

Geological Society of New Zealand



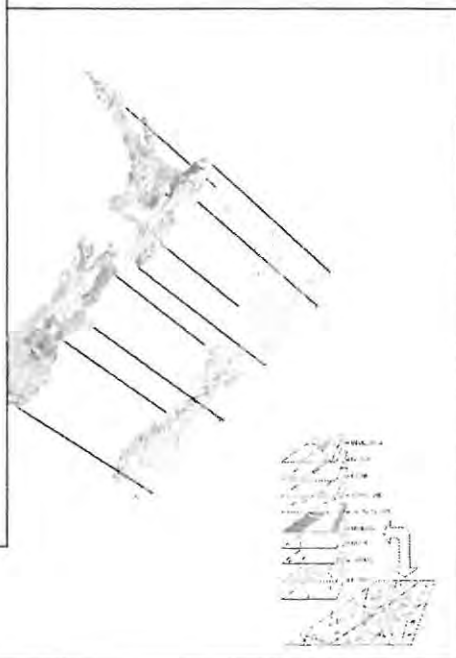
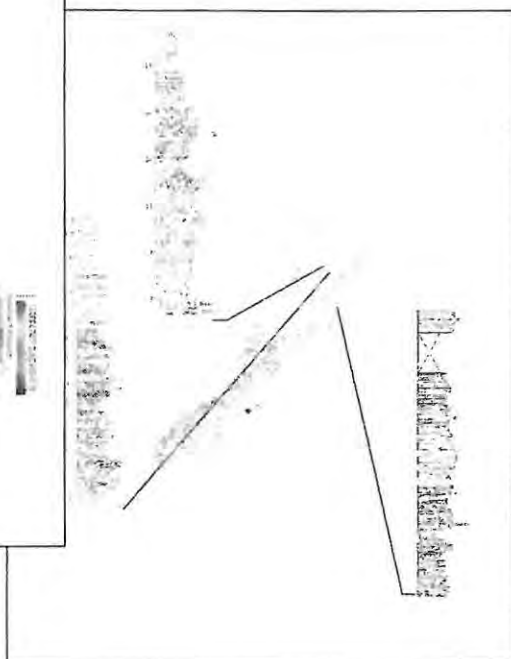
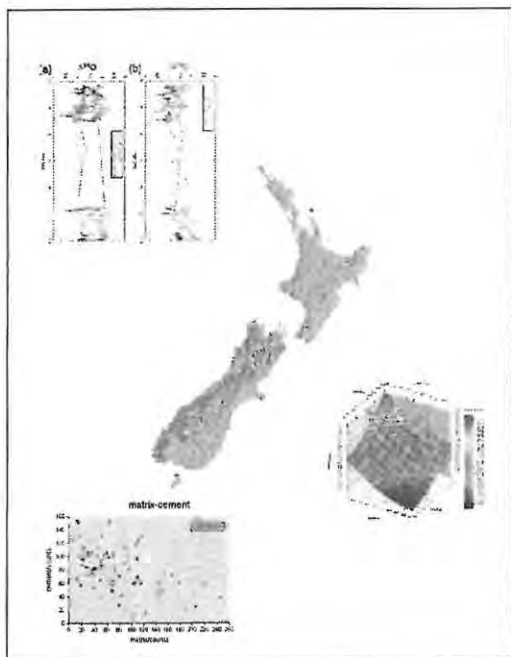
Annual Conference 2001

27th - 29th November, Hamilton

"Advances in Geosciences"



The University of Waikato
Te Whare Wānanga o Waikato



Abstracts & Programme

Bibliographic References:

Abstracts & Programme

Lowe, D.J., Cooke, P.J. and Pallentin, A. Editors (2001): Abstracts & Programme, Geol. Soc. of NZ Annual Conference 2001 "Advances in Geosciences", Univ. of Waikato, Hamilton. Geol. Soc. of NZ misc. publication 110A.

Fieldtrip Guides

for entire guidebook

Smith, R.T., Editor (2001): Fieldtrip Guides, Geol. Soc. of NZ Annual Conference 2001 "Advances in Geosciences", Univ. of Waikato, Hamilton. Geol. Soc. of NZ misc. publication 110B.

for separate guide (e.g.)

de Lange, W.P. (2001): Coastal hazards of coastal Bay of Plenty. In: Smith, R.T. (Editor), Fieldtrip Guides, Geol. Soc. of NZ Annual Conference 2001 "Advances in Geosciences", Univ. of Waikato, Hamilton. Geol. Soc. of NZ misc. publication 110B, x-yp.

GIS Workshop

Fuchs, A., Pallentin, A. and Vonk, A., Editors (2001): GIS Workshop, Geol. Soc. of NZ Annual Conference 2001 "Advances in Geosciences", Univ. of Waikato, Hamilton. Geol. Soc. of NZ misc. publication 110C.

Geological Society of New Zealand



Annual Conference 2001
27th - 29th November, Hamilton
"Advances in Geosciences"

Abstracts & Programme



Edited by

David J. Lowe, Penelope J. Cooke and Arne Pallentin
Department of Earth Sciences, University of Waikato, Private Bag 3105, Hamilton

Convenor: David Lowe

Organising Committee:

Adam Vonk, Richard Smith, Arne Pallentin, Peter Kamp, Barbara Hobden, Anne Hinton, Andreas Fuchs, Willem de Lange, Penelope Cooke, Roger Briggs

Support:

Janet Simes (Conference Manager), Simon Nathan, Ainsley Sanderson, Laurence Gaylor, Annette Rodgers, Blair Lynch-Bloss, Renat Radosinsky, Peter Hodder, Rochelle Hansen, Kyle Bland, Geoff Kilgour, Liz Brodie, Sydney Wright, Elaine Norton, Steve Bergin, Alison McHugh, Chris Hendy, Carole Mardon, QMAP Team (IGNS)

and other Staff and Students of the Department of Earth Sciences,
University of Waikato

Special Thanks to our sponsors:

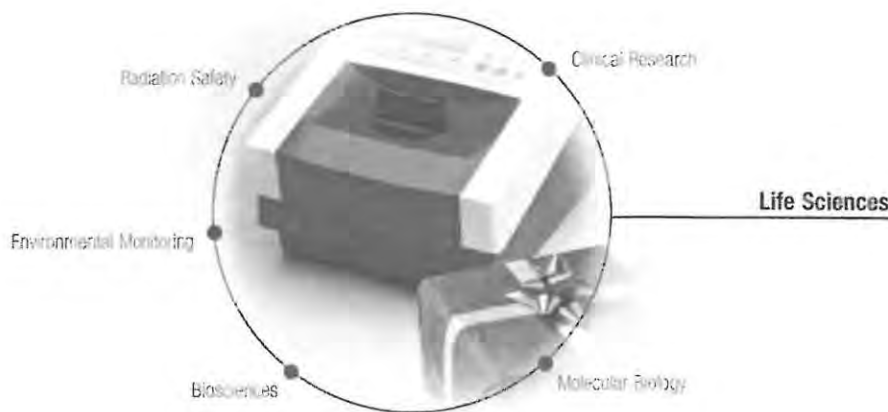
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Introduction

For participants who have travelled from overseas, we welcome you to New Zealand or Aotearoa – “Land of the Long Linger Day” – and the conference. We hope your short stay in New Zealand is both informative and friendly. For the New Zealanders, welcome to Hamilton and the University of Waikato.

The conference has been organised by staff and students of the Department of Earth Sciences of the University of Waikato and by members of the Waikato Branch of the Geological Society of New Zealand. It has been organised on a three-day format (Tues 27 – Thurs 29 November). Each day begins with a series of short invited plenary addresses in L-block lecture theatre no. 1 (L1). The conference then moves to the WEL Academy for the Performing Arts for poster paper presentations prior to lunch (Tuesday and Wednesday). Afternoons each day are devoted to oral paper presentations in four concurrent sessions in L-block lecture theatres L1-L4. Another session of oral papers is scheduled on Thursday morning, before lunch, in place of poster paper presentations. The conference is due to conclude at 4.00 p.m. on Thursday. Note that poster papers will remain on display for the entire duration of the conference.

There are five one-day pre-conference field trips (Mon 26 November) and two three-day post-conference field trips (Fri 30 November – Sun 2 December). A one-day pre-conference GIS Workshop has been organised for Mon 26 November and is fully subscribed. Fieldtrip guides have been compiled into one volume and, as a bonus, all full registrants will receive a copy.

As this goes to press, the conference has more than 180 registrants, nearly a dozen being from overseas. Around 55 students have registered. There are 158 papers in the programme, comprising 10 plenary papers, 88 oral papers, and 60 poster papers.

The organising committee is very grateful to many various sponsors (named elsewhere in this volume) for their support for the meeting. Such sponsorship is essential to the viability of the conference. The support and hard work of the symposia convenors, field trip leaders, and GIS workshop leaders are also much appreciated. The session chairpersons are thanked as well, as are all those involved in catering, accommodation, publications, and IT support. The convenor especially thanks the plenary speakers, and geoeducation keynote speaker Gary Lewis, for their fine efforts. Finally the convenor acknowledges the strong support he has received from the committee and associated helpers, and from Roger Briggs (Chairperson, Department of Earth Sciences), Richard Price (Dean, School of Science and Technology), Simon Nathan (President of GSNZ 2000-2001), Janet Simes (Absolutely Organised), Ainsley Sanderson (Waikato University conference support), and from his family in making preparations for the conference over the past twelve months.

Contacts:

Incoming messages can be sent to delegates via the Dept. of Earth Sciences office (E2.07), or the conference information desk.

Department of Earth Sciences office	Phone 07 838 4024
Dept of Earth Sciences FAX	FAX 07 856 0115
Dept of Earth Sciences Email	s.wright@waikato.ac.nz
Conference information desk	021 293 2642 Janet Simes
Academy manager	Phone 07 858 5105, FAX 07 858 5113, annika@waikato.ac.nz
Bryant Hall	07 838 4070 (or 0800 279268)
Convenor	d.lowe@waikato.ac.nz

Conference at a glance

Monday 26 th	Tuesday 27 th	Wednesday 28 th	Thursday 29 th	Friday-Sunday 30 th Nov – 2 nd Dec
GIS Work- shop	Opening 8.30-9 am		Hastie awards 8.30-8.50 am	Three-day field- trips
One-day fieldtrips	Plenary 1 9-10.35am	Plenary 2 8.30-10.15am	Plenary 3 8.50-10.35am	
	Morning tea 10.40-11am	Morning tea 10.20-10.50am	Morning tea 10.35-11am	
	Posters 11am-12.30pm	Posters 10.50am-12.20pm Geoed workshop 11am-12pm	Oral session 4 11.0am-12.25pm	
	Lunch 12.30-1.30pm	Concert 12.20-12.50pm Lunch 12.50-1.30pm	Lunch 12.30-1.30pm	
	Oral session 1 1.35-3.15pm	Oral session 3 1.35-3.20pm	Oral session 5 1.35-3.00pm	
	Afternoon tea 3.15-3.40pm	Afternoon tea 3.20-3.50pm	Afternoon tea 3.00-3.30pm	
	Oral session 2 3.40-5.25pm	AGM 4-5.30pm	Awards & closing 3.30-4.00 pm	
	BBQ 6-9.30pm	Conference Dinner 6-10.30pm	Post-conference fieldtrips depart	

Registration and Information Desk:

The information desk will be combined with registration on Monday 26th Nov. Registration at Bryant Hall Buttery 5.30 p.m. - 8.30 p.m. Then in the Academy Foyer on Tuesday 27th from 7.30 am; available most other times (to be advised) until Thursday morning.

Oral papers:

Oral presentations have been allocated to symposia and session times. All orals will be presented in the L-block lecture theatres (lecture rooms L1-L4). Please provide PowerPoint files well before you intend to use them (you may need to replace fonts etc). Lecture room L5 is allocated as the AV/IT preparation room, and there will be slide projectors and computers available for presenters to check their presentations. Each lecture theatre has two screens with PowerPoint & data projector, one slide projector, and one overhead projector available. Oral papers are all of 20 minutes duration (15 min talk plus 5 min discussion). Please keep to time.

Poster papers:

All posters have been allocated to symposia and will be displayed in the WEL Academy for Performing Arts in adjacent poster halls Te Whare Tapere Iti and the Dance Studio. Posters can be put up on Monday evening from 5.30 pm, or Tuesday morning from 7.30 am. Authors are asked to be available by their poster, either on Tuesday (even numbered posters) or Wednesday (odd numbered posters) mornings. Posters should be available to all delegates until Thursday 4 pm, when they can be taken down.

Conference meetings:

Monday 26 th	National committee meeting 7.30pm in Bryant Hall dining room Annex
Tuesday 27 th	Student Prizes committee 10.40 am (Academy), and 5.30pm (L-block)
	Historical group meeting/other interest groups 12.30-1.30 pm Lunch
Wednesday 28 th	Student Prizes committee 3.20-3.50 pm Afternoon tea
	AGM 4.00-5.30 pm in L1
Thursday 29 th	National committee breakfast 7.00 am in Bryant Hall dining room/Annex
	Special interest groups/Women in Geoscience 12.30-1.30 pm Lunch
	Student Prizes committee 3.00-3.30 pm Afternoon tea
	Student awards & closing 3.30-4.00 pm in L1

Refreshments:

Morning & afternoon tea, and lunches are provided to all conference registrants. All lunches will be served in the foyer of the WEL Academy for Performing Arts. On Tuesday and Wednesday morning tea will be served in the Academy, but on Thursday it will be served in the L block foyer. All afternoon teas will be served in the L block foyer.

There are a number of other options on or near the campus:

- | | |
|----------------------|--|
| The Station café | - Hillcrest Road |
| Planet Espresso café | - Student Union Building |
| McDonalds | - Oranga Building |
| Stones café | - Knighton Road shops, just along from Bryant Hall |

Social events:

BBQ on Tuesday 27th Nov. held on lawn outside dining room and Buttery at Bryant Hall. This event starts at 6.30 p.m. and is open to all conference registrants (no charge). Some drinks provided, then a cash bar will operate in Buttery. Informal student get-together from 6.00 pm.

Conference dinner on Wednesday 28th Nov. This event is by ticket only and is being held at the Hamilton Gardens. Transport is provided from Bryant Hall, with the first

bus leaving at 6 p.m. and the second at 6.15 p.m. On arrival at the gardens delegates will have the opportunity to stroll around the Themed Gardens and dinner starts at 7.30 p.m. (don't be late) in the Pavilion (Central Court room). Transport back to Bryant Hall will be provided at 10.15 p.m. and 10.30 p.m.

Bar - A cash bar will operate in Bryant Hall Buttery each evening: Mon/Tues 5.30-9.30 pm; Wed 5.30-7.00 pm.

Lunch time concert:

The Turnovsky Trio will perform in the Academy concert chamber 12.20-12.50 Wednesday 28th Nov. All welcome, no charge.

Trade displays:

Several trade displays have been set up in the foyer of the WEL Academy.

Student travel awards:

Cheques may be collected from the information desk.

Campus Facilities:

Campus Police – based in basement L block extn 4550

Campus security (Unisafe) – extn 4444

Library – open 8.30 am – 5 pm

Parking – main carpark via Gate 1, Knighton Road, and Bryant Hall carpark

Money machines – along walkway labelled 'shops' on the map

Medical centre – open 8.30 am – 5 p.m., entrance off main carpark, Gate 1

Campus Pharmacy – located in student union building open 8.30 am – 5 p.m.

Campus bookshop (Bennetts) – located under the library open 8.30 am - 5 p.m.

Hamilton City Facilities:

Refreshments:

In Hamilton there is, frankly, an amazing array of restaurants and cafes in the city centre (Victoria St) catering to most tastes, along with pubs and bars.

Public Bus timetable:

Route 13 buses into Hamilton City depart from the campus bus stop near the student union building and a timetable will be available from the information desk during the conference. Unfortunately, buses do not run in the evenings. Phone 856 4579.

Taxis:

The following taxis companies operate in Hamilton City, local phone numbers given and approximate cost of a journey from Bryant Hall to the city centre (in brackets):

Dial a cab	847 5050	
Hamilton taxis	847 7477	major credit cards, no eftpos (approx. \$15)
Red Cabs	839 0500	major credit cards
Taxi combined	839 9099	major credit cards
The cab company	855 8585	
Wright Taxis	856 0000	Eftpos & visa/master card (approx. \$6-8)

Airport Shuttle:

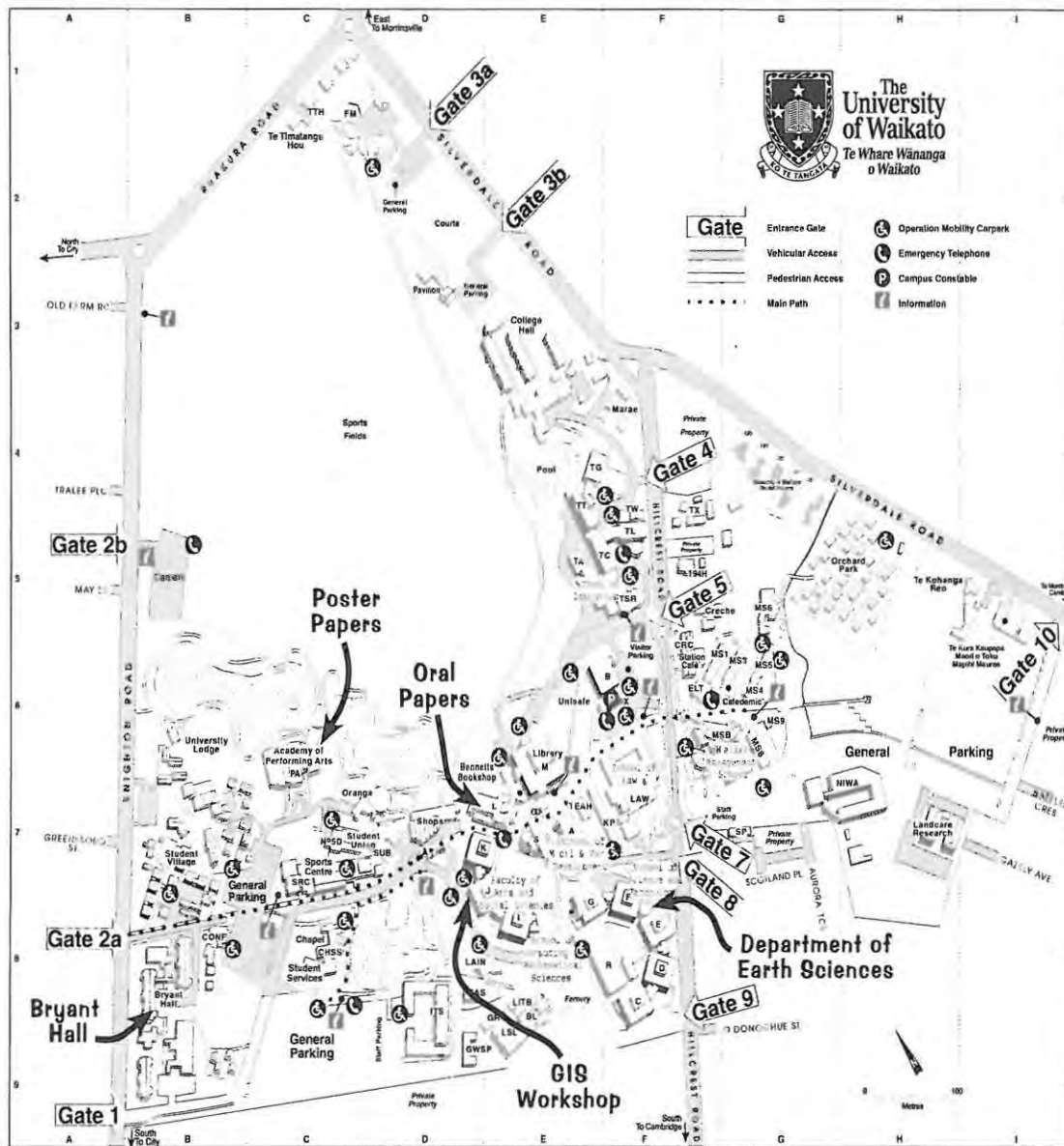
Transport to the airport can be arranged. Phone 07 843 7778 (major credit cards - approx. \$10 University to Airport).

Waikato Museum of Art and History:

Entrance is free, but visitors are asked to consider a small donation. Exhibits in November include: the Von Tempsky water colours and a photographic exhibit on Lake Taupo.

Excite Science centre:

Excite is next to the museum and there is a charge for entrance. The exhibit on during November is 'Out of the toy box' and features amongst other things, interactive toys. Open 10 am to 4.30 pm.





Programme

Tuesday 27th			Page
8.30-9.00 am	L1 - David Lowe (Chair) Plenary 1: Simon Nathan	Opening addresses: Richard Price, Dean of Science & Technology, University of Waikato; Simon Nathan, GSNZ President	
9.00-9.30	P. Kamp et al.	An overview of the Wanganui Basin and its relationship to Taranaki and King Country Basins	76
9.30-10.00	A. Nicol	Fault growth by repeated earthquakes	114
10.00-10.30	C. Hendy	From glacial drift to deep-sea cores.....	59
10.00-10.35 am - Notices			
10.40-11.00 am - Morning tea in the Academy			
11.00-12.30		Posters in the Academy (even numbers) Chair: Penelope Cooke	
12.30-1.30 pm - Lunch in the Academy		Special interest groups meeting - Historic (Mike Johnson)	
Tu session 1A			
L1: Peter Kamp		Sedimentary Basins	
1.35-1.55	M. Laird, K. Bassett, J. Bradshaw, H. Morgans, P. Schipler & S. Weaver	Tumult at Tora - the KT succession in SE Wairarapa	85
1.55-2.15	D. Jugum	Sedimentary structures and oblique planar concretions within a bioclastic sandstone ("Hoteo Beds") from the Miocene Waitemata Group	74
2.15-2.35	S. Hood, C. Nelson & P. Kamp	Diagenetic evolution of the Tikorangi Formation, Waihapu-Ngaere Field, Taranaki Basin: A cool-water carbonate fracture reservoir	69
2.35-2.55	G. Dix & C. Nelson	Significance of some sequence boundary events in the Late Oligocene Terehina Formation, Coromandel Peninsula, New Zealand	33
2.55-3.15	H. Nicholson	Moving views from a shifting outcrop 1950-1985: Another chapter in the history of thought about the New Zealand greywackes	113
3.15-3.40 pm - Afternoon tea in L block			
Tu session 1B			
L2: David Kennedy		Marine and Coastal	
1.35-1.55	N. Domijan, T. Healy & K. Black	Modelling of tidal and current propagation in a shallow Maketu Estuary	34
1.55-2.15	K. Barnett, W. de Lange & R. Bell	The behaviour of storm surges in Whangarei Harbour and Bream Bay	6
2.15-2.35	A. Dunn & W. de Lange	Coastal processes linked to beach erosion at Wainui Beach, Gisborne	35
2.35-2.55	H. Hope, M. Green, & W. de Lange	The sediment dynamics of Waikaraka Estuary: an arm of the Tauranga Harbour estuarine system	70
2.55-3.15	A. Hinton & N. Hartstein	Sediments at Turakirae Head: Onshore and offshore	65
3.15-3.40 pm - Afternoon tea in L block			
Tu session 1C			
L3: Dean Fergusson		Mining (Sponsor: Solid Energy North)	
1.35-1.55	R. N. Campbell	Reconciliation and validation of geological hazards and mining conditions from 3D-seismic reflection data	19
1.55-2.15	R. Boyd	Integrated use of a site-specific drilling strategy, coal chemistry and geostatistics to increase geological confidence - examples from the Spring Creek Mine, Greymouth Coalfield	13
2.15-2.35	D. Mackie & M. Hall	Reserving opencast coal mines with previous underground workings	98
2.35-2.55	J. D. Johnson & D. Fergusson	Engineering geological models for slope design, Rotowaro coalfield, Huntly	73
2.55-3.15	M. Irwin	Structure at the Golden Cross opencast mine, Waihi, New Zealand	72
3.15-3.40 pm - Afternoon tea in L block			
Tu session 1D			
L4: Hamish Campbell		Palaeontology	
1.35-1.55	D. Lee & W. Lee	Does paleontology have a future in New Zealand? - Rediscovering the relevance of the past	89
1.55-2.15	Ha. Campbell	New Zealand fossil collection in the 21st century: The case for national natural heritage status	17
2.15-2.35	M. Eagle	Mesozoic crinoidea in New Zealand and New Caledonia	37
2.35-2.55	M. Gregory	Protovirgularia - local record of a seldom-recognised ichnotaxon	49
2.55-3.15	D. Hikuroa	The Jurassic Latady Formation, Antarctic Peninsula	64
3.15-3.40 pm - Afternoon tea in L block			

Tuesday continued			
Tu session 2A	L1: Cam Nelson	Sedimentary Basins	Page
3.40-4.00	<u>A. Vonk, P. Kamp & A. Hendy</u>	Geological development of the Late Miocene-Early Pliocene succession (Matemateaonga and Kiore Formations), eastern Taranaki Peninsula	151
4.00-4.20	<u>A. Hendy, A. Vonk & P. Kamp</u>	Taphonomic signature of shell accumulations in the Matemateaonga and Kiore Formations (Wanganui Basin): Taphofacies as indicators of depositional environments	58
4.20-4.40	<u>R. Hansen & P. Kamp</u>	Giant foresets formation, Northern Graben, Taranaki Basin: Development of the Late Neogene prograding continental margin	55
4.40-5.00	<u>V. Caron & C. Nelson</u>	Diagenetic and sedimentological recognition of high-order (c. 150-20 ky) parasequences in cool-water carbonates: Plio-Pleistocene Te Aute limestones, New Zealand	22
5.00-5.20	<u>K. Bland, P. Kamp & C. Nelson</u>	Analysis of the Pliocene forearc basin succession, Esk River catchment, Hawke's Bay	11
5.20-5.25 pm - Notices			
Tu session 2B	L2: Anne Hinton	Marine and Coastal	
3.40-4.00	<u>A. Golik</u>	Pattern of sand transport along the Israeli coastline	47
4.00-4.20	<u>A. Orpin, K. Lewis, L. Carter, C. Alexander, S. Kuehl</u>	New sediment pathways on the Poverty Bay continental slope that bypass the major submarine canyon system	119
4.20-4.40	<u>K. Lewis & H. Pantin</u>	Sediment waves, channel return-flow, and start of very long distance turbidity currents in the southern Hikurangi Trough	92
4.40-5.00	<u>D. Kennedy</u>	Carbonate sedimentation on subtropical shelves around Lord Howe Island and Ball Pyramid, southwest Pacific	79
5.00-5.20	<u>P. Cooke, C. Nelson & C. Hendy</u>	Late Miocene cooling trends of southern Tasman Sea palaeotemperatures: How cool is cool?	26
5.20-5.25 pm - Notices			
Tuesday 2C	L3: Roger Briggs	Mining (Sponsor: Solid Energy North)	
3.40-4.00	<u>S. Henley & K. Inwood</u>	Effect of fires and old mine workings on potentially mineable coal resource, Millerton Block, Buller Coalfield	63
4.00-4.20	<u>Z. Li, A. Clemens, T. Moore, S. Weaver & D. Gong</u>	Managing environmental impacts of coal mining and coal combustion ash: The geological and geochemical approach	93
4.20-4.40	<u>R. Packham</u>	Managing outbursts of coal and gas in a new mine, the Mount Davy experience	121
4.40-5.00	<u>T. Moore, J. Harding, A. Kliskey, T. Nash, C. Nelson, K. O'Halloran & D. Trumm</u>	Understanding acid mine drainage	107
5.00-5.20			
5.20-5.25 pm - Notices			
Tu session 2D	L4: Andy Nichol	Palaeoearthquakes	
3.40-4.00	<u>K. Berryman & R. Van Dissen</u>	Late Holocene rupture history of the Wellington Fault, southern North Island, New Zealand	9
4.00-4.20	<u>He. Campbell</u>	Strain partitioning on the Alpine Fault south Westland	18
4.20-4.40	<u>R. Norris, A. Cooper, T. Wright & K. Berryman</u>	Earthquake ruptures on the southern section of the Alpine Fault	116
4.40-5.00	<u>P. Almond, L. Cullen, R. Duncan, G. Stewart, P. Tonkin, B. Alloway, D. Barrell, K. Berryman, M. McSaveny & S. Read</u>	Do Alpine Fault earthquakes cause major aggradation on the south Westland piedmont?	2
5.00-5.20	<u>J. R. Campbell</u>	A look at along-strike variation in fluid flow associated with the Alpine Fault, Westland, New Zealand	20
5.20-5.25 pm - Notices			
6.30-9.30 pm BBQ Bryant Hall - all delegates			
(includes student-get-together from 6.00 pm)			

Wednesday 28th			Page
8.30-8.40 am	L1 - Plenary 2	Introduction to Geoeducation Day: Peter Hodder	
8.40-9.10	W. de Lange	Landslides and tsunami earthquakes - a paradigmatic shift?	30
9.10-9.40	C. Wilson & V. Manville	The 26.5 ka Oruanui eruption and its aftermath	157
9.40-10.10	M. Kozuch et al.	Quake trackers takes geo-education into the 21st century	84
10.10-10.15 am - Notices			
10.20-10.50 am - Morning tea in the Academy			
10.50-12.20	Posters in the Academy (odd numbers) Chair: Arne Pallentin		
11.00-12.00	Geoeducation workshop: C. Wallace	R. Extension activities for the 'Waterways' booklet of the Building Science Concepts series (in E1.06 - soils lab E block, first floor)	153
12.20-12.50 pm - Concert at Academy 'Turnovsky Trio' - all delegates invited (free)			
12.50-1.30 pm - Lunch in the Academy			
W session 3A	L1: Daphne Lee	Geoeducation	
1.35-1.55	G. Lewis	Communicate or die - the future of geoscience - Keynote address (double session)	90
1.55-2.15	G. Lewis		
2.15-2.35	K. Otrell-Cass	Improving geoscience teaching and learning: Final data from the Earthworks study	120
2.35-2.55	S. Gulyaev	Rhythms of the Earth in the introductory Earth Science curriculum	51
2.55-3.15	P. Hodder	Refurbishing a mineralogical museum: A collaborative venture between education, heritage and tourism interests	67
3.15-3.20 pm - Notices			
3.20-3.50 pm - Afternoon tea in L block			
W session 3B	L2: Keith Lewis	Marine and Coastal	
1.35-1.55	H. Neil, L. Carter & M. Morris	Thermal isolation of Campbell Plateau, New Zealand: Permanent constriction of the Antarctic Circumpolar Current over the past 130 ka	110
1.55-2.15	D. Midenhall, C. Hollis & T. Naish	Orbitally-influenced terrestrial palynomorph record in Pleistocene deep-sea sediments (ODP Site 1123), offshore eastern New Zealand	106
2.15-2.35	A. Sabaa & W. Howard	Pliocene foraminiferal biostratigraphy and paleoceanography of ODP Site 1125, eastern New Zealand	134
2.35-2.55	B. Hayward	Global deep-sea extinctions during the Pleistocene ice-ages	56
2.55-3.15	H. Grenfell, B. Hayward, R. Carter & J. Hayward	Benthic foraminifera and the Neogene paleoceanographic history of the south-west Pacific, east of New Zealand	50
3.15-3.20 pm - Notices			
3.20-3.50 pm - Afternoon tea in L block			
W session 3C	L3: Willem de Lange	Geohazards (Sponsor: Environment Waikato)	
1.35-1.55	G. Lamarche & J.-Y. Collot	Undersea avalanche volume calculations. The example of the Ruatoria debris avalanche	86
1.55-2.15	J. Gibb	Advances in coastal hazard mapping 2001	46
2.15-2.35	M. Rattenbury, G. Hancox & G. Dellow	Modelling regional landslide susceptibility using GIS	130
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SEN Award	Sponsored by: <ul style="list-style-type: none"> * Solid Energy North 		

Posters are displayed in either Te Whare Tapere iti or the Dance Studio at the Academy
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Abstracts

LASER ABLATION ICPMS U-PB DATING AND HF ISOTOPIC COMPOSITION OF DETRITAL ZIRCONS: AN APPLICATION TO PROVENANCE COMPARISONS OF LATE TRIASSIC SEDIMENTS IN THE EASTERN PROVINCE OF NEW ZEALAND

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The combination of inductively-coupled plasma source mass spectrometry (ICPMS) with laser ablation microprobe sampling techniques allows rapid, precise and accurate U-Pb dating of individual zircon grains with 30-50 micron spatial resolution. There is the additional possibility of hafnium (Hf) isotopic ratio measurement on these same grains using a multicollector variant of the ICPMS. These data give information on magma sources and ancestries.

