnian sequence was deposited, and early plutonism occurred.
- (5) Continued plutonism and Middle Svecofennian ( $D_2$ ) deformation at ~1.88 Ga, during which  $D_2$  folds, faults and shear zones were superimposed on the earlier W-trending penetrative  $D_1$  structures in the Lappfors group (Fig. 1). These  $D_2$  structures are largely responsible for the present relationship between the Svionian basement and the Bothnian cover.

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 Sorjonen-Ward, P., 2006. Geological and structural framework and preliminary interpretation of the FIRE 3 and FIRE 3A reflection seismic profiles, central Finland. *Geological Survey of Finland Special Paper* 43;105–159.

Williams, I.S., Rutland, R.W.R., Kousa, J., 2008. A regional 1.92 Ga tectonothermal episode in Ostrobothnia, Finland: Implications for models of Svecofennian accretion. *Precambrian Research* 165;15–36



**Figure 1.** Tight ~1.92 Ga pre-Bothnian folds in the Lappfors group overprinted by open minor folds, crenulations and veins (left to right) of the post-Bothnian ~1.88 Ga episode. Note the glacial striae from top left to bottom right.

# Silurian brachiopod faunas, Yass Syncline – taxonomy and biostratigraphy

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A paper on the rhynchonellide species in the Yass fauna, previously undescribed, has been accepted for publication in the Proceedings of the Linnean Society of NSW, with an expected publication date of February 2009. Work is well advanced on revising, and adding to, the species of spiriferide brachiopods from the same succession. This will also involve revision of some species known from the slightly older succession in Canberra. The only remaining aspect of the study will be a compilation of all the biostratigraphic data, for presentation at the next Brachiopod Congress in Melbourne in February 2010.

Sections on Silurian stratigraphy and palaeontology were provided for the recent publication on the geology of the Canberra region compiled by D. Finlayson and published by the ACT Division of the Geological Society of Australia, and I was one of the few involved in reviewing and editing the whole volume. I was also involved in editing a generalized geological map of the ACT prepared by R.S. Abell and D. McCue also under the auspices of the Geological Society of Australia.

As a result of recent excavations in the heritage area on Woolshed Creek, Pialligo, large collections have been made which will be used to revise the species present, particularly the dominant one (*Atrypa duntroonensis*). It was this species which was recognized by Rev. W.B. Clarke as being, for the first time, an indicator of the presence in Australia of Silurian rocks. This study will follow completion of the Yass study, and will be the start of further work on the brachiopod faunas of the Canberra region.

I was consulted by the contractors and Heritage ACT on the possible impact of the work on the Woolshed Creek heritage site, and as a result of that early involvement the workers have been extremely cooperative and interested in preserving as much as possible – the original outcrops are untouched.