These two attributes are applied to a comparison of the provenances of detrital zircon populations in four greywacke sandstones, each of Late Triassic age, from the Rakaia (Wellington), Waipapa (Northland), Caples (Otago) and Murihiku (Southland) Terranes of New Zealand. In this order they reveal a pattern of decreasing polymodality of U-Pb age components. The Rakaia example records the well-known complex pattern of major Permian-Triassic components, and minor Cambrian-Ordovician, Neo-, Meso- and Paleoproterozoic ones. The minor components are much diminished in the Waipapa Terrane example (but include a tiny Carboniferous component) and are almost completely lost in the Caples Terrane example. The Murihiku Terrane sandstone indicates an almost exclusive provenance from Early Permian to Triassic sources.

Hafnium isotopic ratios ($^{176}\text{Hf}/^{177}\text{Hf}$) were also measured in zircons from the Late Triassic Rakaia Terrane (Wellington) greywacke sample. These form two main populations: a principal component (60%, mainly late Paleozoic zircons) 0.2826-0.2828, and a minor one (30%, mainly late Neoproterozoic and early Paleozoic zircons) 0.2821-0.2826, yielding crustal residence ages respectively, in the ranges 500-900 Ma and 900-1100 Ma.

DO ALPINE FAULT EARTHQUAKES CAUSE MAJOR AGGRADATION ON THE SOUTH WESTLAND PIEDMONT?

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Recent paleoseismic studies of the central and southern section of the Alpine Fault confirm three large earthquakes in the last 600 years at AD1717, c. AD1630 and c. AD1460. We hypothesise that these earthquakes triggered massive pulses of sediment into valley systems from landslides in the Western Southern Alps, causing aggradation on the piedmont. In our study we test this hypothesis by establishing the age and extent of aggradation deposits in the Whataroa Valley in South Westland. Three techniques, listed in order of increasing temporal resolution, have been used: (i) distribution and degree of development of surface soils, (ii) soil stratigraphy and radiocarbon chronology in valley fill deposits, (iii) ages of cohorts in remnant forest patches and the spatial distribution of cohorts.

Surface soils across the Whataroa floodplain are all Recent Soils (or Recent Gley Soils) which, on the basis of local soil chronosequence studies, indicates they are likely to be no older than c. 500 yrs. Valley fill deposits are largely greywacke-dominated Whataroa River gravels and that interfinger with or are overlain by schist-dominated fan deposits on the eastern valley margin. Cut/fill cycles on these fans are controlled by variations in the local base level established by the Whataroa River and aggradation sequences comprising the fans vary from 3 to 10 m of stony gravels to cross-laminated fine gravelly sands and silts. Their soil stratigraphy and radiocarbon chronology, indicate aggradation events following (2s error bounds) AD780 ± 117 (n = 3), AD1065 ± 100 (n = 1), AD1350 ± 60 (n = 1), AD1607 ± 33 (n = 6), AD1770 ± 120 (n = 3). Age class distributions from widespread forest remnants on the floodplain show two distinct cohorts. The modal age classes are AD1740-1760 for the younger cohort, and AD1620-1640 for the older cohort. Forest patches belonging to the younger cohort are mostly found in the eastern (upstream) half of the floodplain, whereas patches belonging to the older cohort are found in the western (downstream) half of the floodplain with only a few trees of this age class in the eastern half.

The three lines of evidence demonstrate that pulses of aggradation characterize alluvial sedimentation in the Whataroa Valley. The pulses affect the major part of the floodplain, with the two most recent, within the precision of the dating techniques, synchronous with the last two Alpine Fault earthquakes. The next Alpine Fault earthquake can be expected to bring about valley aggradation that will inundate a major part of the Whataroa and other floodplains in Westland, destroying dwellings and infrastructure in the process. Farming and tourism, major contributors to the local and national economies will be seriously affected.

PHREATOMAGMATIC FORMATION OF POLYPHASE SEDIMENTARY DYKES, MOERAKI PENINSULA, NEW ZEALAND

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Explosive phreatomagmatic formation of polyphase sedimentary dykes as the result of basalt dyke emplacement into wet sedimentary rocks is proposed. Three types of sedimentary dyke occur in volcanic rocks at Moeraki: mudstone, mudstone hosted brecciated sediments, and cross-bedded porcelainite containing fragments of basalt, altered glass and sedimentary material. At Tikoraki Point a single fracture in lapilli tuff hosts a progression from basalt through all types of sedimentary dyke, indicating the possibility of basalt dyke emplacement initiating formation of sedimentary dykes. Moreover, nearby basalt dykes are surrounded by envelopes of highly brecciated, porcelainitised sedimentary rocks interpreted to be derived from underlying lithified sedimentary formations.

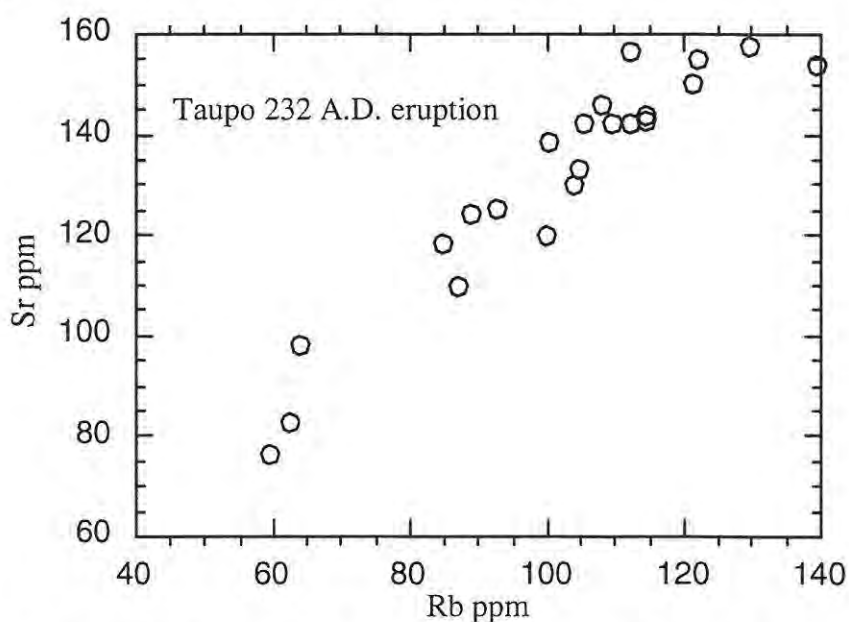
Estimates of pore fluid pressure increase have been derived from iteratively calculated numerical heat flow modelling of basalt dyke emplacement. The results of this modelling show that thermally-induced hydraulic fracturing of wet sedimentary rocks is possible. Sedimentary dyke emplacement initiated by normal faulting cannot be entirely discounted due to occurrence of mudstone dykes in fault planes on one side of a graben on the northern beach of the peninsula. However, the conjugate faults host basalt dykes, suggesting that the mudstone dykes may be the exposed fluidised country rock tips of basalt dykes that failed to propagate as far as the current erosion surface.

Formation of sedimentary dykes at Moeraki is explained as being initiated by the intrusion of basalt dykes into wet, lithified sedimentary rocks. This intrusion heats the pore fluids of the host rock until pore pressure rises sufficiently to fracture the host rock in what is possibly an explosive event. Continued propagation of basalt dykes carries these breccias upward along the margins and low-pressure tips of the dykes. When dykes enter less consolidated sediments, these sediments are fluidised and driven into the tips of the propagating fractures. Sedimentary material that remains near the emplaced basalt is thermally altered to produce porcelainite. The result of these processes is the formation of three distinct types of sedimentary dyke, with the most intensely fractured material porcelainitised and in contact with basalt.

MAGMATIC EVOLUTION OF THE TAUPO SYSTEM: THE STORY FROM MELT INCLUSIONS

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Lake Taupo has been the locus for some of the most violent historical eruptions, including most recently, that which occurred in 232 A.D. This particular eruption has been regarded as unusual (for large rhyolite eruptions) in terms of its overall compositional homogeneity with respect to major-oxide, trace-element and volatile abundances on the basis of similarity between melt inclusions (MI) hosted within phenocrysts from various eruptive units and whole-rock pumice compositions. Previous studies of MI included the techniques of electron microprobe (EMP) and secondary ion mass spectrometry (SIMS), while bulk analyses have been completed with X-ray fluorescence (XRF). We have studied a suite of MI from products of the 232 A.D. and older eruptions (Oruanui, Karapiti, Poronui, Opepe, Hinemaiaia, Whakaipo, and Mapara) using the technique of UV laser ablation - inductively coupled plasma mass spectrometry (LA-ICP-MS), to compare results of previous EMP and SIMS analytical studies on MI from this eruptive sequence. We have also conducted experiments on aliquots of pyroxene- and feldspar-hosted MI in externally heated, pressurised "bombs", simulating estimated pre-eruption magma chamber conditions, in order to determine the compositional robustness of MI to changes in intensive parameters. Among the results obtained to date, we have found considerable compositional variability in the MIs both overall (from the Oruanui to 232 A.D.) and within eruptive units. For example, within MI of the 232 A.D. eruption, specific ranges include (in ppm): Rb 59 ± 3 to 139 ± 3 ; Sr: 76 ± 2 to 158 ± 2 ; and Zr: 125 ± 4 to (290 ± 4) ppm. Positive correlations are observed for these specific trace element abundances (see figure).



Our ultimate aims in this study are to track the evolution of a rhyolite-dominated magmatic system through a time period of ~ 20,000 years, investigating losses of magma batches during eruptive events (including those trace elements that are partitioned into a fluid/vapour phase) and possibly to detect ingress of new magma into the system.

PHYSICAL PROPERTIES OF A PERMIAN ANDESITE INTRUSION INTO WET, UNCONSOLIDATED SHALLOW MARINE SEDIMENTS, SOUTHERN SYDNEY BASIN, AUSTRALIA

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An andesite dyke/sill intruded wet, unconsolidated shallow marine sediments of the Berry Formation, Permian southern Sydney Basin, indicating proximal volcanism was penecontemporaneous with deposition by this period (mid-Permian).

The intrusion exhibits many features associated with previously documented studies of igneous bodies intruded into shallow, wet unconsolidated sediments, including:

- destruction of primary sedimentary structures with mixture/intermingling and displacement of sedimentary and igneous material (i.e. sinuous veinlets/dykelets and protrusions of sediments into the magma and lobes of magma irregularly intruding the sediments);
- entrainment of sediments i.e. flames ('fluidisation');
- cooling fractures in the magma which are filled with and propagated by sediment;
- brecciation/peperite along magma/sediment boundaries with magma (exogenous) incorporated into the surrounding host sediments, and vice versa;
- 'baked' sediments, implying contact metamorphism at sediment-magma contact (i.e. smooth, fine-grained, greenish);
- pillow or 'tube' like structures displaying concentric cooling fractures and concentric discoloration from gradual cooling;
- lateral squeezing out (i.e. beneath 'pillow') of sediment from the weight of the magma due to rapid and uneven loading;
- sliding and sagging of sediments at sediment-magma contacts;
- fumarole-like structures originating within the magma and elongated vertically towards the top contact;
- vesicles within both sediments and magma indicating a near-surface (or upon-the-surface) eruption;
- coarser-grained, buff coloured sandstone from lower beds has intervened overlying siltstone;
- 'bulldozing' of sediments at magma front;
- sedimentary rocks are highly altered beneath the sill, with most grain boundaries and phenocrysts altered by hydrothermal fluids associated with the emplacement of the intrusion.

It is likely that the intrusion was associated with a proximal volcano located at Jervis Bay 6 km to the south.

THE BEHAVIOUR OF STORM SURGES IN WHANGAREI HARBOUR AND BREAM BAY

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The behaviour of storm surges in Whangarei Harbour and Bream Bay has been investigated. Whangarei Harbour is one of the deepest natural harbours in New Zealand, and maritime and recreational activities are important functions for the surrounding communities. Storm surges are a coastal hazard, which have the potential to inundate low-lying coastal communities and cause shoreline erosion and temporary flooding, hence the importance of understanding these coastal phenomena.

Storm surges are broadly defined as the temporary rise in relative sea level due to the passage of a storm. The main processes contributing to storm surges experienced for any coastal situation are, the inverse-barometer effect (from low barometric pressure), timing and height of high water, wind set up within the Harbour, and wave set-up and run-up. These processes raise the sea level experienced at the shoreline during a storm event, which is the primary factor contributing to both coastal flooding and erosion.

New Zealand tides are strongly semi-diurnal (twice daily), with the dominant tidal constituents being the M_2 , S_2 , N_2 , with much smaller diurnal (once daily) tides (K_1 and O_1). Harmonic tidal analysis was used to remove the tidal signal from the 25 year digitised tidal record from Marsden Point, to generate the residual sea level. The inverse barometric effect was calculated from the barometric pressure record using the theoretical oceanic inverted barometer response of 10 mm.hPa^{-1} . This response indicates a 10 mm rise in sea level for a 1 hPa drop in pressure. Cross correlation and linear regression analyses have been carried out to determine the actual barometric effect at Marsden Point. The actual response is less than the theoretical value, being of the order 5.5 mm.hPa^{-1} , similar to the 6 mm.hPa^{-1} determined for the Waitemata Harbour and Bay of Plenty.

However, it is probable that the wind stress contribution is higher than experienced further south, since the total storm surge is similar for the events considered. Work is underway to quantify the wind stress component.

By understanding the behaviour of tides and knowing the inverse barometer effect, some predictions of storm surge severity can be made. If a storm and the resulting rise in sea level coincide with a lunar perigee and a spring tide, the impact of storm surge (or storm tide) may be more severe than under other conditions.

INTERSEISMIC, COSEISMIC AND POSTSEISMIC DEFORMATION FROM ARTHUR'S PASS 1: GPS DATA AND MODELLING

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The M_w 6.7 1994 Arthur's Pass earthquake occurred within a GPS station network first occupied in 1992. Subsequent campaigns in 1994, 1995, 1997 and 2000 allow estimates of co-, post- and inter-seismic deformation in the area. We have processed the year 2000 survey and reprocessed earlier data, using the ITRF97 reference frame. We improve on earlier geodetic inversions and interpretations by: (1) using the 1997-2000 displacements to estimate the interseismic velocity field uncontaminated by coseismic signals; (2) using the method of Beavan and Haines (2001) to estimate the interseismic deformation field in two dimensions, rather than making a 1-D linear assumption; (3) checking the GPS sites for significant gravitational instability; and (4) using F-tests to determine whether a coseismic inversion with more or less degrees of freedom fits the data significantly better than a simpler solution.

We find clear evidence in the coseismic deformation data for a third fault, in addition to the two-fault models discussed by Arnadottir et al. (1995) and Abercrombie et al. (2000). We identify this fault with the largest aftershock on the Harper fault, and find supporting evidence for this interpretation from interferometric SAR analyses by Pearson et al. (in review, NZJGG). We also analyse the data for evidence of significant postseismic creep associated with the earthquake. A strong discrepancy between 1995-1997 displacements and those predicted from the interseismic velocity field results mainly from the coseismic displacements during the smaller Cass earthquake of 1995. Correcting for the Cass coseismic signal suggests that there was only a small to negligible postseismic signal from 1995-1997, but it could also mean that the postseismic signal was approximately linear between 1995 and 2000 and has therefore been removed along with the interseismic signal (see Ellis and Beavan, this volume). A small postseismic signal from 1994-1995 is present in a subset of the station network.

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**THE AKATARAWA FAULT:
A NEWLY DISCOVERED ACTIVE FAULT IN THE WELLINGTON REGION, AND
IMPLICATIONS FOR INCREASED HAZARD ON THE WELLINGTON FAULT**

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The active Akatarawa fault extends northeastward for ca 18 km from its junction with the Wellington fault near the Whakatikei terraces area of Upper Hutt to its junction with the Moonshine and Otaki Forks faults at Cloustonville in the Akatarawa valley. Geomorphic mapping and trenching of the fault trace in the Akatarawa valley indicate that the Akatarawa fault has a minimum dextral slip rate of 0.4 mm/yr, and a maximum average earthquake recurrence interval of ca 9000 yrs. However, given dating and measurement uncertainties, the actual slip rate may be considerably higher, and the recurrence interval may be considerably less. Coulomb failure stress modelling of the Wellington and Akatarawa faults suggests that rupture of the Wellington fault enhances the likelihood of rupture of the Akatarawa fault. An important implication, given the Akatarawa fault's sense of slip and geometry relative to the Wellington fault, is that the hazard posed by the Wellington fault south of its junction with the Akatarawa fault may currently be underestimated.

Funding for this study was provided, in part, by a research grant from EQC.

LATE HOLOCENE RUPTURE HISTORY OF THE WELLINGTON FAULT, SOUTHERN NORTH ISLAND, NEW ZEALAND

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The slightly arcuate, concave to the SE, southern-most 75 km long section of the Wellington Fault was identified ten years ago as the *Wellington-Hutt Valley rupture segment (W-HV RS)*. Here, we tentatively define the next two rupture segments to the north, based on dated natural exposures along the slightly arcuate, concave to the NW, Tararua section of the Wellington Fault, and seven trench exposures on the relatively straight Pahiatua section further to the north.

At Totara Flats, along the Tararua section of fault, a young aggradation event that inundated, and killed, a forest is dated at 1650-1450 AD. This is almost exactly the same age range as the best-estimate timing for the most recent rupture of the *W-HV RS*, and suggests that aggradation at Totara Flats was probably directly linked with rupture of the *W-HV RS*.

Along the Pahiatua section, the timing of ruptures recorded in two adjacent trenches located 10 km north of the Tararua Range is different from the rupture timing derived from the remaining five trenches located a further 16-20 km to the NE. Because single event dextral displacement along the Pahiatua section of the fault is consistently recognized to be about 4 ± 1 m, we expect such displacement to correspond to rupture lengths in excess of many tens-of-kilometers. Therefore, we conclude that the trench sites on the southern part of the Pahiatua section that exhibit a different rupture history to those nearer the Manawatu Gorge must rupture with the Tararua section of the fault in order to attain a rupture length consistent with single-event displacement size. We refer to this segment as the *Tararua-Putara rupture segment (T-P RS)*. The remaining part of the Pahiatua section, extending northeast to at least the Manawatu Gorge, is interpreted to belong to a different rupture segment which we refer to as the *Mangahao rupture segment (M RS)*.

Average dextral slip rate estimates for the *W-HV RS* and the *M RS* are 6-7.6 mm/yr and 4.6-7.2 mm/yr, respectively. Single event dextral displacement is c. 4 ± 1 m for both the *W-HV RS* and the *M RS*, and also for the northern part of the *T-P RS* that is north of the Tararua Range. From these data, indicative average recurrence intervals for the *W-HV RS* and the *M RS* of ca 600 yrs and ca 800 yrs, respectively, are obtained. Indicative elapsed time since the most recent rupture on each of the three segments is 400, 1140, and 240 yrs for the *W-HV RS*, *T-P RS*, and *M RS*, respectively. Earthquakes of approximately M_w 7.4-7.8 are expected on each of the segments based on the above rupture parameters.

None of the fault rupture events so far identified on the Wellington Fault overlap in time with adjacent segments, indicating that rupture has not extended onto adjacent segments, and has not given rise to stress-triggered, along-strike, segment failure. This, coupled with earlier findings of no obvious cross-strike temporal clustering, suggest that rupture segments of the upper-plate strike-slip faults in southern North Island do not exhibit strong temporally coupled, or clustered, fault rupture behavior, except possibly with that of the subduction thrust.

Funding for this work was provided, in part, by a research grant from EQC.

CALLING ALL ROLE MODELS: A HUMAN FACE FOR S&T IN NEW ZEALAND

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New Zealanders generally believe that science and technology (S&T) are important to our nation's success in the world. However, many consider that it is irrelevant to their daily lives. The Royal Society of NZ is committed to the advancement and promotion of S&T in New Zealand and we develop effective promotion programmes to create a culture that is supportive of it. Our present initiative is a programme to develop and nurture the relationship between science and the general public by using S&T Role Models.

Scientists and technologists have a fundamental role in raising an awareness of their work.. A 1997 survey of New Zealand scientists, updated in 2000, showed that the vast majority of respondents supported the view that they must take some responsibility for improving the general public's understanding of the long-term value of basic or fundamental research. Significantly, nearly all those surveyed felt that their own research was not too complex to explain to the general public.

So, research scientists have the knowledge and can demonstrate the relevance of their work to society, however when it comes to communicating this it is often unsuccessful. With a few exceptions, concerted efforts from individuals to raise S&T awareness are often unnoticed, unsupported, and end up fading. New Zealand needs a comprehensive network of effective S&T communicators to permeate society at every level, people who can speak their subject with passion and generate understanding in their audiences.

The Role Models programme identifies effective communicators from within the S&T community. These people attend training workshops to acquire and hone their communication skills. Then we create opportunities for them to speak out in the community, from scout groups to Probus clubs, businesses and marae.

For this initiative to be effective, we need people to be Role Models. Many researchers may be eager to participate but feel they cannot due to work pressure, or they already contribute in their own communities. This time issue is serious. Something to be explored is to require that contracts for research funding from purchase agents have the public explanation of research as a legitimate way of reporting and include that in their budgets.

For too long, S&T has been seen as something worthy but unavailable to the ordinary citizen. What New Zealand needs is a culture that embraces scientists, technologists and innovators, and who values and rewards research and innovation. There is an urgent need to create a recognisable human 'face' for science and technology in New Zealand.

ANALYSIS OF THE PLIOCENE FOREARC BASIN SUCCESSION, ESK RIVER CATCHMENT, HAWKE'S BAY

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The Esk River catchment of northern Hawke's Bay contains a 1000 m thick Pliocene (Opoitian to Nukumaruan) sedimentary succession that accumulated within the principal forearc basin of the Hikurangi Margin. The entire succession has been described in detail as part of a basin analysis investigation. Emphasis has also been placed on facies analysis and determination of the sequence stratigraphy of the succession. Eight formations have been identified and mapped within the area at a scale of 1:40 000. The **Maungaharuru Group** (new) includes the **Mokonui**, **Titiokura**, **Te Waka**, and **Pohue** Formations. The Late Pliocene **Petane Group** (amended) comprises the **Matahorua** (new), **Waipunga**, **Esk**, and **Tutira** Formations. Intraformational members include the **Awhina** and **Oakmere** Members (both new, in the Te Waka Formation), the **Deep Stream**, **Trelinnoe**, **Papakiri**, and **Grassy Knoll** Members (all new in the Matahorua Formation), and **Hikuroa Pumice** (Tutira Formation).

Lithofacies analysis has identified four facies assemblages and a total of 16 lithofacies types, each representing a different depositional paleoenvironment. Siltstone facies have accumulated dominantly at inner- to middle-shelf depths, with sandstone facies deposited in inner-shelf to nearshore and beach environments. Conglomerate facies are either subaerial or shoreface in origin, and accumulated as part of a prograding braided river to fan-delta complex. Carbonate facies are nearshore to inner-shelf in origin. The field area is characterised by rapid facies changes.

Numerous cyclic sequences have been identified on the basis of textural and vertical facies changes that are inferred to have developed in response to c. 41 ky (obliquity-controlled) glacio-eustatic oscillations in sea-level. Each sequence contains at least three systems tracts: transgressive, highstand and regressive systems tracts. A fourth type, the lowstand systems tract, may be present in some of the sequences that contain conglomerate beds. In terms of sequence stratigraphy, conglomerate facies appear to correspond to regressive and lowstand systems tracts, sandstone facies with regressive systems tracts, and siltstone facies with transgressive and highstand systems tracts. Transgressive systems tract deposits are thin (0.5-2 m thick), and resulted from rapid transgressions. Regressive systems tract deposits are typically thick (20-50m thick), and developed during long periods of relative sea-level regression.

The persistence of inner- to middle-shelf facies through the succession suggests that subsidence rates more or less matched sediment flux throughout the Pliocene. Carbonate accumulation was controlled largely by the by-passing of terrigenous sediment. The terrigenous sediment flux into the region was high throughout the Pliocene, and sediment accumulation rates increased from the Waipipian to the Nukumaruan (from 0.12 mm/ky to 2.5 mm/ky). An increase in the rates of uplift and erosion along the North Island axial ranges during the Early Nukumaruan resulted in the deposition of large volumes of greywacke gravels as part of a braided river to fan-delta system that prograded in a southeasterly direction.

SPATIAL AND TEMPORAL EVOLUTION OF RHYOLITE LAVAS FROM THE HAROHARO VOLCANIC COMPLEX, OKATAINA VOLCANIC CENTRE

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The Haroharo Volcanic Complex (HVC) comprises rhyolite lava domes and flows, interbedded with pyroclastic flow and fall deposits, that have infilled the northern and central Haroharo Caldera, Okataina Volcanic Centre. The HVC was built up in four eruptive episodes, each involving eruption of rhyolite lavas and pyroclastics: Te Rere (c. 25 000 cal. years B.P.), Rotoma (c. 9 500 cal. years B.P.), Mamaku (c. 8 050 cal. years B.P.) and Whakatane (c. 5 550 cal. years B.P.). The vents for HVC eruptions lie within a 4 km wide, 050° trending zone known as the Haroharo Linear Vent Zone (HLVZ), and can be divided into four vent areas.

In addition to plagioclase, quartz and Fe-Ti oxides, rhyolite lavas of the HVC may contain phenocrysts of orthopyroxene, calcic amphibole and cummingtonite in varying abundances. Biotite is rare, and apatite and zircon occur as accessory crystals. The lavas contain ~ 5 - 20 % phenocrysts, and temperatures determined from Fe-Ti oxide geothermometry range from ~ 680 - 790°C. The lavas are metaluminous, medium-K, calc-alkaline rhyolites with $\text{SiO}_2 \approx 75 - 77$ wt. %, and have a range in major and trace element compositions that fall into groups that correspond with eruptive episode and vent area.

Petrographic, mineralogical, geochemical and isotopic data for the rhyolite lavas have been incorporated to provide a model for the spatial and temporal evolution of the HVC over the last c. 25 000 years. The lavas erupted in the Te Rere episode were derived from a genetically discrete, relatively volumetrically small magma type. The lavas erupted in the Rotoma, Mamaku and Whakatane episodes are thought to be genetically related, and record the evolution of a relatively larger magma body over c. 4 000 years by closed-system fractional crystallisation processes. This is supported by least squares regression modelling and their similar $^{87}\text{Sr}/^{86}\text{Sr}$ compositions ($0.70531 - 0.70537 \pm 0.00003$). A minimum magma generation rate of $\sim 2 \times 10^{-3} \text{ km}^3/\text{year}$ has been estimated for the HVC.

The length of the current repose period for eruptions from the HVC, in addition to magma cooling rates of $\sim 1.5^\circ\text{C}/100$ years estimated from steadily falling magma temperatures from $\sim 740^\circ\text{C}$ for the Rotoma lavas to $\sim 680^\circ\text{C}$ for the Whakatane lavas, suggest that the future eruption of residual magma from the Whakatane eruption may not be viable unless this magma is revived by basaltic intrusion. The future eruption of a new, genetically unrelated magma type seems more likely, and based on the estimated minimum magma generation rate for the HVC, $\sim 11 \text{ km}^3$ of new silicic magma could theoretically have been generated since the Whakatane eruption.

INTEGRATED USE OF A SITE-SPECIFIC DRILLING STRATEGY, COAL CHEMISTRY AND GEOSTATISTICS TO INCREASE GEOLOGICAL CONFIDENCE – EXAMPLES FROM THE SPRING CREEK MINE, GREYMOUTH COALFIELD

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The Greymouth Coal Ltd mining license encompasses a sizeable part of the western area of the Greymouth Coalfield, West Coast, New Zealand. The license area contains a resource of approximately 250 million tonnes of high volatile C to high volatile B bituminous coal. Seam correlation can be difficult due to the presence of several seams often of considerable thickness (up to 30m), but which may thicken, thin or merge laterally over short distances (80-150m). The second major geological issue facing mining is the presence of two fault sets, one striking approximately 000°, the second striking 030° to 060°. A good understanding of these two geological aspects of the deposit is the pre-requisite for geological risk assessment prior to commencement of mining.

The current focus of geological exploration is an area west of the main access drifts (“West Block”) that is suitable for hydraulic monitor mining. The West Block contains two mineable seams (Main Upper and Main Lower), which merge northward to a single, thick (Main) seam. Field mapping has limited application for indicating the geological structure of the West Block. Projection of outcrop information to depth has proved erroneous in the past due to the variable dip of faults with depth and the complex interrelationship between the two fault sets. Therefore, the provision of geological control for mine planning, and subsequent risk assessment, depends on gathering high quality data at the horizons of interest.

The exploration methodology for the West Block involves drilling several holes from a single site to allow construction of structural cross-sections between adjacent drillholes. Reliable dipmeter logs are imperative for the process of structural interpretation. Confident stratigraphic correlation of coal seams is also required to allow construction of robust structural sections. Additional confidence in seam correlation has been achieved using consistent differences in coal type (indicated using the Suggate Rank chart) between the two seams of interest and by geostatistics (discriminant function analysis).

The structural model has been validated by recent drilling. The results of infill holes drilled in areas previously drilled using this methodology have conformed to within a few metres of the structure contour model. On-going development of the exploration strategy, probably by incorporation of high resolution seismic surveying (where applicable) is intended to provide the best possible level geological confidence for new areas prior to mine development.

HIGH-RESOLUTION SEQUENCE STRATIGRAPHY FOR THE EAST COROMANDEL INNER SHELF, NEW ZEALAND: ANATOMY AND ORIGIN OF A LATE PLEISTOCENE FORCED REGRESSION

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High-resolution seismic reflection data from the east Coromandel coast, New Zealand, provide details of the sequence stratigraphy of a wave-dominated shelf margin during the Holocene and Late Pleistocene (0-140 ka). The east Coromandel coast is a particularly interesting geological setting in that the shelf margin has evolved from a back-arc basin with high subsidence and sedimentation rates in the Pliocene and Early Pleistocene, to a passive margin with limited subsidence (c. 4 cm/ky) and sediment supply throughout the past 1 My. The prevailing accommodation-dominated depositional regime has resulted in extensive reworking of coastal and shelf sediments during the prolonged periods of falling sea level and the brief highstands, lowstands, and marine transgressions that have characterised the Middle and Late Pleistocene. Seismic data show evidence for the preservation of only one complete fourth-order depositional sequence since the onset of passive margin conditions, the Late Pleistocene Waihi Sequence. The Holocene age Whangamata Sequence is also evident in seismic data and modern coastal deposits, but represents an incomplete depositional sequence in the early stages of its evolution. Middle Pleistocene sequences were most likely originally deposited during earlier fourth- and fifth-order sea-level cycles, but have subsequently been entirely reworked into the Waihi and Whangamata Sequences.

The most significant aspect of the sequence stratigraphy on the east Coromandel coast is the presence of forced regressive deposits (FRDs) within the falling stage systems tract (FSST) of the Late Pleistocene Waihi Sequence. The FRDs are interpreted to represent regressive barrier-shoreface sands that were sourced from erosion and onshore reworking of underlying Middle Pleistocene sediments during the period of slow falling sea level during Isotope Stage 3 (59-24 ka). The FSST is volumetrically the most significant depositional component of the Waihi Sequence, with the regressive barrier shoreface sediments forming a 15-20 m thick, sharp-based, tabular seismic unit that downsteps and progrades continuously across the inner shelf (20->50 m water depth). Highstand deposits from the Waihi Sequence are limited to subaerial barrier deposits preserved behind several modern Holocene barriers along the east Coromandel coast. The transgressive systems tract is evident in some seismic sections off Waihi Beach as incised-valley fill deposits that have been partially preserved beneath the regressive surface of erosion from the base of the FSST. The Waihi Sequence FSST is unusual in that it appears to have been sourced entirely from reworking of underlying shelf sediments, and thus represents an autochthonous FRD. Most documented FSSTs from correlative Late Pleistocene sequences contain basinward thickening, often stacked wedges of FRDs that have been sourced to a large extent by onshore river systems. Autochthonous FRDs are also present on the high wave energy, accommodation-dominated southeast Australian coast, and may be a common feature on accommodation-dominated shelf settings provided shelf gradients are relatively low and an underlying source of shelf sediments was available to source the FRDs.

INDUSTRIAL MINERALS AS VOLCANIC PRODUCTS

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Volcanic rocks are the source of a wide variety of industrial minerals and rocks by virtue of either their physical properties and/or mineralogy and chemical composition. These properties are in turn related to the processes of formation of the rocks. Pumice and perlite are examples of volcanic rocks that owe their usefulness to their physical properties. Halloysite clays owe their high value to a combination of their inherent brightness, low iron and titania contents and fine particle size. Primary eruption processes and secondary alteration or sedimentary processes are responsible to varying degrees for the formation of individual mineral deposit types. The deposits may be formed at the original eruptive site (e.g. halloysite clays in rhyolite) or at a distant site by secondary concentration processes (e.g. titanomagnetite ironsands).

Tertiary volcanic rocks make up a significant proportion of the surficial cover rocks of New Zealand, especially in the Taupo Volcanic Zone. Industrial minerals that are associated with or derived from the volcanic rocks include: amorphous silica, allophane, bentonite, diatomite, ignimbrite building stone, illite clays, halloysite clay, obsidian, perlite, pumice, sulphur, titanomagnetite ironsand and zeolite. Of these: bentonite, ignimbrite building stone, perlite, pumice and titanomagnetite ironsand have been mined and processed for 20 to 30 years, but many of the others require further characterisation of the resource and/or development of markets.

As examples we have compiled mineral deposit models for halloysite clays in rhyolite and for zeolites in altered vitric tuffs. These models include geological and mineralogical attributes, which are linked to the underlying volcanic and geothermal processes that have produced the minerals and their source volcanic rocks. Halloysite clay deposits at Matauri Bay (Northland) have formed from hydrothermal alteration and weathering of rhyolite. Clinoptilolite + mordenite zeolite deposits in the Ngakuru area (Rotorua district) have formed from hydrothermal alteration of volcanic glass in lacustrine sediments and ignimbrite. Further refinement and application of these models will result in a better understanding of the mineralogy, localisation and origin of the deposits, with consequent applications in exploration and resource assessments.

MATURATION OF SILICA RESIDUE AND SILICA SINTER FORMED FROM THERMAL FLUIDS IN THE TAUPO VOLCANIC ZONE

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Deposits of silica are common surface manifestations of geothermal systems. The silica that comprises them derives from one of two sources.

(a) Silica sinter, which precipitates at the ground surface from cooling alkali chloride waters of about neutral pH. These waters are oversaturated in SiO_2 with respect to opal and quartz. The silica itself derives from rocks deep within a geothermal reservoir where temperatures exceed 180°C .

(b) Silica residue, which is the main product of the alteration of volcanic rocks, or their derivatives, that have reacted at, or near, the ground surface with acidic steam condensate or acid sulphate water. This silica thus derives locally and superficially. It concentrates where most other constituents have been leached from the reacted rocks.

Both types of silica undergo post-depositional changes although details of the processes involved are poorly understood. Opal-A transforms to paracrystalline opal-CT and/or opal-C and then to microcrystalline quartz plus moganite. This aging sequence is evident from increases in the silica structural ordering, revealed best by XRD, progressive reductions in the porosity of the deposited silica, its water content and a consequent increase in its density.

Scanning Electron Microscope imaging and thin section petrography reveals that these mineralogical transformations are accompanied by textural changes at both microscopic and ultrastructural levels. Opal-A microspheres progressively change into Opal-CT lepispheres and thence to microbotryoids formed of doubly terminated quartz crystals (for sinter) or fibrous quartz (for residue).

Both silica sinter and silica residue are common in the active geothermal fields of the Taupo Volcanic Zone. For example, modern sinter at Orakeikorako contains Opal-A but at Umukuri, 2 km to the west, its ~40Ka predecessor contains both Opal-CT and quartz. The latter also shows a wide range of textural features. Silica residues, occurring at the Te Kopia and Tikitere fields, have rind, crustose and loaf morphologies that show a variety of characteristics.

Opaline silica may initially react with aluminium bearing acidic thermal water, to produce kaolin, or else it transforms to Opal-CT (as at Tikitere), or to quartz plus moganite (as at Te Kopia), or else it is totally dissolved by reacting further with acid fluids.

Distinguishing between ancient deposits of silica sinter and silica residue that have completely transformed to quartz is difficult but the former may show remains of plants or contain pollen and the latter is commonly accompanied by kaolin or sulphate minerals.

NEW ZEALAND FOSSIL COLLECTIONS IN THE 21ST CENTURY: THE CASE FOR NATIONAL NATURAL HERITAGE STATUS

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In this modern age of globalisation, relentlessly turning a once diverse and disparate humanity into something much more homogeneous and commonplace, there is increasing demand and effort to maintain cultural and national identity. In this respect, New Zealand is no different from anywhere else.

Fortunately, we can claim that we have a unique geology and geological history, but this in itself does not a 'national identity' make!

Having said this, we could do a whole lot better with what we have. Our paleontological record in particular is fertile ground for enhancing a stronger understanding of what is 'New Zealand' in terms of our unique natural heritage.

Our New Zealand fossils are an integral part of the fabric of knowledge that relates to the origin and history of our landmass. In so much as minerals, rocks and fossils are the memory banks of our world, so too our New Zealand fossiliferous rocks tell much of the story of the whakapapa of the New Zealand landmass.

Accordingly, there is a case to be made for gaining official recognition of New Zealand fossils as part of our national heritage and hence gaining appropriate resources for their proper curation, retention and protection for all time.

Traditionally, our paleontological collections have developed and have been housed within state-owned geological research and education centres namely GNS (a Crown Research Institute), and the universities. Some museums and private collectors have also played a role.

Times have changed though. There is now increasing uncertainty about retention of collections, especially if they are not well patronised, not associated with paleontologists, take up valuable space in cash strapped central city buildings, and/or are housed within more or less free market business enterprises that are primarily concerned with making money. Are New Zealand's diverse fossil collections in good hands? What can we do?

It is suggested that we follow the example of Wales. The Welsh Parliament has officially sanctioned Welsh fossils as part of their national natural heritage and significant funds have been granted for their proper curation, care and ongoing study. New Zealand could do the same and in this green age, the 21st century, perhaps it can be done. Our Ministry of Culture and Heritage may be ripe for an approach with a well-reasoned argument.

STRAIN PARTITIONING ON THE ALPINE FAULT SOUTH WESTLAND

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The geometry of the Alpine Fault South Westland defines a regional scale, transpressive flower structure across which there is significant partitioning of deformation onto pre-existing reactivated fault structures. The area concerned, between the Arawata River and the Gorge Plateau region, is situated at the transition between a section with an obliquely convergent signature, North of Haast⁽¹⁾, and a dominantly strike slip section, South of Lake McKerrow⁽²⁾. Uniquely, this area is the locality of the convergence with the Alpine Fault of the Dun Mountain Ophiolite Belt, the Maitai, Murihiku and Brook Street Terranes, along with the associated Hollyford Fault System (HFS).

Greenschist facies mylonites exist within a complex geometry characterised by an array of left stepping, sub-parallel fault structures each accommodating considerable deformation, signified by the presence of >50m wide crush zones. All traces are active, cutting erosional and depositional Quaternary features with the overall pattern defining a transpressional flower structure with an average 060° azimuth. Furthermore, azimuths of 020° are widespread which are attributable to linkage structures between the left stepping traces. Kinematic indicators reveal partitioning of strike-slip and oblique/dip-slip deformation across the major fault structures. Analogous partitioning of deformation also prevails in the domains between the major deformation zones, where a complex fold pattern is developed in response to contemporaneous partitioning of coaxial and non-coaxial deformation within the ductile regime. Consistency of mylonitic stretching lineations throughout the variously orientated mylonitic foliations, indicates that the different structures were formed at depth and are not a result of near surface rotation.

Extrapolation of structure, lithologies and mylonite zones into the vicinity of Gorge Plateau, where they can be correlated with the established geology⁽³⁾, demonstrates that the HFS has been rotated into sub-parallelism with the Alpine Fault forming an integral part of the deformation zone. Gouge zones and offset Quaternary features indicate recent deformation on these structures and the flower structure is interpreted to extend East across 10km to the Stethoscope fault.

It is proposed that anisotropies, arising from rheological heterogeneity, lithological contacts and the position of pre-existing fault structures, fundamentally control the geometry. Although, it is evident that splitting of the normal and parallel components of slip is occurring across each major structure it is, however, unclear what fraction of interplate slip is being accommodated by the different structures. The area is under constant readjustment and it is crucial to understand how the strands are interacting with each other to accommodate the strain and how this affects the behaviour of the Alpine Fault with respect to future rupture events.

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⁽²⁾ Sutherland R. and Norris R. J., 1995, New Zealand Journal of Geology and Geophysics, 38, 419-430. ⁽³⁾ Landis, C.A., 1969, Unpublished PhD thesis. University of Otago, Dunedin, NZ.

RECONCILIATION AND VALIDATION OF GEOLOGICAL HAZARDS AND MINING CONDITIONS FROM 3D-SEISMIC REFLECTION DATA

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Solid Energy North's Huntly East underground mining operation is currently working two areas covered by high-resolution 3D seismic, these being the Ralph Block, acquired and modelled in 1997, and the more recent North Block (early 2000).

Conversion of the dataset from the time domain to depth domain and structural interpretation has been undertaken in-house with the seam roof, seam floor and structural features such as fault traces and basement ridges being identified using SeisVision interpretation software.

The 3D seismic derived surfaces are input into the Vulcan software model, which is used for integrating geological hazards, and seam structure into the mine plan, minimising geological uncertainty prior to mining. Features that are routinely identified are seam thickness, seam roof and floor geometry, faulting (strike, dip and throw variations along strike), and the location and severity of underlying basement ridges. The latter also act to modify the orientation and concentrate the principal horizontal stress. All of the hazards negatively impact mine safety, roadway development rates and effectiveness in extraction.

Based on detailed tunnel mapping, current accuracy of the 3D seismic method is such that the roof and floor of the coal seam is possible to within ± 1.5 -2 metres, and fault off-sets as small as 2-3 metres are readily obtained. Seam thickness can be resolved ("top and bottomed") to 4m.

Currently mining has occurred in 65% of the Ralph Block, with the Ralph Block 3D seismic model being validated directly by exposure in development roads and extraction panels of the majority of the structures picked-up in the initial interpretation. Development in the North Block began in mid-September and, to date, the structural model has been validated with the seam roof and floor located to ± 0.3 -0.5m, and the seam topography fitting the model accurately. The North Block survey was designed so as to overlap the edges of pre-existing and accessible underground workings to allow direct correlation between mapped structures and in the 3D model. Every resolvable feature in the model can be tied directly to structures seen in existing drives or extraction panels. This is very advantageous for mine planning and management.

A LOOK AT ALONG-STRIKE VARIATION IN FLUID FLOW ASSOCIATED WITH THE ALPINE FAULT, WESTLAND, NEW ZEALAND

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Rapid Cenozoic uplift associated with the Alpine Fault in Westland, New Zealand has exhumed amphibolite facies mylonites and associated fault rocks. These mylonites and fault rocks show evidence of syn-uplift fluid flow through cross (foliation) cutting structures. Previous modelling has examined 2-D fluid flow normal to the Alpine Fault, but the issue remains of along strike variation. This along strike 'variation' is a result of many factors, most importantly, regional tectonic geometry. Strain intensity, associated with fault damage zones, increases through bends on or near the fault as well as fault intersections.

There is an observable increase in Fe-Mg carbonate content between the Waitaha and Taramakau rivers (between Ross and Arthur's Pass, respectively). This enrichment in Fe-Mg carbonate towards the Alpine-Hope Fault intersection represents a region of enhanced permeability possibly related crustal intersections and increased strain through resultant shallow (<8km) seismicity.

Mineralization in Alpine Fault mylonites and cataclasites has previously been characterized south of the field area (Glacier region) as minimal and localized. Field studies to the north of the previously studied areas have revealed several phases of metallic mineralisation. Chalcopyrite-pyrrhotite-pyrite assemblages form as coarse sulphides in fracture networks crosscutting mylonitic foliation. Implosive breccias contain anomalous As, Zn, and Ni (max = 220, 124, 84 (ppm), n=9) against background mylonite values (avg = <3, 74, 28 (ppm), n=16).

Isotope studies identifying an 'Inboard Fault Gouge Calcite Zone' ($\delta^{13}\text{C}$, -7.0 to -2.9, and $\delta^{18}\text{O}$, 10.4 to 15.0) correlate with values from the Main Divide region at the headwaters of the Arahura River (Browning Pass - Wilberforce Valley). These correlations are supported by the fore mentioned arsenic anomalies found in both regions suggesting fluid sources may be interconnected at depth. Preliminary element mapping reveals As 'lenses' contained in sulphide and carbonate discontinuities (e.g. fractures, cleavage planes).

Ongoing research involving regional structural controls, isotope geochemistry, fracture geometry, and wall rock-fluid interaction will attempt quantify fluid sourcing and evolution along the Alpine Fault in a 3-D fashion.

HYDROTHERMAL ALTERATION ALONG THE ALPINE FAULT, WESTLAND, NEW ZEALAND

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Hydrothermal alteration along the Alpine Fault can be classified based on host structure, alteration style, and resultant mineralization (see table). Alteration was examined throughout central Westland, with field studies concentrating to the NE of the Arahura River (noted Au).

Late, low temperature meteoric fluids migrate through gouge, enhancing retrogression (chloritization) and carbonate precipitation. This near surface (<1 km) flow network evolves through continuous fluid percolation dominated by physical and chemical conditions within the given host structure. Cataclasite and brecciated mylonite exploit similar flow mechanisms under higher P-T conditions (1–4 km). Joint fracturing within coherent mylonites represents a systematic flow network in which fluids begin to readily migrate at depths of approximately 4km. Flow movement through open joints is recorded through wall rock alteration and carbonate mineralization (calcite, dolomite-ankerite).

Where fluid flow is commonly recorded through gouge, cataclasite, joints, etc., cross cutting alteration features are less common. Locally, fracture meshes have developed associated with minor faults and/or shear zones (10 m width). These fracture meshes host extensive ankerite-dolomite veining containing sulphides (chalcopyrite-pyrrhotite-pyrite) and anomalous As implying a deeper fluid source. Although brittle in nature, these cross cutting veins exhibit some ductile characteristics suggesting deposition near the brittle-ductile transition (BDT). Mineralised breccias also contain anomalous metal concentrations and recrystallised hydrothermal minerals.

Fluctuating fluid pressures (P_f) may dominate flow at depth, however, shallow, open space structures generated through uplift related deformation serve as the major flow media in the upper crust.

<i>Hosting Structure</i>	<i>Hydrothermal products</i>	Metallic minerals	Structural Controls
1. Gouge	Calcite, Fe-Mg Carbonate	None, depleted in trace elements	Damage zones (sub mm scale), ppt 'plugging'
2. Cataclasite and brecciated mylonite	Retrogressive chlorite, Fe-Mg group clays	None	Flow through damage zones (mm-cm scale)
3. Joint fractures in coherent mylonite	Dolomite-ankerite, Wall rock clasts, leaching <1cm	Pyrite plating, minor ccp	Spaced (conjugate) joint sets (cm - >m scale)
4a. Fracture mesh	Dolomite-ankerite, Qtz, Wall rock leaching >1cm	Py, po, ccp, minor As bearing mineral(s)	Meshes assoc. w/ faults, shears, (>1km R.I.)
4b. Implosive breccias	Ca-Fe-Mg-Mn carbonate	Py, po, ccp, As bearing mineral(s), high Ni, Zn	Extremely rare breccia 'pods' (>10km R.I.)

**DIAGENETIC AND SEDIMENTOLOGIC RECOGNITION OF HIGH-ORDER
(C. 150-20 KY) PARASEQUENCES IN COOL-WATER CARBONATES:
PLIO-PLEISTOCENE TE AUTE LIMESTONES, NEW ZEALAND**

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The vertical stacking of sedimentary facies between consecutive key surfaces, and the comparison of diagenetic histories recorded on either side of these key surfaces, enable positive distinction of depositional parasequences of transgressive or transgressive-regressive character.

In Plio-Pleistocene Te Aute limestones from Hawke's Bay, eastern North Island, successive surfaces of erosion (TSE=Transgressive Surface of Erosion; RSE=Regressive Surface of Erosion) and surfaces of low or no deposition (TSE; Mfs=Maximum flooding surface) have been used to subdivide sedimentary packages into depositional sequences and systems tracts.

Vertical changes in thickness and depositional facies through the fundamental building blocks recognised in many stratigraphic sections of the studied successions, in association with changes in the type and degree of diagenesis that outline vertical patterns of *pre-compaction* diagenetic sequences, and fundamentally the position of bounding discontinuities, define four type-sedimentary parasequences having the following characteristics:

- ? All type-parasequences are bounded by TSEs
- ? Each parasequence includes a transgressive systems tract (TST)
- ? The upper TSE lies either directly on the TST (type 1), or within the highstand systems tract (HST; type 2), or within the regressive systems tract (RST; type 3), or coincides with a surface of subaerial exposure atop the RST (type 4).

This study shows that each Te Aute limestone formation results from the stacking of metre-scale type-parasequences (from 3 up to 12 fundamental building blocks, each from a few up to c. 15 m thick) with recurring internal facies architecture and specific diagenetic patterns, suggesting that a high-frequency sea-level control (6th to 7th order: c. 40 to 20 ky) may have operated during deposition of the Plio-Pleistocene limestone successions.

However, there is strong evidence, including lateral variations in the number and thickness of parasequences within the same formation, and amalgamated parasequences, to indicate that tectonic, glacio-eustatic, and to a lesser degree internal mechanisms may have operated in concert to build up the carbonate successions.

6th to 7th -order cycles are arranged so as to define a lower-order of stratigraphic cyclicity (5th order: c. 150 ky) with a systematic transgressive-to-regressive stacking pattern of skeletal-rich facies where the carbonates accumulated close to structural highs.

The limestone formations can be paired with an underlying siliciclastic stratum, and each of these mega-couplets is interpreted to represent an individual 4th-order transgressive-regressive cycle. The complex succession of 4th-order cycles can be linked to variations in the development of skeletal carbonate production due to fluctuating periods of terrigenous input that partly or totally suppressed carbonate formation.

THE MID-TERTIARY TE KUITI GROUP IN THE VICINITY OF AOTEA HARBOUR: UNRAVELLING LITHOSTRATIGRAPHIC RELATIONSHIPS

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The mid-Tertiary Te Kuiti Group comprises predominantly carbonates and mixed siliciclastic-carbonate facies assigned to 10 formations and 21 members in western North Island, cropping out from Port Waikato in the north to Mokau in the south. Excluding local basal coal measures, the overall transgressive sequence involves low- to high-energy shelf deposits having temperate-latitude skeletal attributes. Sedimentation continued for about 13 million years throughout the Oligocene (Whaingaroan [Lwh] and Duntroonian [Ld]) into the earliest Miocene (Waitakian [Lw]).

The regional lithostratigraphy of the Te Kuiti Group throughout the wider South Auckland region (Waikato Basin and King Country Basin) has been addressed by several earlier workers, but a soundly integrated noncontroversial scheme still does not exist. This is because the lithostratigraphic subdivisions applied have been founded principally in the rock successions occurring mainly in either the northern parts of the basin or those occurring in the more southern areas. The southern region includes far greater development of limestones than in the north, where mixed siliciclastic-carbonate facies (calcareous mudstones, calcareous sandstones and local limestones) dominate. The rocks in these two regions are lateral equivalents of one another, but the exact interrelations between them remain unclear.

The key to helping solve this problem is detailed section logging, hand-over-hand correlation, and ultimately careful mapping in the transitional zone between the northern and southern regions, which lies between Raglan and Kawhia Harbours in the vicinity of Aotea Harbour. Despite various degrees of burial by widespread Plio-Pleistocene volcanics (Alexandra Volcanics) in this area, sufficiently good outcrops of the mid-Tertiary deposits exist to help clarify stratigraphic relationships through the transitional zone.

This work reports on initial field description of sections through the Te Kuiti Group at over 80 localities near Aotea Harbour. Several stratigraphic anomalies appear to exist in regard to the most recently published suggestions concerning the formations that are supposedly present in this transitional central region. For example, the detailed tracing of certain units from north to south shows them to apparently strongly cross time lines, so that 'older' formations in the north overlie 'younger' formations in the south. While not necessarily violating establishment of a lithostratigraphic classification, such a relationship does not fit with the perceived 'layer-cake' architecture of stratigraphic units in the group.

On-going field work will continue to address the above stratigraphic 'enigmas', and will be supported by laboratory characterisation of the various sedimentary units, and possibly also some strontium isotope analyses of fossil shell material to provide some absolute dates of key units. Using columns and fence diagrams, the poster presents a preliminary scheme for the stratigraphic relationships of the various Te Kuiti Group units in the wider Aotea Harbour region.

RHYOLITE CHRONOLOGY AT TAUPO VOLCANO, NEW ZEALAND: INSIGHTS FROM ²³⁰Th/²³⁸U DISEQUILIBRIUM IN ZIRCONS

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An important question in studies of silicic caldera volcanic systems is: what is the nature of the magma chamber? Is it a large, long-lived fractionating liquid body, or a "sleepy" crystal mush that gets prodded into life every so often, re-mobilizing existing material? What do crystals really represent, i.e. phenocrysts vs. xenocrysts, and what 'memory' do they retain? Related to these issues are questions such as does crystal growth and dissolution reflect protracted fractionation of a single magma body or remobilization and dispersal of crystal mush during injection of fresh magma into the subvolcanic system? Recent work on the archetypal silicic magmatic system at Long Valley, California, using ⁴⁰Ar/³⁹Ar, Rb/Sr or U-series isotope data has led to the suggestion that rhyolite magmas there are stored, following differentiation, for long (105-106 yr.) time scales. This contention has been disputed principally on the basis that it would be difficult to keep a body of magma thermally viable for such long periods, even if >500km³ volume. Alternative physical models have been proposed, such as remobilization of juvenile plutons or cumulate materials, and ion microprobe work on zircons has variously upheld or contested the claims for long magma residence times.

Taupo Volcanic Zone in New Zealand is host to two highly active rhyolitic caldera volcanoes, Taupo and Okataina, each of represents a magmatic system of comparable size to Long Valley. Central to understanding the dynamics and future activity of these volcanoes is knowledge of where the magmas are generated and stored, and over what time periods magma bodies exist prior to an eruption. Towards this, we have undertaken a study of ²³⁸U-²³⁰Th disequilibrium systematics in zircon phenocrysts from young eruptive sequences at Taupo volcano, in order to constrain the crystallization ages and histories of the magma bodies. Zircon is particularly useful for dating <350 ka crystallisation events since it strongly fractionates U from Th and thus precisely constrains isochrons on an equiline diagram. Use of TIMS techniques here yields high precision (+2-5 %) and an ability to date zircons as young as 16 ka, while analysis of various crystal size fractions has yielded information on variability of the zircon age population. At Taupo, U-Th isochrons from, and modelling of Zr-saturation in, eruptives leading up to and including the climactic ~530 km³, 26.5 ka Oruanui eruption imply that part to all of the zircon derives from remobilisation of older (but still <350 ka) silicic intrusives. The same is also true for the post-Oruanui sequence, where this 'xenocrystic' fraction has been overgrown in Zr-saturated magmas by material crystallised over a short period (e.g. 4-10 ka) prior to the eruption. On this basis, generation of rhyolites erupted after the caldera-forming event must be extremely rapid.

Comparisons between chemical/isotopic characteristics and volume/frequency relationships of Taupo post-caldera rhyolites imply that although the former result from assimilation/fractional-crystallization processes, generation of particular magma volumes for eruptions must involve large-scale remobilisation of older, sub-solidus silicic intrusives.

CHARACTERISATION OF MANTLE SOURCES FOR THE SOUTH AUCKLAND BASALTS, NORTH ISLAND, NEW ZEALAND

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The South Auckland volcanic field (SAVF) is situated in a continental intraplate tectonic setting and consists of silica-undersaturated alkalic basalts that can be divided into two groups (A and B) based on their distinct geochemical compositions. Both rock groups fall within a narrow range of Sr and Nd isotopic compositions ($^{87}\text{Sr}/^{86}\text{Sr} = 0.70273 \pm 19 - 0.70330 \pm 17$ and $e\text{Nd} = 5.97 - 6.89$) similar to the composition of HIMU OIB, whereas Pb isotopic compositions are unradiogenic relative to HIMU OIB (e.g., $^{206}\text{Pb}/^{204}\text{Pb} = 18.95 - 19.33$) and range between Atlantic MORB and EM2. The group A lavas have slightly higher $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{207}\text{Pb}/^{204}\text{Pb}$, lower $^{206}\text{Pb}/^{204}\text{Pb}$, and similar $e\text{Nd}$ values compared to those in group B, but there is no isotopic or geochemical evidence to suggest that any of the lavas have been contaminated by continental crust. Therefore, the relatively small but distinct differences in Sr and Pb isotopic compositions and similar $e\text{Nd}$ values are considered to be source-related. Petrogenetic modelling suggests that the group A and B lavas evolved as discrete lineages that appear not to be related by a common parental magma or source. Variations in incompatible element ratios, such as La/Nb and Zr/Nb, support this and indicate that the SAVF lavas were derived from at least two distinct sources. The incompatible element characteristics of the group A lavas indicate an enriched upper mantle source but relatively depleted in Th, K, Nb, Ta, and LREE with small LREE/HREE values, whereas those in group B exhibit trace element affinities with a LREE-enriched, garnet-bearing, OIB-like source.

The mechanism of source enrichment for groups A and B is problematic. Partial melting of a metasomatised subcontinental lithosphere source may account for the group A compositions. In contrast, alkaline basalts from Antarctica, Tasmania, and elsewhere in New Zealand have geochemical characteristics similar to those of the group B lavas. The SAVF basalts could be associated with partial melting of the remnants of a metasomatised and HIMU plume-modified Gondwanaland lithosphere, following continental fragmentation. Extensional tectonics related to orogenic events affecting the SAVF region could create conditions that promoted adiabatic decompression melting of these formerly widely dispersed lithospheric fragments.

LATE MIOCENE COOLING TRENDS OF SOUTHERN TASMAN SEA PALAEOTEMPERATURES: HOW COOL IS COOL?

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Palaeotemperatures are calculated using *Globorotalia miotumida* (planktic) and *Cibicidoides cenop* (benthic) foraminiferal oxygen isotope records from DSDP Site 593 in the southern Tasman Sea between c. 11 and 5 Ma (Tongaporutuan-Kapitean NZ Stages). *Gr. miotumida* is thought to record Southern Component Mode Water (SCMW) temperatures and *C. cenop* the Southern Component Intermediate Water (SCIW). The *C. cenop* record indicates SCIW palaeotemperatures were up to 1.5°C warmer than modern Antarctic Intermediate Water (AAIW; 3.5-7.5°C) during the intervals 11-10 Ma and 6.1-5.1 Ma, and comparable to modern AAIW values at c. 9.9 Ma (Mi6), and 6.4-6.3 and 5.4 Ma. The *Gr. miotumida* record of SCMW palaeotemperatures indicates that during the Tongaporutuan SCMW was up to c. 3°C warmer than modern Subantarctic Mode Water (SAMW; 8-9°C), but only c. 2°C warmer during the Kapitean.

In order to cool both mode and intermediate waters substantial cooling of the source areas is inferred. The modern AAIW is generated at the Antarctic Polar Front from the sinking of Antarctic Surface Waters, and SAMW sinks along the Subantarctic Front. As long as these fronts or their palaeo-equivalents have existed, mode and intermediate-depth watermasses are likely to have been formed. Modern benthic foraminiferal $\delta^{18}\text{O}$ values from Site 593 provide a bench mark for the volume of ice which can be accounted for in sea water, and the palaeotemperature calculations have some mean ocean ice volume component included, hence the cooling during glacial events is genuine. However, the calculations will slightly underestimate the extent of interglacial warming and overestimate glacial cooling as no change in ice volume is included because of the difficulty in determining the amount of that change. Covariance between the two records indicates global ice volume changes in addition to watermass cooling.

A *C. cenop* excursion to heavier $\delta^{18}\text{O}$ values from 6.4-6.2 Ma is interpreted as predominantly SCIW cooling because the SCMW record warms at the same time. The divergence of the records indicates up to 6°C water temperature change, with c. 3.5°C cooling of the SCIW and warming by c. 2°C of SCMW. However, as the benthic $\delta^{18}\text{O}$ values during this event are heavier than modern by c. 0.3‰, equivalent to 1.2°C, the SCIW cooling is more likely to be c. 2.3°C.

Tongaporutuan SCIW palaeotemperatures in the southern Tasman Sea are calculated to have been between 9 and 8°C, with significant cooling during Mi6 (c. 9.9 Ma) to 6.5°C, and during the latest Tongaporutuan-early Kapitean to c. 5.5°C. SCIW palaeotemperatures then returned to 9-8°C during the late Kapitean. SCMW palaeotemperatures are calculated to have been 12-10°C during the early Tongaporutuan, with glacial events Mi5 and Mi6 exhibiting cooling to 9-8.5°C. During the Kapitean, SCMW palaeotemperatures cooled to 10.5-8.5°C. The cooling of these subsurface watermasses was due to cooling of Southern Ocean surface waters. We link this to East Antarctic Ice Sheet expansion and stabilisation by c. 11 Ma (Mi5), and initiation of the West Antarctic Ice Sheet at c. 10 Ma (Mi6) and its expansion at c. 6.5 Ma (SCIW cooling event).

MIDDLE MIOCENE CLIMATE CHANGE IN NEW ZEALAND

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New Zealand has a Middle Miocene sedimentary record that includes paleoenvironmental settings from terrestrial through to open oceanic at paleolatitudes of 40-60°S. Sediments and associated faunas and palynofloras provide an important Southern Hemisphere perspective of paleoceanographic and paleoclimatic changes during an accelerated build-up of the East Antarctic Ice Sheet – a time of major global cooling.

Paleontological and sedimentological data from outcrops, petroleum exploration wells and deep sea drillholes have been compiled onto palinspastic maps for earliest and latest Middle Miocene times, to provide an overview of paleoceanographic and paleoclimatic change. They suggest that in the earliest Middle Miocene (ca. 16 Ma), tropical/subtropical surface waters surrounded much of New Zealand. Warm transitional surface waters were confined mainly to the south of New Zealand, but reached as far north as Chatham Rise. In latest Middle Miocene time (ca. 11 Ma) the Subtropical Front separating warm transitional and subantarctic surface waters, was positioned over the Chatham Rise, similar to the present day. In this configuration, tropical/subtropical surface waters were confined mainly to the northeast of North Island. The $\delta^{18}\text{O}$ record from Site 593 suggests that the Subtropical Front did not extend into the Tasman Sea at anytime in the Middle Miocene.

The terrestrial palynofloral record is generally too fragmented and poorly dated to allow reliable conclusions about climate changes through this period, but there is a general increase in the abundance of *Brassospora* (beech) relative to *Casuarina* (she-oak). This suggests an increase in humidity (moisture and cloud cover) and is consistent with a strengthening of moisture laden westerly winds as warm transitional surface waters moved northwards over the New Zealand subcontinent. Because there is no apparent rain-shadow in eastern areas, until the Late Miocene, uplift associated with plate margin deformation was probably limited in the Middle Miocene, at least in terms of its geographic extent.

High-resolution studies of DSDP Site 593 (south Tasman Sea) have been calibrated against the paleomagnetic record of ODP Site 1123 (Chatham Rise, SW Pacific). They identify major stepwise shifts in the $\delta^{18}\text{O}$ records of benthic foraminifers and at least two marked changes in planktic foraminiferal assemblages within the Middle Miocene, separated by a period of relative stability. The timing and magnitude of these events are consistent with global isotope events and changes in Antarctic ice-volume. Work is currently in progress to identify these events at Bryce Burn outcrops in Southland. This is so that distal oceanic and terrestrial records can be correlated within a well-constrained temporal framework, in order to test whether Middle Miocene climatic changes in New Zealand are coupled to the build-up of the East Antarctic Ice Sheet.

MAGMATIC EVOLUTION OF MAYOR ISLAND: THE STORY FROM MELT INCLUSIONS

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Mayor Island (Tuhua) is a solitary peralkaline volcano located to the north of Tauranga (North Island, New Zealand). It is surrounded on all sides by active and extinct calc-alkaline volcanoes in an overall supra-subduction zone system (SSZ). Volcanism associated with subduction has swept from west to east, encompassing the present position of Mayor Island, and the volcanic front is now located to the east of Mayor Island in the Taupo Volcanic Zone (TVZ) – Kermadec arc. However, the geochemical signature of Mayor Island eruptives is not characteristic of a SSZ system. In fact, the volcanic rocks of Mayor Island are bimodal in terms of SiO₂ content, consisting primarily of rhyolite but with a minor component of basalt preserved as quenched inclusions in individual rhyolite units. The volcanic rocks were erupted in wide variety of styles, including explosive and effusive; a number of these styles of eruption are more commonly found in viscous basaltic magmas. The preserved sub-aerial eruptive history of the island started at ~118ka, with the youngest (intra-caldera) flows estimated to be between 1000 and 500 years old.

Previous geochemical studies have demonstrated that there are no large changes in major oxide compositions over time, apart from increasing total iron with minor associated decreases in alumina and silica, spanning the range from comendite to pantellerite. There are, however, comparatively large and systematic changes in bulk rock trace element abundances.

Many of the feldspars and pyroxenes present as sparse phenocrysts in the Mayor Island suite, host apparently primary glass inclusions, that are likely quenched representatives of the host magma contemporary with a particular growth stage of the phenocryst hosts. It has been recognised that there is a potential for these melt inclusions (MI) to record the evolutionary (including degassing) history of the magma chamber(s) tapped during eruptions. For example, Barclay (1995) analysed (with ion microprobe and infra-red spectroscopy) the abundances of certain oxides and elements (e.g., H₂O, Nb, Zr, Cl, and F inclusive) in the MI, and compared these abundances with those of matrix glasses. Barclay's results demonstrated a secular increase in specific trace element abundances, including rare earth elements (REE), but detected no change in H₂O or F contents in the MI implicating saturation (i.e., buffering) of the magmatic system with a fluid phase. Secular increases in REE abundances can be attributed to fractional crystallisation. We have initiated a comparative study of the MI and matrix glasses using a UV "laser ablation inductively coupled plasma source mass spectrometer". This instrument acquires abundance data for a broader range of trace elements than those previously analysed. Our aim is to constrain the processes of elemental transfer from magma to gas phase in a peralkaline system in a comprehensive manner.

CLAY MINERALOGY AND EROSION OF THE WAIPAEOA RIVER CATCHMENT, GISBORNE, NEW ZEALAND

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The Waipaoa Catchment lies N-NW of Gisborne and has a total area of 2181 km². With a mainstem of 104 km, the river flows south into Poverty Bay ~10 km SW of Gisborne and carries approximately 15 million tonnes of suspended sediment annually, ranking it as one of the most sediment - laden rivers in the world (Hicks *et al.*, 2000).

Deforestation in the early 1900's has led to severe landslide and gully erosion. To assist in catchment analysis and sediment budgeting, Landcare Research divided the Waipaoa catchment into 16 land systems, based on the Land Resource Inventory, principally rock type and erosion, type and severity.

Four of these land systems were chosen to test the hypothesis that clay mineralogy will influence whether landslide or gully erosion is dominant. And, if mineralogical signatures could be established for the different land systems, they could be traced downstream onto the floodplain and into the marine environment.

There is no consistent mineralogical difference between the two chosen landslide dominated land systems and the two gully dominated systems. The Mangatu Land System is dominated by gully erosion. Samples taken from the Tarndale Gully Complex within the Mangatu Land System for example, are dominated by quartz in the clay fraction, whereas gullies in the Waingaromia Land System are dominated by mica and smectite. The landslide dominated Te Arai Land System, like the Waingaromia Land System, is also primarily mica and smectite, while the clay minerals of the Mako Mako Land System consist of mica and feldspar. It appears that tectonic influence of uplift and faulting, and its influence on headward erosion by streams, is most important in predisposition to gully erosion.

Geological formations upstream directly influence the clay mineralogy of both the stream bedload and suspended sediment and can be traced downstream of the erosional processes to the point of mixing with incoming waters. Of the suspended sediment flowing out into Poverty Bay, 50-60% has been contributed to the river system by gully erosion (Page *et al.*, 2000). During Cyclone Bola suspended sediment in the Waipaoa River was estimated at 32 x 10⁶ t, which is twice the estimated annual yield (Hicks *et al.*, 2000). Landsliding alone contributed 64 % (20.5 x 10⁶ t) of the suspended sediment load (Page *et al.*, 1999). From this it is suggested that sediment deposited on the floodplains during extreme storms and flooding is derived from upstream landsliding. The floodplain mineralogy is most similar to that of the Miocene Tolaga Group of marine sediments that make up both the Te Arai and Waingaromia Land Systems.

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LANDSLIDES AND TSUNAMI EARTHQUAKES – A PARADIGMATIC SHIFT?

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Based on an analysis of catalogues of historic tsunami events, Iida (1969) concluded that most tsunami are generated by coseismic deformation. Further, he defined relationships between earthquake magnitude and tsunami magnitude that, with refinements, still hold for many tsunami events. However, some tsunami were found to have larger magnitudes than predicted by the earthquake magnitude. The tsunami also differed significantly in their behaviour compared to normal seismic tsunami. This type of tsunami is commonly referred to as being generated by a special type of seismic event, a *tsunami earthquake*.

Over time, a number of different explanations have been suggested for the additional tsunami energy associated with tsunami earthquakes, including slow rupture velocities, rupture through soft sediments, or unusually large coseismic deformation. Some suggested that the extra energy was generated by a secondary mechanism such as submarine mass movement.

The last decade included an above average incidence of tsunami earthquakes: including the Papua New Guinea, Nicaragua, Mindoro and Kamchatka tsunami. A further two events at Izmit Bay, Turkey, and Skagway Harbour, Alaska were not tsunami earthquakes, but included tsunami generation by mass movement.. These events, particularly the 1998 Papua New Guinea event, have stimulated international research into tsunami generation by mass movement. This research has uncovered suitable submarine landslides in the vicinity of the tsunami source for the anomalous events of the last decade. Numerical modelling has demonstrated that a submarine landslide is the most plausible explanation for the catastrophic tsunami on the Papua New Guinean coast.

It is evident that submarine landslides can fully account for the extra energy associated with tsunami earthquakes, as well as the characteristics of the tsunami waves produced. Re-examination of the seafloor in the source regions of major tsunami earthquake events, such as the Great Meiji Sanriku Tsunami of 1896 and Great Eastern Aleutian Tsunami of 1946, has revealed the presence of large landslides. Subsequent modelling demonstrated that these landslide features are of the appropriate dimensions to generate the observed tsunami.

This suggests that the catalogues of historic tsunami should be re-evaluated as landslide generated tsunami are probably under-represented. This arises because there is a tendency to attribute the tsunami to the obvious source mechanism. Most historic landslide tsunami records involve sub-aerial landslides with eyewitnesses, or represent the only possible explanation. The under-representation of landslide-generated tsunami poses a problem for the development of probabilistic tsunami hazard models. For New Zealand, the potential for landslide-generated tsunami is not well defined, and indicates a need to better map and date submarine landslides around our continental shelf.

NATURAL CLIMATIC VARIABILITY VERSUS ANTHROPOGENIC WARMING: IMPLICATIONS FOR COASTAL MANAGEMENT

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Moves to implement the Kyoto Protocol indicate a political acceptance of the role of anthropogenic gas emissions in global warming and future climate. The emphasis has been on mitigating the consequences of emissions just in case the hypothesis of enhanced Greenhouse warming is correct. For the coastal zone around New Zealand, these consequences are primarily increased sea level, and possible changes to the wave climate, ocean circulation and storminess. Subsequently it may be expected that the frequency and magnitude of coastal hazards such as erosion and flooding may change.

The Intergovernmental Panel on Climate Change (IPCC) has produced 3 assessment reports over the last decade.. A sceptical view of these are that each report has predicted a smaller climatic and sea level response, while attributing a greater proportion of the change to human influence. Levels of some Greenhouse gases have now been increasing for 150 years, and the combined radiative forcing of these gases is more than half the predicted effect of a doubling of carbon dioxide concentrations. Therefore, it seems reasonable to consider the actual changes observed within the New Zealand coastal zone during the last 100-150 years as a basis for assessing the next century.

A feature of the last century has been that the magnitude of inter-annual to decadal scale variability has been similar to or exceeded the magnitude of the long-term trends. Defining the full impact of this variability is limited by the availability of suitable high quality data for sea level, shoreline response, and wave climate and storm behaviour. None-the-less it is apparent that ENSO has a significant impact at time-scales of 2-7 years, and IPO has a comparable effect at 50-70 year time-scales.

Assuming that no significant change in climatic response to human influences occurs in the next 100 years, extrapolating the behaviour of ENSO and IPO provides good constraints on coastal response. This may be a more useful approach to coastal management than relying on IPCC global projections.

GOLD MINERALISATION IN COLLISIONAL OROGENS: GEODYNAMIC CONTROLS ON LOCATION AND TIMING IN THE WESTERN ALPS

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Hydrothermal gold-quartz lodes in orogenic belts are one of the world's largest sources of mined gold and they are a major target for the exploration industry. The deposits are hosted by regionally metamorphosed rocks in orogens of all ages, from Archean to Tertiary. The obvious correlation between orogenic setting and mineralisation leaves no doubt that gold concentration is ultimately driven by the same geodynamic processes that form the orogens themselves, although theories on the origin of the gold-transporting fluids are still debated. Owing to the enormous mappable extent of orogenic belts, gold exploration must be guided by genetic models that predict the localisation of the deposits in space and time. We address this issue by combining new results from geodynamic modelling of Alpine-type orogeny with recent geochemical and geochronological studies of gold lodes in the Western Alps.

We focus exclusively on explaining the 6 main structural and temporal characteristics of vein formation that are common to any orogen-perpendicular cross-section through the mineralised belt: (1) dilatant conduits linking deep fluid sources and vein sites; (2) localisation within crests of syn-convergence back-folds; (3) localisation in the structurally deepest tectonic units exposed; (4) brief hydrothermal activity; (5) temporal lag behind metamorphic peak in the wall rocks; (6) fluid source in deep-lying metasediments undergoing prograde metamorphism. A thermo-mechanical numerical model of Alpine-style continental collision shows that, once uplift and back-thrusting of the orogen is well advanced, narrow zones of extensional strain develop in the core of the orogen, reaching steeply down from the erosion surface into the middle crust where prograde metamorphism is still underway. Such steep dilatant zones are short-lived because the nappe boundaries at which they nucleate are progressively advected into higher structural positions. The location, relative timing, and transience of these dilatant channels match the observed features of the gold deposits in the Western Alps. We infer that syn-convergent extension in the core of the orogen allows deep metamorphic fluids to ascend into shallow brittle-ductile structures where ore is deposited.

**SIGNIFICANCE OF SOME SEQUENCE BOUNDARY EVENTS IN
THE LATE OLIGOCENE TOREHINA FORMATION,
COROMANDEL PENINSULA, NEW ZEALAND**

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The late Oligocene Torehina Formation occurs as scattered eroded remnants near Colville, northwestern Coromandel Peninsula, and is an isolated occurrence of the widespread Oligocene to earliest Miocene temperate-water carbonate facies of New Zealand (i.e. Te Kuiti Group equivalents). At Colville the formation sits with strong angular unconformity on Upper Jurassic Manaia Hill Group basement rocks, and contains two retrogradational depositional sequences (A and B), each displaying net carbonate-platform onlap.

The sequence boundary (SB1) at the base of sequence A is overlain immediately by terrestrial to marine pebble conglomerates containing two groups of clasts. The majority (70-80%) are visually similar to local basement sandstones, but are petrographically and geochemically different and identify with a source associated with a dissected orogen, and with mixtures of felsic and volcanogenic-derived sediment. The most likely source is the complex Torlesse Terrane. The second group of clasts are exotic relative to all basement sources. They are typically less indurated and coarser-grained, some contain coal laminae and particles, and all contain detrital kaolinite as lithic fragments and matrix. This facies identifies a likely non- to marginal-marine source that derived sediment from a granitic terrane subjected to extreme weathering. Mechanical fragility of some clasts, combined with similar sediment type within the matrix and interbedded sandstones of the conglomerates, suggest that there was a once-present, easily eroded proximal source. All of these attributes suggest that the second clast group was derived from an Upper Cretaceous sedimentary cover, either a locally developed basin fill or part of a more regional distribution than is now preserved on the North Island.

Rapid transgression saw sequence A pass upwards through marginal-marine facies to a muddy low-energy, pelagic-dominated carbonate shelf. The overlying sequence boundary (SB2) changes character over very short distances from a burrowed glauconitic firmground, to an undulatory contact with no obvious erosion, to a paleokarst with 25+ m relief. Sequence B strata above the paleokarst are clayey, marine (offshore) siltstones, and are biostratigraphically age-equivalent to open-marine carbonate skeletal grainstones at other sites. There are also paleogeographic differences in relative accommodation space among the basal carbonate facies of sequence B: *Amphistegina*-bearing skeletal grainstones are succeeded by deeper-water, foraminiferal silty echinoderm-bivalve grainstones, which in several locations themselves form the basal unit above SB2. Succeeding higher energy, bivalve- then bryozoan-grainstones record an overall increase in sea level, from inner to outer shelf settings.

We interpret differential tectonic movements to explain the paleogeographic differences in physical characteristics of SB2 and contrasting accommodation space among initial carbonate facies of sequence B. The local depositional/tectonic fabric is strike-parallel to the immediately adjacent Hauraki graben, inferred to have been active with increasing regional tectonism throughout New Zealand by late Oligocene time. Physical attributes and age of the Torehina sequence boundary SB2 are similar to the well documented Marshall Paraconformity in South Island. However, there are regional differences in patterns of subsequent basin fill and interpreted changes in relative sea level that can be explained in the context of regional differences in subsidence histories rather than eustasy.

MODELLING OF TIDAL AND CURRENT PROPAGATION IN A SHALLOW MAKETU ESTUARY

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A two-dimensional numerical modelling was undertaken to investigate the tidal and current propagation in a small shallow microtidal Maketu Estuary in the Bay of Plenty on the north-east coast of North Island, New Zealand. Such modelling has not previously been attempted mainly due to a lack of detailed bathymetric data covering the entire Maketu Estuary, and because of lack of comprehensive field measurements including ground-truth information (tides, currents and meteorology at site) essential for model calibration and validation. BLACK'S (1995) model 3DD (used in 2D hydrodynamic mode) was used. The model was calibrated and validated against field measurements employing a high-resolution computation square grid (30x30m). Comparison between measured and modelled sea levels and currents showed a very close agreement for the sea levels ($R^2 = 0.96-0.98$ with deviations of less than 5%) and for currents ($R^2 = 0.88-0.93$ with deviations of ~ 10%). Model simulations of the residual current field indicated a strong net seaward current which would be expected to begin to purge the estuary of sand and to inhibit new infilling after the 1996 partial re-diversion of the some Kaituna River flow back into the estuary.

Overall, the 2-dimensional hydrodynamic model for Maketu Estuary was shown to have the capacity to be used (i) as a useful diagnostic tool in the environmental management of the Maketu estuarine system, and (ii) in planning future field sampling and investigating dynamic flow responses to changing forcing variables, if used cautiously in stratified conditions.

COASTAL PROCESSES LINKED TO BEACH EROSION AT WAINUI BEACH, GISBORNE

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A long-term trend of accretion appears to characterise the sandy embayment of Wainui Beach. The nature of this accretion, however, is complex. The accretion is controlled by an oscillation of sediment back-and-forth along the beach that is strongly regulated by a wave climate with a wide swell window. The result of these conditions, and several coastal processes, is a very high level of short-term variability that masks the long-term trend, and has painted a misleading impression as to the stability of the beach.

The beach is essentially a thin veneer of sand on a predominantly rocky basement. Structural features on the seafloor appear to confine the main body of this sediment as a localised sand belt within the nearshore, and includes two extensive reef systems and the shore-parallel rocky, Coopers Bank. These structures, combined with other factors, means Wainui Beach can be considered as a “closed” beach system. Coopers Bank was also identified as controlling wave focussing at the shoreline, especially when waves propagate from the southerly quarter.

Several interacting coastal processes are driving beach erosion. A very high level of short-term or episodic shoreline departures drives the most rapid changes, mainly through the beach “cut and fill” cycle. The most destructive erosion periods occur in response to the collective effects of high, persistent storm waves simultaneously with spring tides, topographically-restricted rip currents, bi-directional longshore currents and wave refraction processes generating zones of convergence at the shoreline. Development on the seaward extreme of the large dunal system is another contributing factor.

MODELLING NEAR-SURFACE ATMOSPHERIC TRANSPORT OF THE STROMBOLI VOLCANIC PLUME

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Persistently degassing and erupting basaltic volcanoes may generate air pollution events in physically distant locations because: (a) they emit gases and aerosols into the troposphere for extended periods of time, often in environmentally significant volumes; (b) the plumes generated by such activity may be weak in buoyancy and thus can remain low in the atmosphere; (c) these emissions may not be effectively removed by atmospheric processes and may remain in the air for periods in excess of several days; (d) these emissions are subject to atmospheric transport which may deliver them to environments in excess of 10^3 km downwind, and (e) the emissions may not dissipate significantly during atmospheric transport. Although these general remarks can be made with confidence, there is currently little detailed understanding of the transport regimes of plumes emanating from some of the world's largest persistent volcanic gas sources. In Europe, Stromboli (Aeolian Islands) and Etna (Sicily) are two such volcanoes, both of which generate persistent tropospheric plumes. These emissions exceed those from entire industrial regions in the entrained mass of sulphur dioxide, carbon dioxide and other harmful gases. Since volcanogenic air pollution may cause a host of physiological impacts upon humans, livestock and vegetation even at great distances from the volcano in question, it remains important to gain an understanding of where, when and how such pollution events may be generated. One method of approaching these questions is to use a computer trajectory model to calculate hypothetical plume paths and evaluate the transport and dispersion of material during individual events and over long time series. This paper applies the Hysplit_4 trajectory model to the gaseous emissions of Stromboli volcano with a view to understanding the volcano's impact upon air quality in the Mediterranean region. Twelve months of daily trajectory analyses made between May 1998 and April 1999 are used to evaluate the possible direction, length, dispersion and vertical motion of plumes emanating from the volcano. Particular interest is given to those trajectories indicating a low degree of dispersion and descent to below 975 hPa (~150 m a.s.l.) simultaneously. When these circumstances occur together, the Stromboli plume is likely to influence surface air quality. Trajectories showing these characteristics were observed on 25 days during the 12 month duration of the study. These trajectories most commonly occurred to the E and SE of the volcano over mainland Greece and the Greek islands, Turkey and Egypt (10 events). A second area of clustered trajectories lies to the S and SE of the volcano and includes the Gulf of Sirte and the northern coast of Libya (7 events). Surface-level, undispersed trajectories into these zones to the east and south of the volcano are critical because they demonstrate that air quality in coastal cities around the Mediterranean may be affected by Stromboli's emissions. The results suggest that Athens (Greece), Izmir (Turkey), Benghazi and Tripoli (Libya) in particular may be at risk. If such an event were to occur in coincidence with an anthropogenic urban air pollution event, the addition to pollution concentrations could have serious implications for public health. Indeed, these findings indicate many new research avenues for us to explore in determining the historical, contemporary and potential future role of high-volume volcanic degassing in air pollution globally.

MESOZOIC CRINOIDEA IN NEW ZEALAND AND NEW CALEDONIA

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Mesozoic crinoids are known from the Murihiku, Rakaia, Maitai, and Bai de St. Vincent Terranes as well as from Cretaceous rocks of the Kaipara Harbour, Chatham Islands and Kaikoura coastline. A mix of endemic, Tethyan and bi-polar crinoid species inhabited the Maorian Province during the Triassic and Early Jurassic. This population was replaced by local radiation and an influx of cosmopolitan faunas from the Middle Jurassic onwards. Preliminary identifications indicate that Mesozoic taxa included species of the Pentacrinidae, Paracomatulidae, Isocrinidae, Holocrinidae, Encrinidae, Millericrinidae, Phyllocrinidae, Bourgetocrinidae, and Dadocrinidae. Only species of the Isocrinidae and Encrinidae transgressed terranes. Maorian taxa appear to have reduced in diversity from the Late Triassic onward. This trend, however, may simply be due to non-collection, an artifact of preservation, lack of suitable biofacies, Triassic-Jurassic extinction event, since favourable conditions seem to have prevailed well into the Middle Cenozoic.

No New Zealand Mesozoic crinoid has been found intact. Incompleteness may be due to: fragility, predation, post-mortem scavenging, or delayed burial. Terrane emplacement, tectonism, and rock diagenesis have also precluded good preservation. Disarticulation precludes estimation of population sizes. *Paracomatula triadica* from the Late Triassic of New Caledonia is the only almost complete crinoid known. Few Jurassic calyces have been found yet only calyces are preserved of the Late Jurassic cyrtocrinid species *Phyllocrinus furcillatus*. Cretaceous specimens are of columnals only.

Triassic and Jurassic crinoids are found in mid-shelf deposits. Cretaceous crinoids occur in shallow-water facies at the Chatham Islands. Across the K/T boundary, crinoids are still present in Paleocene shallow-water facies in storm-deposits of the Kaitangata coast. This conflicts with Northern Hemisphere records, where pelmatozoan faunas apparently migrated offshore to deeper water from the Triassic onwards. Where more than one species of the same genus have overlapping ranges they are invariably mutually exclusive, probably because they lived in distinctly different biotopes. New Zealand crinoids are often found in close association with filter-feeding brachiopods, limids and *Halobia* during the Triassic. No crinoid has been found in association with the filter-feeding bivalves *Retroceramus* in the Jurassic or *Inoceramus* in the Cretaceous. Some crinoid taxa are only known from a single geologic stage. Although not abundant, some New Zealand crinoids may, when no other diagnostic fauna is present, be used as biostratigraphic index fossils.

CITYMAP MANUKAU: GEOLOGICAL MAP OF MANUKAU CITY, 1:50 000

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The CityMap Manukau poster presents a 1:50 000 scale geological map of Manukau City, produced from a GIS urban geological database compiled by the Institute of Geological and Nuclear Sciences with the assistance of Manukau City Council. Sedimentary and volcanic rocks underlying the city are mapped and their properties, including engineering properties, described. The major geological hazards facing Manukau City are assessed.

The seismic hazard model for New Zealand, based on the distribution and long-term recurrence behaviour of active faults and the spatial distribution of historic earthquakes, indicates that Manukau City is in an area of low seismic hazard, away from areas of high seismicity rates. The greatest potential for fault rupture and consequent large earthquakes exists along faults in the Hauraki Plains and South Auckland. Kerepehi Fault in the Hauraki Plains is a known active fault capable of generating moderate shaking in Manukau City. Recent investigation of Wairoa North Fault in the east of Manukau City indicates that it is probably active and is a potential source of large earthquakes. Drury Fault, immediately south of Manukau City, may also have potential for future activity. Earthquake ground shaking hazard at any site is modified by the earth materials beneath the site. The seismic hazard map for Manukau City shows the effect of variable ground conditions on the earthquake ground shaking hazard.

Late Quaternary volcanoes of the Auckland Volcanic Field are prominent landforms in the west of Manukau City and continued activity in the field can be expected. During a future basaltic eruption, the highest hazard zone will be within 3 km of the vent where pyroclastic surges and small blasts, thick ash falls, and lava flows are likely to have destructive effects. A moderate to low ash fall hazard could affect areas up to 30 km from the vent. Volcanic risk in Manukau City is high because of the concentration of population, buildings, transport and communication systems, and economic activity, together with uncertainties in predicting the time and location of the next eruption. The city also faces the threat of deposits originating from rhyolitic and andesitic eruptions in the Central North Island, Taranaki and on Mayor Island. Tephra fallout layers originating from these centres are numerous and widespread in the Auckland region, and more can be expected in the future.

The stability of slopes is controlled by the strength of the rock material and the nature, attitude and spacing of fractures and bedding planes in the rock mass. Slope angle, groundwater conditions and rock weathering are also important factors. The risk posed by slope failure depends on the proximity of unstable ground to the presence of people, buildings, transport routes and communication and service lines. Slope failure hazards in Manukau City are present where unfavourable combinations of slope and rock type exist. These are typically areas where saturated, thick mantles of weathered materials are present on slopes $>20^\circ$. Rock falls, slides and slumps from steep, eroding coastal cliffs are also a significant hazard.

INTERSEISMIC, COSEISMIC AND POSTSEISMIC DEFORMATION FROM ARTHUR'S PASS 2: CONSTRAINTS ON RHEOLOGY OF THE LOWER CRUST

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Postseismic displacements are commonly observed after moderate to large earthquakes, as a result of the slow adjustment to the new stress field by creep in the ductile lower crust and mantle. However, little evidence for a postseismic signal was found following the 1994 Arthur's Pass earthquake (Beavan and Ellis, this volume). We examine whether the lack of postseismic signal is due to crustal structure (high viscosities within the lower crust) or owing to assumptions used in processing the data. We use the pseudo-3D viscoelastic code of Pollitz (Pollitz, 1997) to predict post-seismic signals for the best-fit coseismic inversion fault model, for a variety of assumed upper and lower crustal structures in the vicinity of Arthur's Pass.

Forward models show that negligible postseismic signal from 1995-1997 would be expected for average viscosities in the lowermost 10 km of the crust of around 10^{19} Pa.s or greater. This lower bound on viscosity is consistent with strength profiles based on experimentally-derived flow-laws for hydrous quartz (e.g., Luan and Paterson, 1992) for a reasonable range of crustal geotherms and strain-rates. Alternatively, synthetic model results also suggest that a post-seismic signal could be present, but almost linear between 1995 and 2000. A linear signal is particularly expected for a temperature-dependent viscosity profile with depth, because the sequence of Maxwell relaxation times for each viscosity can combine to produce a linear time response. This suggests that the interseismic velocity field used to correct earlier data sets from the Arthur's Pass region may be contaminated with a small postseismic signal.

The data from 1994-1995 covered a subset of the campaign network and does show a small signal consistent with postseismic effects. This could result from higher rates of postseismic deformation in the period immediately following the earthquake, and/or be due to a separate process such as aseismic creep along the faults at depth.

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ANALYSIS OF FLUID PRESSURES IN SEDIMENTARY BASINS USING A MODIFIED TERZAGHI CONSOLIDATION FACTOR

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Abnormal fluid pressures in basins significantly affect hydrocarbon resource exploration. Overpressure (fluid pressures greater than normal hydrostatic pressure) compromises trap integrity and controls the migration of hydrocarbons, while underpressure (sub-hydrostatic fluid pressure) can cause significant drilling problems. Additionally, fluid pressure influences the geodynamics of the basin by determining the effective stress acting on the sediment. We reconsider the factors influencing fluid pressure during sedimentation and erosion, by introducing a variation in the analysis of Terzaghi (1943) accounting for a moving boundary. Using this approach, we derive a modified Terzaghi consolidation factor T_f' , which takes the rate of erosion or deposition into account. This non-dimensional number provides a simple diagnostic term for analysing the basic hydrodynamic behaviour of a depositional/erosional system in one dimension. Bishop (1979) derived a similar number in terms of storativity, S , but did not fully derive it in terms of a moving boundary condition.

Results from one- and two-dimensional numerical models incorporating stress and fluid-flow can be analysed in terms of the modified Terzaghi number, and show that factors promoting overpressure during sedimentation are high compressibility, low permeability, and high sedimentation rates. Conversely, the same factors also promote underpressure during unloading. A low- T_f' system which experiences an episode of deposition with generation of overpressure, followed by erosion at the same rate, will maintain overpressure as the system continues to respond to the mechanical disequilibrium from the loading phase. Eventually, the system will become underpressured. High T_f' systems will instead remain in hydrostatic equilibrium. Where horizontal tectonic stresses are significant, significant overpressure may be generated or prolonged.

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AUTHIGENIC SULPHIDE MINERALISATION AT BELLE-BROOK, WAIMUMU, SOUTHLAND

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Authigenic sulphide mineralisation at Belle-Brook, Eastern Southland, is dominated by fine-grained framboidal marcasite hosted within an early Tertiary fluvial sequence. Structurally the area is dominated by a series of steeply dipping reverse faults.

Textural evidence suggests at least two initial phases of Fe-sulphide mineralisation at Belle-Brook: an earlier stage of fine grained framboidal pyrite composed wholly of microcrysts; and a later stage of massive (sometimes radial) marcasite occurring either as overgrowths on earlier pyrite or as discrete marcasite framboid/polyframboidal masses.

Trace element analysis of marcasite has shown anomalously high amounts of As, Ni, Co and to a lesser extent Zn, Pb and Cu. Element mapping has established Ni occurs within colloform bands, most probably as bravoite (Fe,Co,Ni)S₂. Discrete bravoite grains are not common. Repeated bravoite deposition postdates initial pyrite/marcasite mineralisation and earliest annealing recrystallisation phase. Base metal remobilisation occurs along early massive marcasite framboidal grain boundaries. Pronounced As depletion-enrichment remobilisation signatures occur within the earliest framboidal microcrystalline pyrite. Remobilisation to this extent does not occur within the less reactive massive marcasite.

The origin and paragenesis of sediment-hosted sulphide mineralisation has been strongly debated over the years. At Belle-Brook sulphide mineralisation is still occurring today and is unmetamorphosed. This provides an ideal opportunity to examine the initial sulphide / pre-ore mineralisation in an immature sediment-hosted system.

AUTHIGENIC GOLD MINERALISATION AT BELLE-BROOK, WAIMUMU, SOUTHLAND

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Gold mobility in the surficial environment is well documented in the literature. Authigenic gold-sulphide mineralisation is hosted in the Gore Lignite Measures, an early Tertiary, fluvial, quartz gravel sequence, approximately 500m thick, resting on argillitic Triassic-Jurassic basement. The Waimumu Quartz Gravels (Pliocene) are derived from localised reworking of the underlying Gore Lignite Measures and are significantly enriched with respect to authigenic gold mineralisation. Structurally, the area is dominated by a steeply dipping series of NE trending reverse faults.

The morphology of authigenic and detrital gold grains have been examined using scanning electron microscopy. Aggregational and dissolution textures characteristic of colloidal gold mobilisation are documented. Aggregational textures include: colloidal gold aggregates; budded gold / budded gold masses; development of budded chain structures and the development of accretionary gold deposition "fronts". Dissolution textures involve the preferential dissolution of gold along original grain boundaries, this serves to highlight aggregational textures, i.e., the classic "spongy" texture of remobilised gold is a conspicuous dissolution texture of original budded chain structures. An intermediary stage featuring characteristic annealing textures (i.e., development of triple junction grain boundaries) exists between the aggregational and dissolution mobilisation phases.

Unusual authigenic gold occurrences are also documented, i.e., grains with apparent 5-fold symmetry and triangular plates.

The Belle-Brook and Parker Road authigenic gold localities are from naturally occurring unmodified fluvial systems, this lack of contamination is of considerable significance particularly since numerous gold mobilisation textures documented in the literature are of dubious origin.

HYDROCARBON RESERVOIR POTENTIAL OF SOME THIN-BEDDED TURBIDITES, EAST COAST, NORTH ISLAND

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Thin-bedded turbidites rank highly as hydrocarbon reservoir targets. Studies of East Coast examples should help modelling of local reservoir potential and assist the development planning of future discoveries in this facies.

The Whakataki Formation at Waipouri's Mark, near Whakataki, comprises Early Miocene turbidites with over 600 beds per 30 m of section. Facies characteristics favour a medial to distal levee setting. Three facies are distinguished in the 30 m of section studied and these might reflect channel migration.

Bed thickness cyclicity has wavelengths of about 1 m and 14 m. Poor age control hinders interpretation of these as specific Milankovitch cycles but individual beds are likely to have been deposited much more frequently than the 6000 year frequency recognised in other turbidite successions, and a frequency of 2000 years or less is likely.

Net to gross values vary from 65% to 90% sandstone thickness, depending on the interval analysed, with an overall average of c 70%. The main sandstone lithology is slightly greenish grey, moderately hard, slightly calcareous to calcareous, fine and very fine sandstone. Three samples gave porosities of 19-20% and permeabilities of 1-12 millidarcies at confining pressures of 5 MPa.

Bed-orthogonal fractures have spacings controlled by bed thickness and hence are a function of bed cyclicity. Some sandstone beds are not fractured. This might reflect heterogeneous fluid pressures during fracture formation and hence that the reservoir is compartmentalised. Through-going fractures extending several metres in length are present and could enhance fluid connectivity if open at depth.

Younger, Middle Miocene, bathyal sediments nearby in the subsurface (Titihaoa-1) contain significant gas. FMI logs show the unit is thinly bedded and probably consists of turbidites, with cyclic variations in bed thickness and c 90 fractures over a 500 m interval.

THE TRANSITION FROM ANDESITE TO RHYOLITE IN THE TAUPO VOLCANIC ZONE: TECTONICS, TRACE ELEMENT AND ISOTOPE GEOCHEMISTRY

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In this paper we review aspects of andesite magma petrogenesis in Taupo Volcanic Zone (TVZ) and examine possible links between andesites and rhyolites which are emerging through the application of micro-analytical methods.

Andesites are known to have complex origins through partial melting, fractional crystallisation, mixing, mingling and bulk contamination of magma batches over a variety of pressure regimes. Moreover, recent U-Th-Ra isotope disequilibrium measurements infer that these processes may occur over a variety of time-scales ranging from thousands to tens of thousands of years. As a result, magmas emerging at the surface may carry direct geochemical evidence of the source from which they were derived, alternatively, this may be masked by an array of non-systematic secondary processes. For example, standard plots of $^{87}\text{Sr}/^{86}\text{Sr}$, $^{143}\text{Nd}/^{144}\text{Nd}$ and Pb isotopes for volcanic rocks from TVZ define a broadly overlapping array, which has been interpreted as Assimilation with Fractional Crystallisation (AFC). A traditional, and convenient, approach to modelling these processes has been to select a primitive magma type (usually basaltic) and to model the evolutionary process from this composition with respect to a heterogeneous contaminant. But what if the magma source region were small in volume, heterogeneous and variably depleted through previous melting episodes? Given that the putative “subduction component” may comprise a hydrous fluid phase, bulk sediment, sediment melt, slab melt or a mixture of all of these, the magma source region may become variably contaminated on time-scales appropriate for magma genesis. Indeed, this scenario, plus heterogeneous crust, may afford the most credible explanation for the spread of data array on isotope diagrams.

Silicic magmas such as rhyolites can originate in many ways, with two extreme end members: (i) Partial melting of crust and (ii) Fractional crystallisation of mafic magma. Recent studies have invoked models which embrace both, but in all cases the source of heat lies in the upper mantle and in central TVZ, rapid extension, thin crust, high heat flow, He isotopes and a bimodal basalt–rhyolite association support this model. Moreover, subjacent andesite edifices, engulfed by younger rhyolitic ignimbrites have been detected in drill holes and as lithics associated with caldera forming eruptions.

A study of phenocryst melt/glass inclusions and groundmass glass in andesites from Ruapehu by combined electron microprobe and Laser Ablation Induced Coupled Plasma Mass Spectrometry (LA-ICP-MS) is presently under way. This has shown that glass compositions define trends from dacite (>63% SiO_2) to rhyolite (>69% SiO_2) and that trace elements (LA-ICP-MS) overlap with those from TVZ rhyolites leading us to re-examine the links between andesite and rhyolite magma chambers. It now remains to place our geochemical observations into a realistic tectonic perspective.

A TALE OF THREE MAGMAS: A REINTERPRETATION OF THE KAKANUI MINERAL BRECCIA, NEW ZEALAND

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The Kakanui Mineral Breccia (KMB), North Otago is an Oligocene submarine volcanoclastic deposit. The KMB is characterised by upper mantle assemblages, including megacrysts (kaersutite, clinopyroxene, garnet, anorthoclase, ilmenite, apatite & phlogopite) and garnet pyroxenite nodules within a nephelinite host.

Geochemical and experimental evidence points towards three potential magmas involved within the petrogenesis of the Kakanui Mineral Breccia. Two magmas are involved in the formation of its distinct and unique megacryst and pyroxenite suites, while the third triggered the eruption through magma injection.

Megacryst phases are chemical distinct from their garnet pyroxenite equivalences. Megacryst phases typically contain more magnesium and aluminium whilst containing less iron, sodium and titanium, reflecting their primitive nature compared to their more evolved garnet pyroxenite counterpart. In addition, all indicators (geochemical, experimental) point towards a higher-pressure origin (25-15kb, 1200-1150°C) for the megacryst suite compared to the garnet pyroxenite suite (15-16kb, 930°C). Megacryst trace element chemistry obtained by Laser Ablation ICPMS confirms that the nephelinite host is the parent to the megacryst suite.

Pyroxenite suite (cumulate) phases are more evolved, reflected by elevated trace element concentrations compared to their megacryst counterparts. A hypothetical parent melt was calculated from using basaltic experimental partition coefficients for Cpx/Liquid. The parent composition is similar to the host nephelinite but more evolved, hence constituting a potential second magma (Magma 2 - evolved nephelinite). Geobarometry and geothermometry of the pyroxenite suite indicates formation conditions between 15-16kb and 930°C.

The third magma is recognised from the presence of quenched pyroxenites; they have typical quenched textures and variable chemistry, equivalent to a primitive Alkali Olivine Basalt. The quenched nature suggests rapid extrusion before the liquid could equilibrate with the host nephelinite.

	Magma 1	Magma 2	Magma 3
Composition	Nephelinite (primitive)	Nephelinite (evolved)	AOB
P/T conditions	25-15kb, 1200-1150°C	15-16kb, 930°C	Unknown
Assemblage	Megacryst Suite	Pyroxenite Suite	Garnet & Phlogopite? Quenched Pyroxenites
Relationship to others	Host & Parent to Megacrysts	Parent to Garnet Pyroxenites	Triggering Magma?

ADVANCES IN COASTAL HAZARD MAPPING 2001

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Since colonisation of New Zealand about 700 years ago by Polynesians and about 200 years ago by Europeans, many coastal settlements have unwittingly been placed at risk from geological processes. When such processes threaten the things that we value they are termed coastal hazards. The most widespread coastal hazards in New Zealand are marine erosion and flooding, and coastal landslip. Almost half of New Zealand's 15,000km-long coastline is exposed to both long and short-term marine erosion.

Prior to the enactment of the Resource Management Act in 1991 (RMA-91), the prevention and mitigation of coastal hazards was primarily the responsibility of the National Water and Soil Conservation Authority (NWASCA) and the 20 Catchment Authorities and Regional Water Boards serviced by NWASCA under both the Soil Conservation and Rivers Control Act 1941 and Water and Soil Conservation Act 1967. Under both the Town and Country Planning Act 1977 and Local Government Act 1974, local authorities had powers to identify areas vulnerable to natural hazards in Regional Planning Schemes, make appropriate provisions in District Planning Schemes, and regulate subdivision, use and development in hazardous areas. Despite these powers, Coastal Hazard Mapping was conspicuous by its absence in New Zealand and development generally repeated the legacy of the past by proceeding in areas at risk from coastal hazards.

Always acting as the ambulance at the bottom of the cliff started to wear thin with NWASCA as it continued to subsidise costly property protection works throughout New Zealand. The philosophy of "*prevention is better than cure*" emerged and along with it a commitment to developing Coastal Hazard Mapping techniques for nationwide application. In 1979-1980, Dr Gibb formerly introduced the concept of Coastal Hazard Mapping into New Zealand through NWASCA. In March 1981 NWASCA adopted standardised Coastal Hazard Mapping techniques for erosion, flooding and landslip and developed a Natural Hazards Policy. In the late 1980s, both Central and Local Government agencies were restructured and the powers and functions of NWASCA were transferred to Regional and District Councils under the RMA-91. Initially, Coastal Hazard Zones (CHZ) were identified as a single line on a map with respect to the reference shorelines of either the duneline (seaward toe of foredune), cliffline (seaward toe of seacliffs) or cliff top. The first single line mapping was carried out at Peka Peka (Kapiti Coast District) by Dr Gibb in 1976, and at Piripai (Whakatane District) by Professor Healy in 1977. In 1981, the concept of Risk Zonation was introduced for a CHZ assessment for Wainui Beach (Gisborne District) by Dr Gibb and in 1994, he introduced a broad general reconnaissance-type category termed Areas Sensitive to Coastal Hazards (ASCH) for the first time in the Bay of Plenty and Gisborne regions. Today, local authorities have the choice of using either single line or multi-line CHZs to control coastal subdivision, use and development in New Zealand.

During this century, robust Coastal Hazard Mapping techniques that have been tested before the Environment Court are being widely applied and CHZs are being incorporated into District and Regional Plans. As our understanding of Quaternary geology and coastal processes increases along with GIS mapping techniques, Coastal Hazard Mapping methods will continue to be refined. In this paper, the key parameters used to assess CHZs are discussed and illustrated with types of maps. Coastal Hazard Mapping continues to be a growing field of opportunity for geoscientists in the South Pacific.

PATTERN OF SAND TRANSPORT ALONG THE ISRAELI COASTLINE

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In 1960 Emery and Neev proposed a model describing the pattern of sand transport along the Israeli Coast. The model consists of two mechanisms. The first, a wave induced, longshore current, drives the sand in the surf zone in two directions: from the south northward and from the north southward with a convergence point in the central part of the Israeli Coast near Tel Aviv. The second mechanism is a northerly sand transport, driven by the local currents, on the continental shelf beyond the surf zone. According to this model the sand source for the beaches of Israel is the Nile River, only that the southern beaches (south of Tel Aviv) are fed by the longshore transport of the first mechanism and, in addition, by on-shore contribution from the inner shelf. The northern beaches, on the other hand, are nourished with sand from the inner shelf only, as there is no major sand source north of the Israeli Coastline.

In order to prove the validity of this model one must show that: a) sand transport in the near shore zone follows the pattern described above; b) sand transport on the sea bottom beyond the surf zone is directed northward, and c) there is sand contribution from the continental shelf to the beach, mainly in the northern beaches.

A survey of beach accretion and erosion next to coastal structures reveals that beach accretion occur south to, and erosion north to, all the six coastal structures existing in the southern and central part of the coastline. In the northern coast, the accretion/erosion pattern, next to the two coastal structures there, is reversed. This fulfills the first requirement necessary to validate Emery and Neev's model.

A study was conducted between 1982 and 1990 on the distribution of coal particles that fall to the sea bottom from the Hadera Coal Terminal, located off the central part of the Israeli Coast at a water depth of 22 m. This study showed that in all 9 sea bottom sampling sessions which were carried out there during that period, concentration of coal particles were found to a distance greater than 10 km north of the terminal. No such concentrations were ever found south of it. Although coal particles are poor tracers for sand movement, it is hard to see how coal particles and sand would move in opposite directions, and we must accept that northward sand transport occurs on the seabed in the continental shelf.

Grain size analyses were carried out on 115 samples collected along the Israeli Coast between the back of the beach and water depth of 30 m. The samples were divided into two groups, deep samples, collected from depths greater than 5 m, and shallow samples _ between 5 m water depth and the back of the beach. The mean grain size of the deep samples ranged between 120-244_μm and did not show any dependence on the geographical location along the coast. The shallow samples ranged in size between 132_335 _μm and showed a decrease in size from the south to Tel Aviv and remained similar in magnitude to that of the deep samples, on the beaches north of Tel Aviv. It is suggested that the sand on the northern beaches is derived from the offshore and this is why their grain size is finer than that on the southern beaches. If this explanation is accepted the last requirement for validation of Emery and Neev_s model is also fulfilled.

THE ENIGMATIC OHAKURI IGNIMBRITE

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The Ohakuri Ignimbrite has been the subject of debate among geologists working in the Taupo Volcanic Zone for many years. The origin, source and age, of the Ohakuri Ignimbrite still remain unknown. Both Maroa and Kapenga calderas have been suggested as sources, as well as a previously unidentified caldera that may exist within the Atiamuri (Whangapoa) Basin.

The Ohakuri Ignimbrite covers approximately 225 km², from Orakei-Korako in the south to Haparangi dome in the north. Sedimentary-like structures within the deposit lead early researchers to suggest a sedimentary origin. Later, the sedimentary-like structures were inferred to be the result of pyroclastic surges near the vent source. In this poster, I propose the deposits may result from hydroeruptions, similar to those observed at Mount St. Helens following the deposition of pyroclastic flows from the 18 May 1980 lateral blast. Hydroeruptions occur when water trapped beneath hot pyroclastic deposits is superheated to steam (Moyer and Swanson 1987). At Mount St. Helens the hydroeruptions produced surge and airfall deposits comprised of the primary pyroclastic material. Sharp contacts between the primary pyroclastics and the overlying secondary hydroeruptive deposits can be distinguished in the field.

The Ohakuri Ignimbrite and the hydroeruption deposits at Mount St. Helens show similar cross-bedding, reverse-graded packages (centimetre scale), fines-depleted coarse-grained layers, and high-angle deposits that may be associated with fill and/or back-fill into hydroeruption craters. More fieldwork is necessary to thoroughly compare the similarities and detail the sedimentary-like deposits within the Ohakuri Ignimbrite. The poster is intended to provide an opportunity for discussion.

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PROTOVIRGULARIA – LOCAL RECORD OF A SELDOM- RECOGNISED ICHNOTAXON

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Scolicia is a well known and frequently encountered trace fossil in local Tertiary strata. It is now generally accepted that it has an irregular echinoid progenitor, although this was not always so. In an early systematic description of *Scolicia* from the Miocene Waitemata Group of the Auckland Isthmus, other progenitors, including errant holothurians and polychaetes were erroneously given serious contemplation. At this time, Gregory (1969, Plate 7, Figs 1 and 2) also included illustrations of two specimens that were considered variants of *Scolicia*. One of these (X11) and a further specimen (X13) held in the paleontology collection at the University of Auckland are now placed in the ichnogenus *Protovirgularia*. They consist of a central, cylindrical and structureless core which is bilaterally flanked by sharply defined, thin 'twinning ribs'. One specimen (X12) is preserved in convex (positive) hyporelief on the sole of a sandstone bed, and the other (X13) in concave (negative) epirelief on the top of a bed. X11 is preserved on a sandstone bedding surface with slight positive epirelief and consists of bilaterally arranged, lobate offshoots from a thin central core and offers some similarity to *Nereites* or *Polykampton*. These separately identified structures are discrete elements in a compound trace fossil that has probably been produced through the feeding activities of a 'cleft foot clam' (e.g., *Yoldia*). Comparisons will be drawn with a large and spectacular, "feather boar-like", compound trace fossil being described from the Cretaceous Formation of Point Lobos California.

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BENTHIC FORAMINIFERA AND THE NEOGENE PALEOCEANOGRAPHIC HISTORY OF THE SOUTH-WEST PACIFIC, EAST OF NEW ZEALAND

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Canonical correspondence analysis indicates that the distribution of Neogene benthic foraminiferal faunas (>63 μm) in seven DSDP and ODP sites (500-4500 m water depth) east of New Zealand (38-51°S, 170°E-170°W), is most strongly related to depth (water mass stratification), and secondly to age (paleoceanographic changes influencing faunal composition and biotic evolution). Stratigraphic faunal changes are interpreted in terms of the pulsed sequential development of southern, and later northern, polar glaciation and consequent cooling of bottom waters, increased vertical and lateral stratification of ocean water masses, and increased overall and seasonal surface water productivity.

Planktic foraminiferal fragmentation index values indicate that carbonate dissolution was significant at abyssal depths throughout most of the Neogene, peaking at upper abyssal depths in the late Miocene (11-7 Ma), with the lysocline progressively deepened thereafter. Peak abundances of *Epistominella umbonifera* indicate increased input of cold Southern Component Water to the Deep Western Boundary Current at 7-6 Ma. Faunal association changes imply establishment of the modern Oxygen Minimum Zone (upper Circumpolar Deep Water) in the latest Miocene.

Significant latitudinal differences between the benthic foraminiferal faunas at lower bathyal depths (1000-2000 m) indicate the existence of the Subtropical Front along the Chatham Rise, since the early late Miocene, with more pulsed productivity (higher *Epistominella exigua*) along the south side. Modern Antarctic Intermediate Water faunal associations were established north of the Chatham Rise at 10-9 Ma, and south of it at 3-1.5 Ma. Middle bathyal faunas (500-800 m) on the Campbell Plateau are dominated by reticulate bolivinids during the early and middle Miocene, indicative of sustained productivity above relatively sluggish, suboxic bottom waters. Faunal changes and hiatuses indicate increasingly vigorous currents over the Campbell Plateau from the latest Miocene on.

Three intervals of deep-sea benthic foraminiferal taxonomic turnover are recognised (16-15, 11.5-10, 2-0.5 Ma) corresponding to intervals of enhanced global cooling and possible productivity changes. Surface water productivity (food supply) appears to have increased in three steps (at times of global cooling) marked by substantially increased relative abundance of: 1. *Abditodentrix pseudothalmanni*, *Alabaminella weddellensis*, *Cassidulina norvangi* (16-15 Ma, increased seasonally-pulsed productivity); 2. *Bulimina marginata* f. *aculeata*, *Nonionella auris*, *Trifarina angulosa*, *Uvigerina peregrina* (3-1.5 Ma, increased annual productivity); and 3. *Cassidulina carinata* (1-0.5 Ma, further increased annual productivity).

RHYTHMS OF THE EARTH IN THE INTRODUCTORY EARTH SCIENCE CURRICULUM

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One of the goals of modern geoscience is to integrate the natural sciences to strive towards understanding the entire system – the Earth. This paradigm shift from the reductionist to the systems approach in geoscience is usually taken into account in modern Introductory Earth Science curriculum. Such chapters as The Earth as a Planet, The Dynamic Earth, The Earth as a Resource, have become common in the course curricula. Nowadays the notion of global cycles has become firmly established in geoscience. Modern textbooks and courses are normally provided with a section about the Earth cycles, where the geological cycle, the hydrologic cycle, the carbon cycle, and others are considered (e.g. [1,2]). In this report we argue that in the introductory Earth science course attention should also be paid to the *global rhythms*. A different and more perspective viewpoint on the global cycles, as a part of wider range of periodic (recurrent) processes, will therefore be developed in the course. This is an important step towards the integration of the material and development of the system approach in the Earth science curriculum.

Rhythms of the Earth (or the global rhythms) are periodic alterations in the natural world occurring under influence of cosmic/planetary factors. These factors can be of a mechanical nature (the rotation and revolution of the Earth and the Moon, spatial orientation of the axes of rotation, tidal forces and so on), as well as of more complex physically related phenomena (the 11-year cycle of sunspots). Many of the global rhythms are closely connected with different types of periodic motions, which we can observe, and in which we participate, together with our planet. The notion of time itself has come from observations of the apparent periodic movement of the sky. Why do the global rhythms arise? What are the mechanisms of their influence on environment and inhabitants of the Earth? These and similar questions are to be considered in the Introductory Earth Science course.

The module an Introduction to the Earth is being offered for the first time at AUT. It uses systems theory as its core approach to understanding geoscience and its complexity. The topic Rhythms of the Earth is one of the examples of this approach. Inclusion of the global rhythms in the course has a number of advantages. Firstly, it allows to show the Earth as a part (member) of a bigger system: the solar system or the universe itself. Important terrestrial processes can be shown as the effect of more general (cosmic) causes. From the methodology of education point of view, this permits bringing together usually separated or even disconnected sections of the course, such as seasons, tides, climate change, geomagnetic field and its variation, solar-terrestrial phenomena, etc. Some philosophical problems, such as "the rare Earth" concept, the anthropic principle, and others can be discussed in this section of course. Further, considering the Earth rhythms and global cycles jointly develops a general integrated approach to the long-term periodic processes and changes on the Earth and in its systems. In this perspective the Earth cycles become part of a wider range of general recurrent processes in nature.

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CLUSTER ANALYSIS OF GLASS SHARDS NEAR PUKETITIRI, WESTERN HAWKE'S BAY

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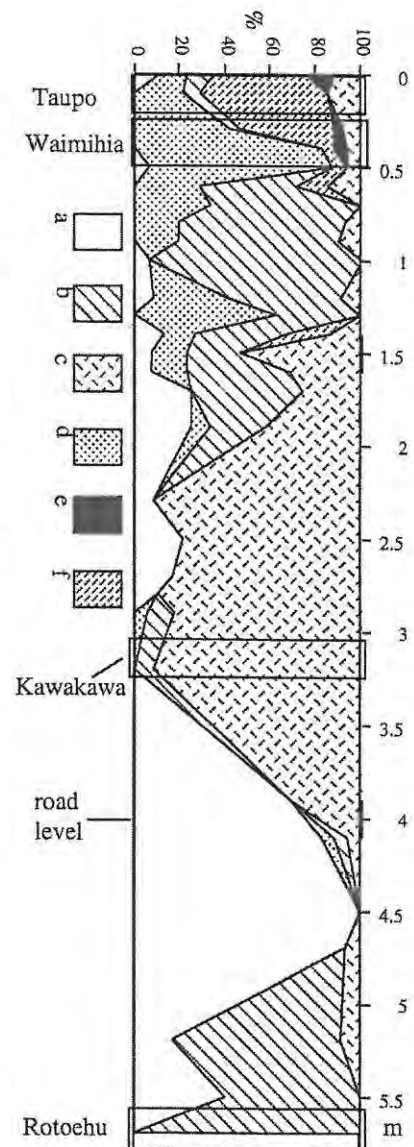
496 shards from a road cutting and pit that exposed Taupo, Waimihia, Kawakawa and Rotoehu ash in tephric loess, about 5 km NW of Puketitiri, were subjected to microprobe analysis by APH. A radiocarbon date and tephras indicated that the sampled interval recorded perhaps 45 ky (Hammond, PhD thesis, Massey Univ.). Nine variables were determined.

Tephra correlations that use discriminant function analysis compare unknowns to tephras that have already been defined. APH thought that these original definitions might include aberrant shards, and desired a method that would limit chance errors of shard selection. We have applied cluster analysis to this problem. In cluster analysis the number of groups in a data set can be unknown. We included with our data, as potential identifiers of unknown clusters, the averages for 57 possible parent tephras. These were compiled from the literature. As chlorine was not reported for some, we omitted it in our study.

The cluster analyses found that shards examined with a 10 micron beam gave results that differed from those where a 20 micron beam had been used. Sixtytwo 10-micron results were therefore set aside. The final groups identified by the numerical analyses did not correlate well with the tephras reported in the literature. We thought the variety found in the beds seen in the field might indicate contamination at the time of the eruption, at the source or by slope wash or wind action, but the supposed contamination levels are much too high for this. We tested the groupings many times but could not produce a different outcome. We conclude, therefore, that the shard groupings are real, and that the parent tephras contain significant variations in composition.

The clustering algorithms defined 6 groups (a-f, below). A total of 25 atypical outliers was revealed by numerical analysis of the groups. The graph shows the abundance of the groups at the 30 levels where samples were taken.

Group:	a	b	c	d	e	f
SiO ₂	77.18	77.86	77.43	76.11	68.59	74.91
TiO ₂	0.16	0.16	0.17	0.22	0.21	0.34
Al ₂ O ₃	12.52	12.35	12.42	12.99	18.20	13.35
FeO	1.10	0.96	1.22	1.72	1.16	1.98
MgO	0.14	0.14	0.15	0.21	0.25	0.29
CaO	0.95	0.85	1.09	1.33	3.54	1.51
Na ₂ O	3.71	4.24	4.04	4.23	5.46	4.60
K ₂ O	4.06	3.27	3.27	3.03	2.42	2.85
n	72	115	106	80	4	32



REPLICATE MEANS OF RHYOLITIC TEPHRAS

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The literature for New Zealand tephra provides mean electron-probe data for many ash beds. There is some duplication but for many beds slightly different averages are given. The different values are usually from different localities and are meant to enable correlation. Mostly there are two or three sets of values for single ash beds. For some beds, however, there are large numbers of replicates. For those who seek representative values, the data are difficult to evaluate, because the tephrostratigraphers have not indicated which averages, if any, should have precedence.

To clarify the relationships among the replicates, we have sorted them using two methods of cluster analysis. The first, fuzzy k-means (Ward et al., 1992), is a non-hierarchical method that seeks to identify similar groups in data. The second is a hierarchical clustering method (Wilkinson, 1987) that forms groups by joining similar individuals. Its results are normally displayed as a branched tree or dendrogram.

We have applied these methods to 76 tephra means revealed by an incomplete survey of the literature. The different strategies yield similar results. A few individuals appear to be borderline but the means mostly fall into five fuzzy groups. The separations of duplicates within groups could reflect inadequate sampling, or geographic variation. There has possibly been chance convergence of analytical results for stratigraphically distinct units. There could also be faults in our management of the number-crunching model. Of course, some variation might be due to human errors such as misclassification, or mistaken correlation. None of these factors is easily resolved.

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PLIOCENE SILICA SINTER AT WHENUAROA, NORTHLAND: BRECCIAS, MICROBES AND MINERALISATION

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The Whenuaroa Sinter occurs near Puhipuhi about 30 km north of Whangarei. It is one of three fossil sinters exposed in the southern portion of a mid- to late-Pliocene geothermal system. The sinter consists of three main outcrops at Bush Hill, Plumduff and Mt Mitchell; the latter two are reported here. Plumduff consists of many large sinter breccia boulders, including rudrocks (very coarse breccias), scattered around the flanks and summit of the small conical hill. Mt Mitchell is composed of a large 600 x 400 m sinter sheet at least 12 m thick. The sinter masses are composed of rudrocks consisting of large, matrix supported angular to sub-angular clasts of layered sinter up to 0.8 m across, as well as smaller clasts 20-100 mm diameter. Rudrocks also include fragments of sinter with stromatolitic structures. The rudrock matrix consists of microcrystalline, transparent to translucent to milky quartz. Other breccias contain fragments of layered angular to irregularly mottled sinter of white to grey or distinctive bluish hue supported in a translucent to opaque silica matrix. Less abundant, smaller matrix- and clast-supported breccias with clasts both partially surrounded and/or penetrated, by a clay-like weathering rind of very fine-grained quartz, and sinter conglomerates with round to oblate clasts also occur. The breccia boulders are similar in size and texture to those at Steamboat Springs, Nevada and Norris Basin, Yellowstone National Park, Wyoming, and at Waiotapu, Taupo Volcanic Zone, however the rudrocks appear to be unique to the Whenuaroa deposit.

Three principal types of fabrics constitute the bulk of the sinter in the breccias. Stromatolites, including columnar, palisade and filamentous networks, showing progressive silicification, in fenestral, tufted to clotted fabrics that display varying degrees of preservation. Peloids and pisoids are incorporated throughout most fabric types, and plant-rich facies in which various silicified plant species occur in a porous to non-porous silica matrix. All fabrics observed in the Whenuaroa Sinters have counterparts in hot spring deposits in the TVZ and Yellowstone, formed at temperatures from 75°C to 30°C. They also share many similarities and identical features with fabrics in fossil sinter deposits at Drummond Basin, Queensland, Australia; Rhynie Chert, northwest Scotland; and Umukuri, TVZ. The preservation of the morphology (living habit) of these microbial organisms and microflora in the sinter provide evidence of the prevailing palaeoenvironments and palaeohydrology of the geothermal system.

Also present at Whenuaroa is steam-condensate-produced alteration: kaolinite and alunite as well as boulders of quartz lattice texture. Cinnabar and stibnite are abundant at Mt Mitchell but only minor cinnabar occurs at Plumduff.

GIANT FORESETS FORMATION, NORTHERN GRABEN, TARANAKI BASIN: DEVELOPMENT OF THE LATE NEOGENE PROGRADING CONTINENTAL MARGIN

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The Giant Foresets Formation reflects the Pliocene-Pleistocene progradation and aggradation of a major regressional sedimentary wedge that built-up the modern shelf and slope in Taranaki Basin. In the Northern Graben, which is the focus of this paper, the formation is up to 3 km thick, and its accumulation coincided with normal faulting and eustatic sea level oscillations. This paper details new information for the succession about its age, the geometry of seismic packages, wireline log motifs, the timing of faulting and its influence on sedimentation, and the progradational history. The seismic series utilised (P95) encompasses the part of the Northern Graben between Mangaa-1 and Arawa-1 and between Wainui-1 and Turi-1.

Re-evaluation of existing biostratigraphic data together with new data shows that the age of the base of the formation is early-Late Opoitian (~4.7 Ma). An unconformity at the base of the formation includes Late Tongaporutuan (latest Miocene) to Early Opoitian. It has variable expression mainly as a condensed horizon incorporating the Ariki Formation (marl). In the axis of the graben the unconformity lies at the base of the Mangaa Formation, which in turn underlies the Giant Foresets Formation.

Multiple seismic packages, some at the sequence level, have been mapped within the Formation through a grid of seismic reflection lines by marking distinctive reflectors that can be traced from the paleoshelf down slope and on to the basin floor. These define at high resolution the progradation and aggradation of the regressive continental margin. The geometry of the seismic packages have been mapped over the seismic grid, and show the direction of progradation, phases of degradation of the shelf margin, and the influence of synsedimentary faulting.

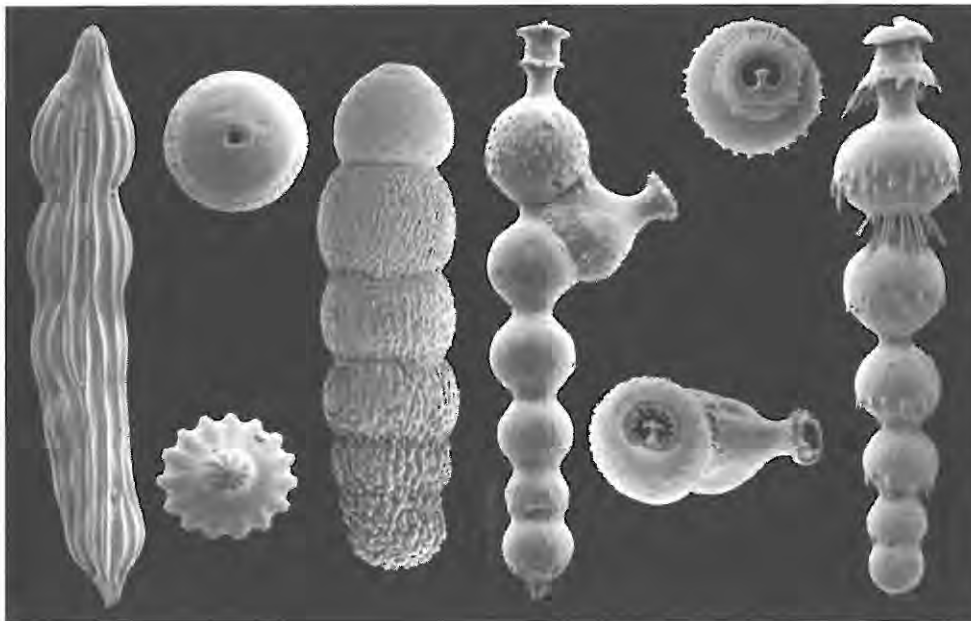
Seismic reflection lines have been backstripped and decompacted in 2-D to generate palinspastic reconstructions showing the evolution of accumulation of the Giant Foresets Formation. In the reconstructions, changes in paleobathymetry have been constrained by new data on foraminiferal paleoecology from unwashed cuttings. These data and analyses provide new insights into the Late Neogene development of the continental margin in Taranaki Basin and the influence the Giant Foresets Formation have had on the maturation and migration of hydrocarbons sourced from deeper parts of the succession.

GLOBAL DEEP-SEA EXTINCTIONS DURING THE PLEISTOCENE ICE-AGES

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The dark, near-freezing environment of the deep oceans is regarded as one of the most stable habitats on Earth and this stability is generally reflected in the slow turnover rates (extinctions and appearances) of the organisms that live there. By far the best fossil record of deep-sea organisms is provided by the shells of benthic foraminifera (Protista), and a little-known global extinction of deep-sea benthic foraminifera occurred during the Pleistocene Ice Ages. In the Southwest Pacific, it caused the disappearance of at least 53 species (~20 % of the fauna), 17 genera, and two families, and of dominantly uniserial, elongate foraminifera with distinctive apertural modifications. These forms progressively died back and became extinct during glacial periods in the late Pliocene to middle Pleistocene (c.2.5-0.6 Ma), with most extinctions occurring between 0.9 and 0.7 Ma. This was the time of the middle Pleistocene climatic revolution related to intensification of northern hemisphere glaciation.

This study of Ocean Drilling Programme cores from around New Zealand, indicates that the extinction event was far more significant for deep-sea diversity loss than previously reported (10 species). In this region, 60% of the impacted species were cosmopolitan, 20% were endemic to the SW Pacific and 20% had Indo-Pacific distributions. The middle Pleistocene extinction was the most dramatic last phase of a world-wide decline in the abundance of elongate cylindrical species, which began during cooling associated with formation of the East Antarctic ice sheet at the end of the Eocene, and continued during middle Miocene cooling related to further expansion of the Antarctic ice sheets. The exact cause of these extinctions (e.g. cooler temperatures, food change, increased oxygenation) is yet to be determined, but was clearly distinct from the cause of the other major Cenozoic, deep-sea extinction event, during the Late Paleocene Thermal Maximum.



Some of the deep-sea foraminifera that became extinct globally in the middle Pleistocene.

**LATE MIOCENE - EARLY PLIOCENE BIOFACIES :
PALEOENVIRONMENTAL ANALYSIS OF THE MATEMATEAONGA FORMA-
TION, WANGANUI BASIN (TONGAPORUTUAN-OPOITIAN)**

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Biofacies analysis has allowed for the characterisation of benthic assemblages that accumulated in the Matemateaonga Formation during the Late Miocene and Early Pliocene. The Matemateaonga Formation, which is up to 2500 m thick, is composed of shelf cyclothem lithofacies that typically comprise coquina, siltstone, and sandstone lithofacies. Temporal patterns in both lithofacies and macrofaunal composition indicate a close link with environmental shifts that took place during sixth-order glacio-eustatic sea-level fluctuations. Census data on 202 species of mollusca, brachiopoda and echinoderms from 168 bulk samples have been analysed by cluster and correspondence analyses. Sixteen mollusc-dominated biofacies are recognised from the Matemateaonga Formation, and are assigned to associations characteristic of either transgressive or highstand and regressive phases of sea-level change. The identification of biofacies provides a useful tool in the reconstruction of the paleoenvironmental history of the Matemateaonga Formation

By combining faunal evidence and the nature of associated lithologies and taphonomic characteristics of fossil assemblages, these biofacies may be assigned to particular physical environments. This has applications to the sequence stratigraphic analysis of the Matemateaonga Formation through providing evidence of the timing, rates and magnitude of environmental change (e.g. sea-level fluctuation, and sediment flux). A recurring pattern of community replacement has been observed throughout sequences of the formation. It is inferred that the community replacement involves the lateral, facies-related shifting of biofacies belts (faunal tracking) across the continental shelf as ecosystems respond to relative sea-level changes and the position of contemporary shorelines. The distribution of benthic communities on the modern Wanganui and Taranaki continental shelf provides a good analogue of the 'Matemateaonga paleoshelf', with a mix of broad belts and smaller pockets of biofacies, reflecting localised sediment and current conditions. In most cases tracking patterns appear asymmetrical within sedimentary sequences due to the condensation of transgressive biofacies into shellbeds of the transgressive systems tract and the markedly higher sedimentation rates during highstand and regressive phases.

The identified biofacies show some similarity to other faunal associations described in existing literature, both in terms of species composition and rank abundance. A search of literature on faunal associations documented from the Neogene in New Zealand has provided some comparable examples throughout Pliocene, Pleistocene and Recent faunas. A major difficulty in making any interpretations based using existing literature, however, is the lack of consistent methodology used in collecting, interpreting and describing faunal associations. Therefore, confirmation of a pattern of persistence in community structure within the late Neogene of New Zealand requires further data collection and analysis.

**TAPHONOMIC SIGNATURE OF SHELL ACCUMULATIONS
IN THE MATEMATEAONGA AND KIORE FORMATIONS (WANGANUI BASIN):
TAPHOFACIES AS INDICATORS OF DEPOSITIONAL ENVIRONMENTS**

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Shellbeds, which are conspicuous components of the shelf-slope sedimentary successions in the Late Miocene to Early Pliocene (Tongaporutuan-Opoitian) Matemateaonga and Kiore Formations, are the source of significant paleoecologic and taphonomic data. Careful taphonomic analysis of skeletal elements in shellbeds of the Matemateaonga Formation, combined with paleoecologic and lithologic interpretation of their enclosing sediments, permits a detailed understanding of the range of shellbed types and their relationship to the sequence stratigraphic model. Recent analyses of laterally discontinuous shellbeds of the slope-deposited Kiore Formation reveal that skeletal material has undergone considerable transport by a range of emplacement processes. Furthermore, the paleoecological and taphonomic data of skeletal elements in shellbeds of the Kiore Formation indicate close associations with those of shelfal Matemateaonga sequences, and may enable the application of sequence stratigraphic principles to explain their origin.

Taphonomic signature is the cumulative effect of physical and biological processes that have acted upon biogenic hard-parts before and during deposition and prior to lithification. Taphonomic attributes that can be semi-quantified include levels of disarticulation, fragmentation, packing, sorting, and bioerosion, types of orientation, and various diagenetic features. Taphofacies, which are fossil accumulations possessing similar taphonomic signatures, can be assigned to specific paleoenvironmental settings. Six distinct taphofacies are identified from the Matemateaonga Formation on the basis of these signatures. These taphofacies appear to occur predictably throughout sequences of the Matemateaonga Formation. A further three taphofacies are identified from initial observations of shellbeds in the Kiore Formation.

The facies characteristics, faunal composition, and stratigraphic significance of shellbeds have been described extensively in Pleistocene and Pliocene sequences of the Wanganui Basin (e.g. Abbott and Carter, 1997, Naish and Kamp, 1997). Little attempt has been made to characterise the shellbeds of older cyclothems in Wanganui Basin, and make comparisons to the more studied Pliocene-Pleistocene examples. This study is an attempt to document the range of shellbed types, their distinguishing characteristics, reconstruct the processes responsible for shellbed formation and assess relationships to sequence stratigraphic strata of the Matemateaonga and Kiore Formations.

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FROM GLACIAL DRIFT TO DEEP-SEA CORES - THE EVIDENCE OF THE TRANSITION FROM THE LATE GLACIAL MAXIMUM TO THE HOLOCENE IN AND AROUND NEW ZEALAND

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At the climax of the Late Glacial Maximum large glacial tongues and piedmont glaciers extended east and west beyond the mountain front of the Southern Alps. Bands of clearly recognisable moraines mark these limits but are dwarfed in volume by extensive outwash sheets. Organic material is rarely exposed within either the moraines or the outwash, but is commonly found in depressions within the moraines and associated drift. Radiocarbon dating of such sediments yeild a minimum age for retreat from the LGM of 14.7 - 14.9 ka with a maximum age of 15.5 ka from organic clasts within tills.

The transition from the LGM to the Holocene in the marine record off the east coast of New Zealand is marked by a transition from a micaceous hemipelagic ooze to a calcareous ooze in the south and a general reduction in clastic sedimentation in the north, a decrease in the $^{18}\text{O}/^{16}\text{O}$ of planktonic and benthic foraminifera, and changes in the assemblages of both foraminifera and pollen. The presence of TVZ-derived tephra in cores off North Island allow a timescale to be transferred from terrestrial sediments to the marine record, showing that the marine oxygen isotopic signals display significant lags behind the terrestrial glacial record and furthermore that a major change in the oceanic carbon reservoir occurs at this time.

The sequence of transition from glacial to interglacial climate in New Zealand appears to have been retreat of glacial ice from extended positions (Late Glacial Maxima) between 15,500 and 14,900 yr BP. An abrupt change in rates of erosion and vegetational cover occurred simultaneously, but the isotopic signal of glacial meltwater altering the composition of the ocean does not appear in intermediate waters off the coast of New Zealand until between 14,100 and 13,800 yr BP and in surface waters between 12,500 and 13,000 yr BP. Micaceous silts continued to dominate Bounty Trough sediments until about 13,500 yr BP.

**DATING THE WRINKLES – FIXING A TIMESCALE TO THE
GLACIAL GEOMORPHOLOGY OF SOUTH ISLAND, NEW ZEALAND**

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To the east and west of New Zealand's Southern Alps extends a landscape shaped and modified by repeated episodes of local glacial advance and retreat and global glacio-eustatic sea level fluctuations. Our mapping of the glacial geomorphology of the central portion of this zone (from the headwaters of the Grey Valley south to Fox Glacier and east to the MacKenzie Basin) is nearing completion. This paper describes progress towards establishing a timescale to the land surface based on a coherence of radiocarbon dating, exposure age dating, optically stimulated luminescence dating, tephrochronology, palynology and loess stratigraphy. The nature of dated material and its relationship with the geomorphic features are described.

THE GREAT BARRIER REEF SINCE 1565 AD FROM A CORAL'S PERSPECTIVE

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Corals are an invaluable source of paleoclimate information. The aragonitic skeleton of massive *Porites* corals accumulates over centuries at approximately 1-2cm a year, allowing better than monthly resolution. Archived within this skeleton are physiological, isotopic and elemental tracers that vary according to ambient sea surface temperature, salinity, river runoff and primary productivity. In my PhD research I set out to test how faithfully corals record changes in their environment over decadal-to-century timescales. To do this I have compared proxy-climate records from eight coral cores, spanning 120 to 420 years of continuous growth, collected from the central Great Barrier Reef, Australia. I will concentrate in this talk on the records from oxygen isotopes ($\delta^{18}\text{O}$), and the 'coral palaeothermometers' Sr/Ca and U/Ca. Salinity changes are also resolved by the tandem measurement of coral Sr/Ca ratios and $\delta^{18}\text{O}$, which allows the separation of temperature changes from changes in seawater $\delta^{18}\text{O}$. Composite records of the 8 cores are constructed for each of the proxies along with a 95% confidence envelope for the reconstructions. The coral palaeotemperature reconstructions indicate some interesting climatic shifts that do not fit the typical Northern Hemisphere-centric records of the period since the Little Ice Age. Surface-ocean circulation changes in the tropical SW Pacific are also evident.

HISTORICAL DIE-OFFS IN MASSIVE PORITES CORES

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Two incidents of coral tissue death and subsequent regrowth were discovered during the cross-dating of 8 multi-century *Porites* cores from the central Great Barrier Reef (GBR). Although growth discontinuities are a problem for accurate dating of coral records, the presence and dating of any hiatus is of interest because it is likely to represent a biotic response to unfavourable environmental conditions. We use fluorescent bands, distinct annual lines visible in the coral skeleton under UV light, to cross-date the cores. The first die-off occurred between 1782-85, in a coral from Brook Island (18°09'S, 146°17' E), and the second in 1817 in a coral from Pandora Reef (18°49'S, 146°26' E). Through x-radiographs and fluorescent photographs it is possible to see the pattern of regrowth and the period taken by the coral to recover. Reported El Niño events coincide with both coral die-offs. The width and intensity of fluorescent bands in central GBR corals correlate strongly with the seasonal discharge from the Burdekin River, Queensland's largest river. Intense fluorescent lines recorded in the surviving corals from 1817 suggest that heavy runoff contributed to this die-off event; similar conditions were associated with bleaching events at the same reef in 1994 and 1998.

EFFECT OF FIRES AND OLD MINE WORKINGS ON A POTENTIALLY MINEABLE COAL RESOURCE, MILLERTON BLOCK, BULLER COALFIELD

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Solid Energy International is currently undertaking a mining feasibility study of potential opencast coal resources in the Millerton Block of the Stockton Coal Mining License. Millerton Block consists of approximately 450 hectares of abandoned underground mine workings. Mining operated from 1896-1969, producing 10.3 million tonnes of coal. The main coal seam is generally 5-8m thick, overlain by 20-40m of Brunner Coal Measure sandstones and mudstones. Original in ground coal resource is estimated at 30 million tonnes of which a substantial quantity remains today.

Millerton Mine was plagued by fires throughout its life, primarily resulting from poor mining practices. The first reported fire was in 1904 with at least 20 additional fires during the mine life. Some regions within the mine are still burning, although other areas are now considered dormant. Parts of the ground surface have been severely affected by subsidence and heat where underground fires have baked large areas of overburden. Fire has altered and consumed significant volumes of coal from the seam roof and edges of pillars, although a large proportion of the remaining resource is considered unaffected.

Completion of the mining feasibility study requires accurate definition of: Extent of the remaining coal resource; Location of current fires and hot spots; Overburden characterisation and; Quality of remaining coal.

Investigation methods included: Mapping surface disturbance; Mapping lithologies affected by heat; An aerial infrared survey (to identify hot spots); Down hole temperature measurements in drillholes (to delineate underground extent of heatings) and; Overburden characterisation (using geotechnical logs from a 1976-77 drilling program). Annual mine statements, mine plans and various reports on the Millerton Mining Area have provided additional information. An infill drilling program is planned from October 2001 to provide additional data on coal quality and overburden characterisation. Ultimate objective of this investigation is to provide a reliable model of remaining coal resources to be used with confidence for mine planning.

THE JURASSIC LATADY FORMATION, ANTARCTIC PENINSULA

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The author undertook three months fieldwork over the 1999/2000 field season with the aim to determine the fauna and biostratigraphy of the Latady Formation. Extensive mapping and collecting of material was undertaken. The Jurassic Latady Formation is a thick sequence of black and grey shale and siltstone with subordinate sandstone and conglomerate and sparse thin coal and limestone with locally interbedded volcanic rocks. It occurs in an area that extends more than six hundred kilometres, and possibly as much as one thousand kilometres, along the Weddell Sea coast of the southern Antarctic Peninsula, and inland as much as two hundred kilometres.

Paleontologic evidence indicates that most of the Latady Formation is of Late Jurassic (Kimmeridgian-Tithonian) age although Middle Jurassic beds occur in the Behrendt Mountains. These ages are supported by radiometric dates calculated for plutons intruding Latady Formation beds. Faunal assemblages, sediments and sedimentary structures suggest most of the Latady Formation was deposited in marine shelf environments. Terrestrial and nearshore marine environments are represented in the interior of the southern Antarctic Peninsula. Deeper water, possibly open marine anoxic environments are represented in a few areas near the present day coast. The affinities of the faunas are overwhelmingly with those of coeval New Zealand (Murihiku Supergroup) assemblages and also with South America.

SEDIMENTS AT TURAKIRAE HEAD: ONSHORE AND OFFSHORE

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The origin of the sediments that form the raised beach sequence at Turakirae Head, near Wellington, has not been determined from previous research. This paper presents new onshore and offshore sediment data maps for the area around Turakirae Head.

Offshore sediment data were gathered using a C-MAX CM800 side-scan sonar at 100kHz, combined with Echotrac echosounding in September 2001. The data were then processed through CODA Technologies Ltd. mosaic system software by A. Hill at NIWA (Wellington). The onshore sediment characteristics are currently being mapped.

Preliminary observations indicate that there is a broad correspondence between the sediments found onshore and those in the nearshore area, suggesting that there is little alongshore transport of material in the vicinity of Turakirae Head.

TRACKING MAGMATIC DIFFERENTIATION THROUGH TIME: CONSTRAINTS FROM ISOTOPIC AND CHEMICAL DISEQUILIBRIA IN WHOLE ROCKS, CRYSTALS AND GROUNDMASS OF HISTORICAL NGAURUHOE LAVAS.

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To predict the size, style and timing of future eruptions at frequently active volcanoes like Ngauruhoe we need to understand the subsurface processes in the magma plumbing systems. The mechanisms and timescales of magmatic differentiation can be very effectively investigated by analysing samples of the erupted lavas on a variety of scales such as whole rock, separated groundmass/glass, individual crystals, zones or inclusions within crystals, and xenoliths. The stratigraphic relationships or eruptive ages of the lavas provide an important context within which to interpret magma composition data.

New mapping of lava flows and use of tephra cover bed correlations at Ngauruhoe has helped establish a time line for lava flow emplacement and growth of the cone. More lava flows than previously thought are covered by Taupo ignimbrite pumice and thus were erupted more than 1850 years ago. The whole rock data show striking variations in composition over short time periods and do not define coherent curvilinear trends indicative of simple closed system evolution of a single, large, long-lived magma chamber beneath Ngauruhoe. Rather the data suggest the frequent injection of small (<0.1 km³) and short-lived (years to decades) magma batches into a complex plumbing system of narrow conduits and small holding chambers, where ascent rates and residence times could often vary for different batches. We are using the historical lava sequence to test this model of frequent recharge and short magma residence times by comparing the whole rock evidence with isotopic and chemical disequilibria recorded in Ngauruhoe crystals and liquids.

Analysis of single crystal Sr isotopic compositions of historical lavas indicates disequilibrium between crystals (lower ⁸⁷Sr/⁸⁶Sr) and groundmass (higher ⁸⁷Sr/⁸⁶Sr). For any one lava, ⁸⁷Sr/⁸⁶Sr varies between phenocryst phases, as well as between different size populations of the same phase. The evidence strongly suggests that many of the 'phenocrysts' in Ngauruhoe lavas should be regarded as entrained 'xenocrystic' remnants of earlier magma batches or the crust, which mingled with variably contaminated magmas to produce the lava sampled at the surface. Microdrilling of plagioclase crystals has revealed complex internal Sr isotope stratigraphy that confirms the existence of multiple crystal populations. Contamination by a high ⁸⁷Sr/⁸⁶Sr component during crystal growth resulted in increasing ⁸⁷Sr/⁸⁶Sr from core to rim. Different absolute values for ⁸⁷Sr/⁸⁶Sr were obtained for the historical eruptions, e.g. crystal cores: 1949 = 0.70527; 1975 = 0.70502. If the crystal isotope record allows us to follow the trail of recharge events between historical eruptions, it may be possible to estimate magma residence times, the number of magma reservoirs and the extent of connections within the plumbing system.

To further explore how stratigraphic age, magmatic age and magma composition are linked we are examining how the degree of U-Th and Ra-Th isotope disequilibria in as near liquid compositions as possible (i.e. groundmass) vary with the degree of differentiation in the historically erupted lavas. Results obtained to date indicate that U-Th isotopic disequilibria do exist between eruptions. The disequilibria may be linked to the repeated injection and eruption of short-lived magma batches, a process that we expect would repeatedly reset/significantly disturb the isotopic system.

**REFURBISHING A MINERALOGICAL MUSEUM:
A COLLABORATIVE VENTURE BETWEEN
EDUCATION, HERITAGE AND TOURISM INTERESTS**

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The Mineralogical Museum of the Thames School of Mines is housed in a complex of buildings now owned by the New Zealand Historic Places Trust (NZHPT). As owner of the School, NZHPT is working closely with representatives from the Ngati Maru Iwi Authority and Nga Kaitiaki to establish a management partnership for the School. Earlier in 2001, NZHPT invited expressions of interests from invited groups and individuals to contract for the operation of the museum.

Although the Museum has been publicly accessible since 1901, and has a rich collection of mineral specimens and mining memorabilia, there has been a decline in attendance in recent years: from 4309 visitors in 1996 to 2025 visitors in 2000.

In its proposal to the NZHPT, a consortium comprising *Department of Earth Sciences, University of Waikato*, the *Exscite Trust*, and *Waikato Institute of Technology*, envisages developing at the Mineralogical Museum:

- . Several interactive exhibits and displays relating to the formation of mineral deposits in the Thames gold-field, and the region's wider geological history. These will be based on the Exscite Trust's experience with developing and constructing such exhibits from its involvement in the Earthworks project several years ago;
- . Displays of heritage items and mineral samples in ways that are more in line with current trends in galleries, having regard to much of the extant collection is from the original period of the museum: it is "a museum of a museum";
- . Dioramas, art-work and other representations of the Maori history of the region, recognising the particular significance of the Museum site as an urupa.

The development provides an opportunity for the involvement of community volunteers, teachers on professional development courses or fellowships, and tourism and science students on placements from educational institutes.

While interested in developing and operating the mineralogical museum in the first instance, the consortium hopes to foster a relationship with NZHPT that enhances the educational potential and tourist possibilities for the complex of buildings which comprises the Thames School of Mines.

This paper describes the history of the Museum and the concepts the consortium envisages for the Mineralogical Museum, and outlines the time-scale envisaged for its development from the entering of an agreement with NZHPT.

CENTENNIAL SCALE CYCLICITY OF THE 14C INTERHEMISPHERIC OFFSET IN TREE RINGS

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A number of previous studies have demonstrated an interhemispheric offset in the ^{14}C content of contemporaneous tree-ring dated wood. McCormac et al. (1998a, 1998b) found that Southern Hemisphere wood was ca. 27 years older for the interval AD 1725 to AD 1885, using cedar (*Libocedrus bidwillii*) from New Zealand and oak (*Quercus patrea*) from the British Isles. This paper presents a continuation of this research, using the same species and localities. High precision ($<\pm 20$ yr) measurements on contemporaneous pairs of cedar and oak covering approximately 550 years from AD 1305 to AD 1855 were duplicated in the Waikato and Belfast laboratories to reduce the influence of laboratory offsets.

Here we compare the offset between New Zealand and the British Isles from ca. 1300 to 1850 AD with previously published data sets. We also perform spectral analyses on the interhemispheric offset, and demonstrate centennial scale periodicity. Possible mechanisms are discussed.

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DIAGENETIC EVOLUTION OF THE TIKORANGI FORMATION, WAIHAPANGAERE FIELD, TARANAKI BASIN: A COOL-WATER CARBONATE FRACTURE RESERVOIR

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The subsurface mid-Tertiary Tikorangi Formation is the sole limestone-dominated and only fracture-producing reservoir within Taranaki Basin. It is also of interest because the reservoir carbonates are of cool-water and not tropical-water origin. This study is based on core material from seven wells in the onshore Waihapa/Ngaere Field, Tarata Thrust Zone. A range of petrographic (standard, CL, UV, SEM) and geochemical techniques (stable isotope, trace element data, XRD) has been used to unravel a complex diagenetic history for the Tikorangi Formation. A series of major geologic events for the Tikorangi Formation host rock and fracture systems has been established between the time of sedimentation through to hydrocarbon emplacement. For each diagenetic event a probable temperature/burial depth field has been identified which, combined with a geohistory plot, has enabled the timing of events to be determined.

This study has shown that the Tikorangi Formation comprises a complex mixed siliciclastic-carbonate-rich sequence of rocks that exhibit generally tight, pressure-dissolved, and well-cemented fabrics with negligible porosity and permeability other than in fractures. Cementation occurred at temperatures of 27-37°C at 0.7-1.0 km burial depths. Partial replacement dolomitisation occurred during late burial diagenesis at temperatures of 36-50°C and at burial depths of 1.0-1.5 km, without any secondary porosity development. Following dolomitisation, fracturing occurred during compression and thrusting on the Taranaki Fault. The location of more dolomite-rich units may have implications for the location of better-developed fracture network systems and for hydrocarbon prospectivity and production. Hydrocarbon productivity has been ultimately determined by original depositional facies, diagenesis, and deformation.

Within the fracture systems, a complex suite of calcite, dolomite, quartz, and celestite minerals has been precipitated prior to hydrocarbon emplacement, which substantially healed and reduced fracture porosities and permeabilities. A sequence of mineralisation events and their probable burial depth/temperature fields has been defined, ranging from temperatures of 50-80°C and burial depths of 1.5-2.5 km. The major period of hydrocarbon emplacement into the Tikorangi Formation has occurred over the last 5 m.y., following the vein mineralisation events.

The Tikorangi Formation must continue to be viewed as a potential fracture reservoir play within Taranaki Basin wherever it is encountered within an appropriate structural environment.

THE SEDIMENT DYNAMICS OF WAIKARAKA ESTUARY: AN ARM OF THE TAURANGA HARBOUR ESTUARINE SYSTEM

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Waikaraka Estuary is a small “arm” that feeds the greater body of the Tauranga Harbour estuarine system. It displays the classic distribution of bottom sediments: the upper reaches of the estuary comprise soft muds, whereas at the seaward extremity, sandy intertidal flats dominate. Two small tributaries feed the estuary. At the opposite end, a wave-built spit isolates the estuary from the wave climate of the greater harbour.

It is the simplicity and semi-enclosed nature that makes this system ideal to investigate estuarine sediment dynamics. In particular, the correlation between the development of the catchment and the rapid change in geomorphology and ecology in the form of sedimentation and propagation of mangroves have been issues that local residents have identified.

The main issues that are of interest in Waikaraka are: (1) how much of the terrestrial sediment load is deposited and how much passes on into Tauranga Harbour; (2) which processes control the sediment bypassing; (3) are there processes that drive fine sediment back from the main estuary into the arm; (4) how do the processes of infilling change over time as the estuary infills; and (5) what are the implications for spreading of fringe habitats in these kind of arms and their ultimate fate.

The field study has utilised several optical backscatter sensors and Dobie wave gauges, which look at suspended sediment concentration and wave statistics at various locations in the estuary over six months from late summer to spring in 2001. The main tributary flow was gauged between for the same period. S4 pressure sensors were deployed to investigate the tidal characteristics at the estuary mouth for a spring-neap tidal cycle in late summer and again early spring 2001. A 3DACM wave meter was deployed in early spring 2001, focussing on the wave and tidal current climate within the estuary. Temperature and wind data were recorded on-site for three months from late summer to mid winter. Additional data was obtained for Te Puna, the nearest NIWA meteorological measurement site. Sediment samples were collected along several profiles in the estuary. Textural and mineralogical characteristics, organic content and available phosphorus were determined. Sediment traps were deployed to look at time-averaged sedimentation along the length of the estuary. Sediment cores were obtained to determine sedimentation rates within the past century. Aerial photo analysis was used to determine the rate of mangrove progradation and changes in geomorphology over the past 50 years. A hydrographic survey was carried out to consider the effect of morphology and bathymetric profile on hydrodynamics.

REGIONAL LANDSLIDE SUSCEPTIBILITY IN WELLINGTON

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This project investigates the extent to which an existing database of landslide occurrence in the Wellington region can be used to provide information on landslide susceptibility and for disaster management planning.

The Wellington region is subject to episodes of landsliding. These periods are usually related to high intensity rainfall events or extended periods of relatively high rainfall.

Landsliding primarily causes damage to property, roads and services, absorbing resources in clean-up and mitigation operations. An appropriate information base would assist in reducing the related costs and would be instrumental in the formulation of land management plans for avoidance and mitigation of the hazard. A landslide susceptibility map would also assist local government to discharge their duties under Section 36 of the Building Act and Section 106 of the Resource Management Act.

A database of landslide occurrence in Wellington was used to generate a regional landslide susceptibility map for the area. Data from a landsliding episode during the winter of 1974 were used as a basis for the model and two other sets of data, from 1976 and 1996, served as a test for the effectiveness of the final susceptibility map.

The data were digitized from field maps using the GIS program ARCVIEW. This program was also used to determine terrain classification units for Wellington using parameters of slope angle, aspect and road density. These parameters were chosen based on findings from previous studies while recognizing that they represent only a few of the many factors contributing to actual landslide occurrence. These parameters were divided into three terrain factor classes, representing their relative apparent influence on landslide occurrence. The three classes of factors from each parameter were combined to determine the combination of factors that coincides with the highest incidence of landsliding. The relative landslide density for each combination of classes was ranked and the twenty-seven possible combinations amalgamated into three final classes – High, Moderate and Low Susceptibility. These classes were mapped and then overlain with the landslide data from 1976 and 1996 to test the ability the map to indicate areas susceptible to landsliding. The Landslide Susceptibility map was then projected onto a street map of Wellington, highlighting those arterial transport routes and utility pathways that are susceptible to landslide hazard.

Early results suggest that a map based on this kind of landslide database might be useful in determining areas where landslides are likely to occur in the future. This makes a strong case for the development of national standards for landslide data collection.

STRUCTURE AT THE GOLDEN CROSS OPENCAST MINE, WAIHI, NEW ZEALAND

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The Pliocene epithermal gold deposit at Golden Cross, 10km northwest of Waihi, is made up of two contrasting deposits: a higher level “stockwork” and a deeper vein type deposit, known as the Empire Vein Zone. Both are hosted by Miocene andesites of the Coromandel Group. Bedding in lake sediments associated with the volcanics strike N-S and dip eastwards at angles of 50-70°. Tilting occurred before the overlying, unmineralised Omahia andesite, which is very shallowly dipping-horizontal.

The “stockwork” zone, which was mined by opencast methods in the 1990’s phase of mining, consists of a network of relatively thin (mostly cm scale-up to 50cm wide) quartz-carbonate veins. Few crosscutting relationships are seen and it seems that the veins opened up more or less simultaneously.

This is in direct contrast to the Empire Vein Zone, mined by underground methods, which has two very clear phases of veining, early banded quartz veins, which can be several metres in thickness, and have complex internal structure, followed by late, barren carbonate veins, with very simple internal structure.

This study concentrates on one bench of the opencast. There is a relatively simple pattern of veining. In the west of the section the pattern is particularly regular. The majority of the veins- especially the thickest- tend to dip eastwards, sub parallel to bedding. Halfway along the section there is a more complex zone, containing very few veins. The veins are thin and irregular. In the east of the section the pattern changes again. The veins have more diffuse orientations, but the majority dip Westwards, sub-perpendicularly to both bedding and the western veins. .

Stereographic plots of veins show a NW cluster of poles and an equivalent planar spread of intersections. These are the veins which are sub-parallel to bedding. A more diffuse cluster of poles plunges SE, which represents the bedding-subperpendicular veins. A major and very significant cluster of intersections runs horizontally NE-SW. This orientation is pole to a broad planar spread on the poles plot. The NE-SW cluster of intersections probably represents the intermediate axis of strain. This is consistent with fold axes seen in the area.

The overall pattern of veining is, then, relatively simple two dimensional strain. The East and West dipping sets of veins may represent conjugate sets of planes or main and en echelon sets. If either of these scenarios were true, their current orientation points to a normal system, but if bedding were rotated back to horizontal, the system would be reverse.

The pattern of veining in the opencast is more similar to the pattern of the underground calcite than that of the underground quartz veins.

The term “stockwork” is problematic and needs redefining or abandoning.

ENGINEERING GEOLOGICAL MODELS FOR SLOPE DESIGN, ROTOWARO COAL FIELD, HUNTLY.

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Solid Energy North (SEN) is actively mining coal from open pit operations at Rotowaro, Huntly, New Zealand. A key development over the next few years is the extension of open pit mining into the South and West Pits of Township Opencast. For the mine development, highwall cuts up to 100 m will be required within a sequence comprising Mesozoic greywacke of the Newcastle Group, early-mid Tertiary coal measures and mudrocks of the Te Kuiti Group and Quaternary soils (Tauranga Group).

The boundaries of the South Pit are delineated by a number of major normal faults (with throws of up to 80m) and moderately dipping strata and geological contacts. Civil and mine infrastructure are situated about the margins of the South Pit, and reliable slope performance is essential.

Engineering geological and groundwater models have been developed for the South and West Pits that enable geological variability and uncertainty to be incorporated into a risk based highwall design methodology. Key components in the engineering geological and groundwater models for which variability and uncertainty have influenced stability assessment, include:

- Low strength bedding shear surfaces
- Bedding orientation
- Basement paleo-relief
- Location and orientation of faults
- Width of fault-disturbed rock mass
- Persistence and spacing of major joint sets
- Presence of old underground workings

Comprehensive field investigations, supported by historic underground mine records and observed slope performance, were used to develop input distributions for slope stability analysis using probabilistic methods. These analyses allowed the probability of slope failures for a number of different failure modes to be assessed and consequences of failure estimated (in terms of failure volume) to provide a non-financial measure of risk ("risk-volume"). The calculated risks were then compared with design risk criteria.

This approach has enabled direct incorporation of engineering geological and groundwater models into a risk-based slope design approach and the development of highwall designs that take due account of variability and uncertainty in the engineering geological and groundwater models.

SEDIMENTARY STRUCTURES AND OBLIQUE PLANAR CONCRETIONS WITHIN A BIOCLASTIC SANDSTONE (“HOTELO BEDS”) FROM THE MIOCENE WAITEMATA GROUP

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These gently dipping bioclastic sandstones (“Hoteo Beds”) outcrop 80km north of Auckland in a 6km long series of inland bluffs. In the north they are underlain by the structurally complex Timber Bay slope facies (0.1-60m thick), which directly overlies the Northland Allochthon. In the south the “Hoteo Beds” sit within the Pakiri turbidite facies, where both units have the same shallow (5-10°) southwest dip.

The “Hoteo Beds” consist of inner-shelf fauna and sediment that was transported to the deep slope. It includes three sedimentary units, firstly 10-40cm of basal mudstone breccia with a shell hash matrix, then 1-2 metres of thin-bedded bioclastic sandstone. This sandstone contains cross beds, planar laminations, basal ripples and water escape structures, and is both conformably and unconformably overlain by 25 metres of massive bioclastic sandstone.

The lower third of this massive sandstone contains planar, bedding-parallel calcite concretions. There is also a 2km long zone containing planar concretions which lie oblique to bedding (Figure). These form sets of similar dip and strike that cross cut each other and the bedding parallel concretions. Each of these distinct sets dips to the northeast quadrant with the bedding parallel concretions dipping southwest. Cathodoluminescence and structural analysis have been used to show the order and origin of these features. The origin is believed to be a shear system caused by alternating phases of compression and extension on top of the Northland Allochthon during its emplacement. This stress field created differential strain and fluid flow between the underlying weak Timber Bay facies (complex folding and bedding parallel veins) and the stronger “Hoteo Beds” (sandstone dykes and concretions).



NEOGENE THERMAL HISTORY OF HAWKE'S BAY BASIN

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Northern Hawke's Bay comprises two sedimentary depocentres, one north of Wairoa containing Middle Miocene Tunanui Formation with a depositional axis oriented northwest-southeast, 90° to the trend of the modern plate boundary zone, and another south of Wairoa containing mainly Late Miocene to Early Pleistocene section uplifted along the axial ranges to form the northeast-southwest striking Hawke's Bay Monocline. Northwest directed shortening since the Late Miocene (Kapitean), driven by the growth of an accretionary prism offshore to the southeast, has folded the Tunanui Formation in the northern depocentre into a series of anticlines and synclines, which have been drilled in the search for petroleum resources.

Apatite fission track (FT) analysis has been applied to samples from five exploration holes (Opoutama-1, Hawke Bay-1, Taradale-1, Te Hoe-1 and Ruakituri-1) to establish the thermal history of the sedimentary sections in both depocentres. The porosity of samples of mudstone sequences from the flanks of folds have been determined to independently estimate from an established porosity-depth relationship the amount of section eroded from the surface. Restoration of this section enables the paleogeothermal gradient to be estimated for the host rocks in Opoutama-1 (16°C; possible range 11-18°C) and Te Hoe-1 (18-20°C) for the Late Miocene (Kapitean) peak in burial. It is argued that the subnormal geothermal gradient developed during the Middle Miocene when the northern depocentre formed parallel to the contemporary plate boundary, and in response to the cooling effect of emplacement of the subducted slab beneath the basin. This timing is supported by Neogene plate reconstructions of New Zealand that incorporate the extent of the subducted slab of Pacific plate lithosphere. An effect of the cooling of the basin concurrent with its subsidence and sedimentation would be reduction in the rate of hydrocarbon generation and expulsion from possible source rocks at depth in the basin, compared with Taranaki basin which has a more normal thermal regime.

The apatite FT results for Taradale-1 imply 2.9 km of erosion of Eocene-Miocene section, which explains an unconformity between Paleocene and Pliocene sediments in the well section. The FT parameters for Late Miocene sediments analysed from Hawke Bay-1 and Ruakituri-1 are dominated by provenance characteristics. Samples obtained from Middle Miocene Tunanui Sandstone in outcrop, both in the Lake Waikaremoana and Nuhaka-Opoutama areas, have apatite FT ages around or slightly younger than stratigraphic age and together with their track length parameters indicate former exposure to partial annealing in the basin, with cooling via denudation having occurred since c.6 Ma. Samples of Late Miocene Makaretu Sandstone may have experienced mild partial annealing in the basin. Sandstone samples of Late Miocene age obtained from the Mohaka-Tutira section in the Hawke Bay Monocline all retain provenance characteristics.

AN OVERVIEW OF WANGANUI BASIN AND ITS RELATIONSHIP TO TARANAKI AND KING COUNTRY BASINS

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Wanganui Basin is located in southwestern North Island, adjacent to the Central Graben and Southern Inversion Zone of Taranaki Basin, with which it shares a common Plio-Pleistocene geological history. The basin has evolved since the Late Miocene (Late Tongaporutuan) through southward migration of a depocentre previously located in the King Country Basin (North Wanganui Basin). The southward migration of the depocentre was followed by broad uplift driven by intrusion of a mantle wedge beneath central North Island. Currently the northern half of the basin is onshore and deeply incised, giving rise to superb outcrop exposure; the southern half is offshore, over which there is reasonable seismic reflection coverage.

During the past four years we have undertaken a complete analysis of Wanganui Basin in the framework of those completed recently for other New Zealand Cretaceous-Cenozoic basins. Industry seismic reflection data have been used to map six seismic horizons throughout the grid of data, leading to the production of a suite of new structure contour and isopach maps for mainly offshore parts of the basin. Extensive section description and geological mapping in the onshore realm have resulted in a new and detailed lithostratigraphy. The chronology of the basin fill has been established through biostratigraphy and magnetostratigraphy. The application of facies analysis and sequence stratigraphy have established the depositional paleoenvironments occurring in the basin fill, and have identified a very detailed cyclothem succession that accumulated under repeated glacio-estatic sea-level oscillations. This cyclostratigraphy has been mapped into hydrocarbon exploration holes via interpretation of wireline log records. These data have helped to constrain the interpretation of the paleogeographic development of the basin and particularly the margin with Taranaki Basin. Detrital fission track thermochronology shows clearly that the bulk of the sediments were sourced from the evolving plate boundary zone located to the south. The possible petroleum systems of the basin have been addressed, in addition to the parameters considered above, by establishment of the modern thermal regime, and by thermal modelling incorporating VR and FT constraints on maturation levels in a burial history context, calibrated by new organic geochemical data from possible source rocks.

Wanganui Basin holds a key position in central New Zealand and through much of the late Neogene lay between Taranaki Basin and the plate boundary zone. The dynamics of the basin record intervals of marked increase in bathymetry, which modulated the supply of sediments to Taranaki Basin. This affected the late Neogene progradation of the continental margin succession and hence the burial-maturation and petroleum generation history of Taranaki Basin.

NORTH ISLAND LATE CENOZOIC TECTONISM

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Three shorter-length “Tectonic Events” separate longer intervals of Late Cenozoic time, during which tectonic activity was relatively consistent in direction and pace. The “Events” were times of rapid change, when a new tectonic regime was imposed.

The Waitemata Tectonic Event, of 26 to 25 Ma, followed a long stable period. It created the unconformity between the Te Kuiti and Waitemata Groups, and triggered the establishment of a subduction system from NE of Northland. Offshore sediments and ophiolites were conveyed forward by the subducting slab, and deposited as nappes on to a sinking Northland - thus forming the Northland Allochthon (24-23 Ma). Subsequently (and continuing to 16 Ma) volcanism in Greater Northland was in two belts - the eastern Marshall Belt (andesitic + acidic) and the western Searle Belt (andesitic + basic) - the boundary between the belts perhaps reflecting the depth there to the subducting slab (more than 100 km).

The Kiwitahi Tectonic Event, of about 16 to 14 Ma, ended subduction-related volcanism in Greater Northland. It also initiated transcurrent fault movement which transported, to the SE, the established subduction system and trough, along with the North Island’s present East Coast (which always remained in a “forearc” location). This activity is also shown by: (a) the SE migration of the limit (volcanic front) of subduction-related volcanism in Coromandel and Kiwitahi; and (b) by the transcurrent movement, from Northland-Coromandel sources of: a Cretaceous basin, Miocene pumiceous sediments, Ihungia conglomerate pebbles, and the East Coast Allochthon. This dextral transcurrent fault is accepted as a now-abandoned, earlier extension, of the Alpine Fault. An initial 25° of tectonic curvature was imposed on the North Island. The two volcanic belts remained, with rhyolitic volcanism beginning in the Marshall Belt from 10 Ma, or earlier. The SE movement of the subduction system and the Alpine Fault, allowed “tectonic quiescence” and intraplate volcanism to extend progressively from the NW, through Northland & South Auckland. It later reached from south of Raglan to Mayor Island.

The Kaimai Tectonic Event, of about 5 to 2 Ma, initially halted (even reversed locally) the SE migration of subduction-related volcanism (perhaps as the “Hikurangi Trough” joined with the Tonga-Kermadec Trench system). From 2.5-2 Ma, volcanism continued migrating to the south and SE, still in the two contrasting Marshall and Searle Belts. The Event led, since <3 Ma, to the rotational rifting of the Central Volcanic Region (CVR) and Hauraki Graben, thus imposing an additional 40° of curvature on the North Island and NZ. This total of 65° since 14 Ma compares well with Walcott & Mumme’s figure of 60° of rotation since 15 Ma on paleomagnetic grounds. Such rotation is also compatible with the conclusions of Sarah Beanland & John Haines, Peter Ballance, and the many authors of the Circum-Pacific Tectonic Map. The CVR was ripped open along the weakened abandoned trace of the Alpine Fault, with the hinge point moving always southwards. It created successively the Mangakino (to 900 ka), Manawahe (900 to 400-350 ka), and Taupo (400-350 ka to today) Volcanic Zones. The strain, resulting from this rapid rotational opening, was relieved by the creation of the North Island “Shear Belt”. Comparable east-branching subsidiary faults are inferred in the North Island, to those in the northern South Island. The Alpine Fault (from the S), and Shear Belt faults (from the N), terminated at those branch faults in turn. Southwards, one after the other of the branch faults became inactive, together with the intervening length of the Alpine Fault; while the Shear Belt faults extended southwards, and became less active in the north.

WAIPA SUPERGROUP

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An emphasis on the use of terranes for North Island basement nomenclature and tectonic models has led to the overlooking of important regional stratigraphic relationships.

We propose the new name Waipa Supergroup for a regionally extensive Late Jurassic (to probable Early Cretaceous) stratigraphic unit in the central North Island. Waipa Supergroup is present on both sides of the Waipa Fault and includes Apotu and Huriwai Groups (formerly of Murihiku Terrane), Manaia Hill Group (formerly Waipapa Terrane) and, probably, rocks of the Waioka petrofacies (formerly Torlesse Terrane). Although depositional setting, metamorphic grade, and style of deformation vary from east to west, distinguishing features of Waipa Supergroup include its age, volcanic litharenite-dominated petrofacies, conglomerates, abundant indications of reworking and presence of *Belemnopsis aucklandica*.

In a regional tectonic context, the Waipa depositional system is a Late Jurassic overlap assemblage that rests on older, deformed and mutually amalgamated Murihiku, Maitai, Caples and Rakaia terranes. In contrast to the previous naming of terranes after supergroups (e.g. Murihiku, Torlesse) this is an instance of the naming of a supergroup subsequent to terrane definition; Waipa Supergroup gives a stratigraphic formality to previously proposed detrital links between the younger parts of the North Island Murihiku, Waipapa and Torlesse terranes (Kear 1971, 1993; Black 1994; Mortimer 1995ab; Cawood et al. 1999). Waipa Supergroup litharenites were deposited in shelf, slope and trench settings and were probably sourced from the magmatic arc represented by the Median Batholith. A coeval, but largely sedimentologically and petrologically separate, Late Jurassic-Early Cretaceous depositional system, represented by Pahau Terrane feldsarenites, was sourced from Rakaia Terrane and Haast Schist.

In our opinion, correlation of parts of former terranes, groups and petrofacies via a single, high level stratigraphic unit considerably simplifies and clarifies North Island basement nomenclature. It also emphasises that there are major along-strike changes in the Eastern Province (Rangitata Orogen) between the North and South Islands. Apart from 10-100 km scale tectonic consolidation, most elements of the present day New Zealand basement may have been in close to their present mutual positions by the Late Jurassic.

CARBONATE SEDIMENTATION ON SUBTROPICAL SHELVES AROUND LORD HOWE ISLAND AND BALLS PYRAMID, SOUTHWEST PACIFIC

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Lord Howe Island and Balls Pyramid are mid-oceanic islands composed of basalt derived from Tertiary hot-spot volcanism in the Tasman Sea. Subaerial carbonates dating back at least 350 ka and a Holocene fringing reef, the southernmost in the world, occur on Lord Howe Island. No reefs or subaerial carbonate deposits occur on Balls Pyramid 20 km to the south. Both islands sit near the centre of wide shallow shelves indicating planation of previously larger volcanic edifices. The Lord Howe shelf is characterised by a discontinuous drowned ridge, composed of limestone, and interpreted as a fossil reef.

The surface sediments across the shelf are calcareous, except in close proximity to the island where volcanic content is significant. Coralline algae represents the dominant grain type, with minor amounts of coral. Bryozoans and *Halimeda* are common; however, they are not volumetrically important. The fossil reef is largely bare of sediment, but is veneered by Holocene coralline algae. Early to mid Holocene coral gravels are found locally in the lee of the fossil reef, indicating limited give-up reef growth during the postglacial transgression. Rhodoliths and molluscs occur on the shelf edge, but they are bored and infilled, suggesting a low rate of carbonate production or lack of deposition. These areas may have been most active at times when the sea level was lower. These subtropical shelves are mid-oceanic examples of the transition between tropical and temperate carbonate sedimentation. They indicate the potential for carbonate production on broad planated shelves outside reef-forming seas.

NEW ZEALAND PERSPECTIVE ON QUANTITATIVE FOSSIL LEAF BASED PALEOCLIMATE ANALYSIS

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With its extensive and varied leaf-bearing terrestrial deposits and relatively limited geographical area, New Zealand is proving to be a very interesting focus for quantitative fossil leaf-based paleoclimate studies and, not surprisingly, quite a challenge for existing methodologies. Quantitative paleoclimate methods using leaf fossil morphology are based on correlations seen in modern plant assemblages between morphological characters of dicotyledonous angiosperm leaves and specific climate variables. Most of this research has been focused on Northern Hemisphere fossil and modern assemblages. To date, most analyses of Southern Hemisphere fossil material have been undertaken using modern analogue data from the Northern Hemisphere.

Isolation has been the driving factor in the development of our highly endemic modern flora. The flora is unique both in its systematic composition and, with respect to dicotyledonous angiosperms only, it appears to differ in the response of leaf morphology to climate. In fact, one of the most important correlations seen between leaf morphology and climate in Northern Hemisphere data sets does not seem to be significant in existing New Zealand data sets. That is the strong correlation in the Northern Hemisphere data between mean annual temperature and the proportion of leaf types in an assemblage that have entire (smooth) margins. On its own this correlation is weak in the New Zealand assemblages. However, when a number of different leaf characters are analysed together (multivariate analyses), the New Zealand modern assemblages do produce surprisingly accurate climate estimates.

How do these observations affect paleoclimate analyses and interpretations from New Zealand leaf fossil assemblages? This question can only be answered by collecting more data from both modern and fossil leaf assemblages from New Zealand and by comparison with other data sources (e.g. paleoclimate models, palynology, marine microfossils). However a working hypothesis is that younger fossil assemblages, those more like our modern flora, should perhaps be analysed using data from modern New Zealand leaf assemblages only. It may be more appropriate to analyse older floras, such as those from the Cretaceous and Early Tertiary, with the larger Northern Hemisphere-based data sets. The current New Zealand modern data set cannot be successfully added to those from the Northern without significantly increasing the uncertainty values.

Several fossil leaf assemblages from New Zealand have now been analysed using leaf morphology methods. These include the middle Cretaceous Clarence flora, a latest Cretaceous assemblage from Cameron's Pit in North Otago, one latest Cretaceous and two Paleocene assemblages from NW Nelson, and a Paleocene flora from Greymouth. Data from these assemblages are suggesting that terrestrial temperatures in these regions were slightly warmer in the Late Cretaceous than in the Paleocene. Eventually, with the acquisition of more leaf fossil data and improved stratigraphic control of New Zealand terrestrial sequences, we hope to have a more comprehensive quantitative terrestrial record of temperature change for significant parts of our Late Cretaceous to Recent climate history.

CAN GEO-EDUCATION AND GEOPRESERVATION ADVANCE INDEPENDENTLY?

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Without field visits earth science education is incomplete. The Society's Geopreservation Inventories have increased awareness of scientifically significant geological features. Some are potentially threatened with over-use and long-term degradation by visitors. The current earth science curriculum for schools has evoked various responses that are intended to assist both teachers and students in their understanding of geology in the classroom and in the field. Because degradation of some popular geological sites is already occurring, it is an opportune time for the Society to develop Site Conservation Strategies.

Several parliamentary statutes require geological features to be protected. A mere listing and description of notable sites is not sufficient. Involvement by Society members in the preparation of Site Management Plans is important and desirable. The statutory obligation to manage the sustainable use of natural resources puts each local authority in a powerful position to protect those geological features that have important educational potential.

Not only do tertiary and secondary educational institutions require access to appropriate geological field sites, but also, the politicians, bureaucrats, and officers of local authorities require an understanding of the heritage value and scientific importance of protecting geological features of educational significance.

THE NATURE AND DYNAMICS OF THE ROTORUA ERUPTIVE EPISODE

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The Rotorua eruptive episode (15,700 cal yr BP) represents the latest expression of volcanism from southwest Okataina caldera and provides an opportunity to examine the nature, dynamics and impacts of a long-lived eruption from this frequently active silicic system. The products of the Rotorua eruption can be separated into three distinctive types:

a widespread ($> 25,000 \text{ km}^2$) well-stratified plinian fall deposit (the Rotorua Tephra), dispersed primarily to the NW, from a vent area immediately E of Lake Tikitapu, proximal density current deposits with associated elutriated ash fall, and later-stage, multi-lobed rhyolite lava domes between Tikitapu and Tarawera lakes.

In proximal locations ($< 15 \text{ km}$) the plinian deposit is very coarse, generally well-sorted and multiple bedded on a cm scale. Ten proximal subunits (A-J) have been identified which vary in thickness and grain size, and may be normal or reverse-graded, indicating eruption intensity fluctuated widely over very short time intervals. The basal subunit (B) is typically the coarsest and grain size decreases unsteadily up section suggesting maximum discharge was achieved very early then weakened erratically. A basal phreatomagmatic layer (subunit A) indicates the involvement of external water in initial explosions, but clast vesicularities show that explosive degassing largely drove the plinian phase. The distal ($> 20 \text{ km}$) fall stratigraphy is dominated by three stratified, well-sorted subunits that have similar dispersal patterns and represent only the higher intensity intervals of the plinian phase.

Pyroclastic density current deposits appear to be confined to areas south and east of the vent area and are associated exclusively with late-stage lava dome construction rather than plume collapse. Samples from the dome lavas and density current deposits have consistently higher crystallinities and SiO_2 contents (75-76 wt.%) compared with pumice samples from the preceding plinian phase (SiO_2 72-74 wt %). These data suggest tapping of a thermally and compositionally zoned magma reservoir, or involvement of multiple discrete reservoirs.

New mapping of the Rotorua deposits gives a revised volume of 2.8 km^3 (1.9 km^3 pyroclastics; 0.85 km^3 lava dome) for the episode, equivalent to 1.8 km^3 of magma. Comparison with well-studied historic eruptions suggest an eruption duration of a few hours for the initial pyroclastic phases, and 6-9+ years for the later dome-building phases (using an average lava eruption rate of $3 \text{ m}^3/\text{s}$).

An eruption of this size today would cause the total destruction of Rotorua City (home to $> 50,000$ people) and the entire central North Island would be crippled for many months. Due to the length of the eruption, an extended emergency response would be required that would have critical economic and social impacts. There would be major losses of livestock and productive land, and it would cause the complete collapse of intensive forestry operations in the Rotorua District. National and international flights from Hamilton and Auckland airports would be heavily disrupted causing major economic losses. Public health issues, such as respiratory problems and contaminated water would continue for a long period after the cessation of volcanic activity.

ISOTOPIC COMPOSITIONS OF CRUSTAL MELTS FROM EXPERIMENTS PROVIDE INSIGHT INTO COLLISIONAL MAGMATISM

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The isotopic characteristics of melt and restite during crustal melting have received little experimental attention. The issue is typically dismissed by the assumption that the isotopic compositions of melts are given by the bulk composition of the protolith—an assumption which implies isotopic equilibration is attained between the melt and source minerals. Recent experiments and observations have called this into question at shallow crustal pressures (e.g., Hommouda et al., 1996; Knesel and Davidson, 1996), leading us to extend the question to deeper levels in the crust.

Melting experiments in the granite system conducted at 6 kbar and 850-1000°C demonstrate that a wide variety of isotopically distinct, but petrologically similar, melts can arise from progressive anatexis of a single source. Near the solidus, muscovite-dehydration melting yields granitic liquid of lower $^{87}\text{Sr}/^{86}\text{Sr}$ than the source rock. Above the muscovite-out boundary, dissolution of alkali feldspar results in gradual increase in melt $^{87}\text{Sr}/^{86}\text{Sr}$ with increasing temperature, until extensive breakdown of biotite produces melt of greater $^{87}\text{Sr}/^{86}\text{Sr}$ than the starting powder. These results show that, in addition to constraining source compositions, isotopic signatures of anatectic magmas can be used to fingerprinting melting reactions in natural systems.

Application of this approach to the Miocene intrusive bodies of the High Himalaya, arguably our best example of pure crustal melts, shows that the well-known bimodal isotopic and trace element geochemistry of these controversial granites is consistent with distinct episodes of dehydration melting and fluid-fluxed melting of muscovite-bearing metapelites of the Greater Himalayan Crystallines. This result alleviates the need to invoke multiple source components to account for the large isotopic variations preserved (even at the metre scale!) in these leucogranites (e.g., Deniel et al., 1987; Guillot and Le Fort, 1995). Furthermore, we show that these contrasting styles of magma generation, and associated geochemical signatures, can be linked temporally to tectonic features associated with exhumation of the orogenic wedge.

The take-home lesson from our findings is that in some cases the isotopic composition of an igneous rock is a function not only of the isotopic composition of its precursor, but also, and perhaps more strongly, of the processes by which the rock formed!

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QUAKE TRACKERS TAKES GEO-EDUCATION INTO THE 21ST CENTURY

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Geological byproducts are fundamental to the well being of mankind. When considering all the variety of geological resources from minerals to hydrocarbons, air and water, it is easy to appreciate how intimately dependent we are on these elements for our survival. Yet, careers in geoscience appear doomed to extinction when compared to the more lucrative careers in hi-technology. If we are to effectively manage, exploit, and understand our natural resources, then it is critical to bring science literacy into all aspects of the public domain (government, law, industry, etc.). Geo-education is perhaps the most relevant course of study that we could possibly promote. The caveat lies in training our future geoscientists with skills that also appeal to the current “flavour of the month” in order to boost their survival in the marketplace.

Geo-education in the next century will be focussed on *distance learning* more than ever before, and already there are over 90,000 general education courses taught in US colleges and universities alone. As the internet gains popularity and curriculum materials are thrown on-line, web education will be big business. New Zealand has no shortage of on-line material and a very successful geoscience project is starting to put New Zealand on the map.

A novel earthquake geo-education programme, titled Quake Trackers, has been running for the past 4 years and is growing all the time. The goals of the project were to increase earthquake hazard awareness and provide exciting hands-on science education in secondary schools. This has been accomplished via a programme that includes student-operated seismographs and a website that has been designed for use by students, teachers, and the general public. The website allows students to share their seismic data with other schools and also includes information about earthquakes in New Zealand, ranging from maps and photos of past earthquakes to an interactive programme that teaches the basic principles of earthquake location, using New Zealand examples. The website also includes a set of curriculum materials that gives teachers the opportunity to teach basic scientific principles using practical examples from seismology. Quake Trackers is also building a platform to work into other natural hazards.

Quake Trackers is satisfying a real need in school curriculum. By leveraging the power of the internet with massive in-kind contributions and volunteer time, Quake Trackers is a prime example of what can happen when collective efforts and interests are harnessed. Web education is a trend of the future and Quake Trackers is certainly pushing into that frontier. Quake Trackers is a joint programme initiated by Victoria University and the Institute of Geological and Nuclear Sciences with primary funding by the Earthquake Commission. To go there, type www.quaketrackers.ac.nz.

TUMULT AT TORA – THE K/T SUCCESSION IN SE WAIRARAPA

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The succession exposed on the Tora coast, ranging from Piripauan to Teurian age, is distinguished by an unusual lithofacies of the Whangai Formation, and by an apparently unique formation - the Manurewa Formation - which spans the K/T boundary.

The Whangai Formation, of Haumurian age, throughout much of its 200 m+ thickness is represented by massive dark grey siltstone to very fine sandstone. In its upper portion, however, zones of slumps and olistostromal conglomerates, with megaclasts of limestone up to 3 m long occur. The common occurrence of hummocky cross-stratification suggests shelf deposition above at least storm wave depths. The olistostromal deposits suggest steeper topography with a higher rate of erosion, and imply tectonic activity.

The overlying Manurewa Formation, which appears to be restricted in occurrence to the Tora area, is interpreted to represent the infill of a major channel complex spanning the K/T boundary in time. Two channelled units are represented. The oldest, of late Maastrichtian (latest Haumurian) age, varies in thickness, reaching a maximum of ~14 m in the NE and wedging out to the SW. It consists of alternating thin sandstone and mudstone with thin limestone beds in the NE, and calcareous sandstone and mudstone in the SW. The younger channel system, of early Paleocene (early Teurian) age, consists dominantly of medium to coarse, slightly glauconitic sandstone, with common feeding traces, some vertical burrows, and local low-angle cross-stratification. It contains several olistostromal units with megaclasts of limestone and Whangai very fine sandstone up to 1 m long. In the SW, the early Paleocene channel deposits rest directly and sharply on Whangai Formation. The older channel complex is likely to have been deposited in a quiet environment, probably deeper than that of the Whangai. The paleoenvironment of the younger channel is uncertain, but the generally coarser nature of the deposits than the underlying strata and the probable shallow water nature of the overlying strata suggest shallow shelf depths. The inclusion of megaclasts of Whangai Formation indicates that local emergence and erosion of older strata was occurring.

The overlying, thinly-bedded sandy and strongly bioturbated Awhea Formation of mid to late Paleocene (mid to late Teurian) age, rests mainly gradationally on older strata, although in the SW it forms a draped infill into concave-upward depressions (wave-formed troughs?) formed in the top bed of Manurewa Formation. The Awhea Formation includes beds with low-angle planar cross-stratification, interpreted as very shallow marine, probably nearshore deposition.

The Haumurian-Teurian succession along the Tora coast contains a record of frequent slumping and olistostromal activity which does not relate closely to correlative deposits. New Zealand was in a passive margin tectonic setting at the time, but local tectonic activity and uplift was evidently occurring. The effects may have been enhanced by a climatic shift in storm tracks and intensity, which is supported by the evidence of strong wave activity.

UNDERSEA AVALANCHE VOLUME CALCULATIONS – THE EXAMPLE OF THE RUATORIA DEBRIS AVALANCHE

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The massive Ruatoria debris avalanche and debris flow located east of East Cape is associated with a large-scale, morphologic re-entrant of the Hikurangi Margin. The re-entrant extends 65 km landward from the toe of the slope to within 25 km of the adjacent land. The blocky, debris-avalanche deposit projects 40 km out across horizontal trench-fill, and consists of well-bedded slide-blocks, up to 18 km across and 1.2 km high, embedded within a highly diffractive, incoherent matrix. A large debris-flow deposit projects over 100 km SE of the re-entrant and is 65-170 m-thick. Because of its size and comprehensive data set, the Ruatoria avalanche is a good natural example to conduct a comparison between the negative volume of the associated re-entrant and the positive volumes of the avalanche and debris flow.

Areas and volumes of rocks associated with the Ruatoria re-entrant, avalanche and debris flow were calculated using Digital Terrain Models (DTM) compiled from swath bathymetric and seismic reflection data. Three 3D surfaces were defined and used to calculate volumes. The three surfaces are: the simplified reconstructed topography of the margin and trench, interpreted as before subsidence and avalanche occurred, the present seafloor topography, and the base of the debris avalanche derived from seismic reflection data.

The re-entrant covers an area of 3,300 km² and has a total negative volume of 1508 km³, and a total positive volume of remobilised material of 1515 km³. The Ruatoria debris avalanche deposit covers an area of about 3,400 km² and has a gross volume of over 3,146 km³. The associated debris flow covers an area of about 8,000 km² and is composed of 960 km³ of uncompacted sediments. The volume's accuracy depends on errors made on parameters that include seismic velocities, seismic reflection picking, area contours, and reconstruction of pre-avalanche topography. Uncertainties on the avalanche gross volume calculation is estimated to be 20%.

Because the avalanche, debris flow and margin rocks have different porosities, calculations of areas, volumes and uncertainties must take into account compaction factors for each component of the system. The volume of the debris avalanche can be further subdivided into 40% of rafted blocks and 60% of matrix, each with a distinct compaction factors. Compaction factors at the seafloor were estimated as 15% for the margin rocks, 20% for the rafted blocks and 60% for the avalanche matrix and debris flow. Compaction factors decrease with depth was also taken into account.

The total compacted volume of the re-entrant, including negative volumes and re-mobilised debris-avalanche, is 2570 km³. The total compacted volumes for the debris avalanche and debris flow are 1958 km³ and 390 km³, respectively. These calculations suggest that the compacted volume of the avalanche deposit is 612 km³ less than that of the indentation indicating a loss of margin material other than by avalanching, and supporting the suggestion that the re-entrant is primarily a seamount-impact depression.

DIFFERENT STAGES OF SUBDUCTION INITIATIONS ALONG SEGMENTS OF THE MACQUARIE RIDGE COMPLEX

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The Pac/Aus plate boundary runs along the intracontinental dextral Alpine Fault, and extends southward along the 1600 km-long intra-oceanic Macquarie Ridge Complex (MRC). The MRC consists of four transpressive segments, characterised by ridges approximately 80 km-wide and 6000 m-high, along which different development stages of oblique subduction are identified. From south to north: (1) subduction of oceanic AUS beneath oceanic PAC probably occurs at the Hjort segment, but no Benioff zone is clearly identified; (2) The Macquarie segment shows thrusts either side of the ridge, more developed on PAC side; (3) The MacDougall segment presents only diffuse transpressive deformation, and (4) oceanic subduction at Puysegur Trench is indicated by a developed Benioff zone beneath Fiordland and Puysegur Bank (PAC), both of continental nature.

We present a synthetic tectonic map of the MRC that highlights incipient, active and ancient plate boundary structures. Kinematic reconstructions enabled us to establish the plate boundary structures for different key periods of its evolution toward subduction. The plate reconstructions enabled us to determine the shape, structures and nature of the crust that first subducted at Puysegur Trench, which in turn helped in identifying the geodynamical conditions that preceded initiation of the Puysegur subduction.

The evolution of the MRC trough time shows that progressive changes in plate motion may result in strike slip plate boundaries developing transpressive segments representing potential subduction nucleating points. The model reveals that concomitantly to inception of the Alpine Fault (ca. 23Ma), a 150 km-wide transpressive relay developed along inherited structures of southern New Zealand on the western flank of Puysegur Bank. The relay enabled localization of compressive deformation and eased development of shallow dipping structures. Lateral motion at the relay progressively juxtaposed oceanic and continental crusts of different densities and thickness, thus facilitating inception of subduction and controlling the subduction vergence. Subsequently, the Puysegur subduction initiated at the transpressive relay ca. 20 Ma. Inherited structures guided and facilitated the lengthening of the subduction zones during the Neogene. MRC segments appear to develop distinct vergences of subduction, depending on local geodynamical conditions. Trough time, well-developed subducting segments of similar vergence may coalesce into a single subduction zone or trench-trench transform faults may appear between mature subduction systems of opposite vergence.

NEW OBSERVATIONS ON HOLOCENE LAHAR DEPOSITS IN THE WHAKAPAPA CATCHMENT, RUAPEHU VOLCANO

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In order to complete our survey of lahar distribution and frequency at Ruapehu during the Holocene, further fieldwork has been completed in the northwestern sector of the ring plain.

Whakapapanui Stream

Lahar deposits of late Holocene age are well exposed in this catchment between 1,000 and 1,300m altitude. In the top part of stream bank exposures, 5m-high sections reveal a succession of at least 3 light grey, pebbly diamictos separated by thin sandy horizons and ashy paleosols. The sheet-like deposits extend laterally in overbank positions and correspond to small to moderate sized, post-Taupo lahar events that flooded the valley-floor, saturated with rhyolitic pumices. Massive, clast-supported bouldery and clay-rich diamictos form the main pre-Taupo units in these sections, indicating that large volume, well-confined debris flows preceded the deposition of andesitic tephra from Papakai and Mangatawai Formations. The avalanche-sourced 9.5 ka Murimotu Formation underlies the laharic sequence at river level.

Wairere Stream

Clast-supported, poorly graded bouldery diamictos exposed in this tributary suggests that Wairere Stream was the major lahar route between 5,000 and 3,400 yrs B.P., and confirms that massive debris flows were initiated at this time from a source area located on the northern part of the massif (upper flanks or summit plateau). Lahars channelled down the Wairere Stream fed the Whakapapanui Stream and contributed to the accumulation of voluminous debris in the lower part of the catchment.

Lower Whakapapa River

The Ohinetonga Reserve bridge is located east of Owango, 25km downstream of the confluence between the Whakapapaiti and Whakapapanui Streams. At this site, a wood sample collected near the base of the middle unit of a sequence of 3 matrix-supported, bouldery-pebbly andesitic diamictos gave a radiocarbon age of 1970± 40 yrs B.P. (Wk 3167). The overlying upper unit contains numerous clasts of Taupo Tephra pumices, suggesting that debris flows were emplaced in the catchment a short time before and after the production of the rhyolitic ignimbrite. This age indicates 2 laharic events in the last 2,000 yrs, which has been integrated into our 1:100,000 Ruapehu lahar hazard map.

Conclusions for the Whakapapa catchment

In the Whakapapaiti Stream valley, we previously recognized a major period of lahar aggradation between 10,500 and 7,000 yrs, following the pyroclastic Taurewa event and the ensuing emplacement of the Murimotu debris avalanche. Lahar activity then shifted to the Wairere Stream between 5,000 and 3,400 yrs, before the Whakapapaiti Stream became the dominant lahar route for the last 2,000 years.

**DOES PALEONTOLOGY HAVE A FUTURE IN NEW ZEALAND?
– REDISCOVERING THE RELEVANCE OF THE PAST**

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The rediscovery by natural scientists that understanding the past is essential for managing the present and predicting the future, especially at large spatial and temporal scales, is providing fresh impetus for paleontology in the 21st century.

Increasingly paleontology is making major contributions to key research questions in areas such as global climate change (temperature, CO₂), terrestrial-marine ecosystem linkages, abiotic/biotic controls on the differentiation of regional biotas, biotic resilience following local or mass extinction, invasion processes, and the rates and patterns of species turnover within and between habitats. Holocene paleontology is providing a new perspective on the present by revealing the full complexity of the pre-human biota of the New Zealand region.

New methods are now enabling extraction and identification of exceedingly small organisms from almost any sediment sample. Isotopic and DNA analyses are yielding new approaches for understanding fossils, while paleontology is becoming critical for constraining molecular phylogenies (rooting molecular mythology in paleontological fact). Taxonomy of modern animals and plants depends on accurate biosystematic information on closely related fossils.

Traditional research strengths in paleontology such as stratigraphy, biosystematics, and biogeography continue to be indispensable in refining global and regional correlations, in paleogeographic reconstructions, and in shedding new light on tectonic processes including uplift and terrane dispersal.

The only way in which we can adequately answer any of the major questions about the present biota of New Zealand is by constant reference to the exceptional Mesozoic and Cenozoic marine and terrestrial fossil record.

COMMUNICATE OR DIE — THE FUTURE OF GEOSCIENCE

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The future of our science lies in all our hands. It does not involve some remarkable feat of economics, or a change in government or an upturn in mining or even a catastrophic geological event. All it requires is enthusiastic earth scientists talking to the wider community about the relevance and importance of their work.

Communicating our science is not a difficult task, but it requires an understanding of some communication fundamentals. These fundamentals are not rocket science, but basic common sense that we can all master and use to our advantage. Also, having an understanding of the community and mechanisms to reach them can increase the impact of your message dramatically.

A small, but active, group in AGSO – Geoscience Australia have been doing just this over the last number of years. During this time they have reached a huge audience through schools and have built up sound communication activities that target many groups in the community.

But Geoscience Australia does not do it in isolation. Through partnerships, sponsorship and team work with other organisations, such as the Geological Society of Australia and the Minerals Council of Australia they have produced a number of educational and promotional resources which have been distributed around Australia and overseas. Geoscience Australia has also coordinates the successful Earth Science Week activities which ties into events organised internationally.

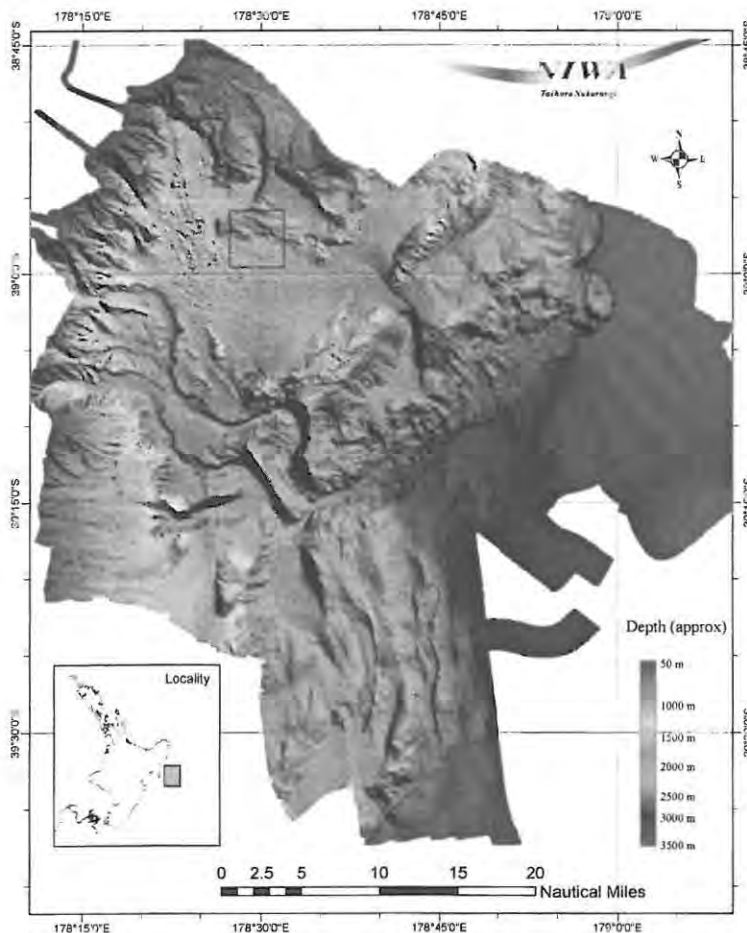
Through partnerships, and understanding of the community and clever communication strategies, our science can be reborn within the community. Together we can all make an impact and bring about a true renaissance for our science.

COTTON GOES UNDERWATER: SUBMARINE LANDSCAPE EVOLUTION IN THE POVERTY RE-ENTRANT WITH NEW SIMRAD MULTIBEAM

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Bathymetric and backscatter images of the seabed in the Poverty Re-entrant off Gisborne, were obtained in May this year using a Simrad EM300 swath-mapping system, hull-mounted on the research vessel *Tangaroa*. In only a few days (of bad weather) over 4000 km² of rugged slope topography was mapped, at depth ranging from 100 – 3,500 m deep. Images were available in real time. Maps with contour intervals down to 2m were available within a few hours. These high-resolution maps are comparable with the most detailed maps onshore and prompt a thorough re-interpretation of the Late Pleistocene “landscape evolution” of the Poverty Re-entrant.

The re-entrant has been partly in-filled by debris flow and avalanche deposits, which range from a few hundred metres to more than 25 km down-slope. At some places, cracks in the slopes indicate incipient avalanches. The re-entrant has been simultaneously eroded by a canyon system that exhibits many of the complexities of incised river systems onshore, including offset, capture and slump dams. A new canyon system appears to be in the process of forming a separate northern route to the Hikurangi Trough. On the lower slope, slumping seaward of a bulge indicates collapse in the wake of a small, subducting seamount.



SEDIMENT WAVES, CHANNEL RETURN-FLOW, AND START OF VERY LONG DISTANCE TURBIDITY CURRENTS IN THE SOUTHERN HIKURANGI TROUGH.

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In the southern apex of the turbidite-filled Hikurangi Trough, swath bathymetry swath backscatter, seismic profiles and cores show three types of long (1-5 km) wavelength sediment waves. These represent different responses to channel-axis turbidity currents, to overbank flows and to deep ocean bottom currents.

In the axis (and locally on the walls) of the Hikurangi Channel, sediment waves are less than 6 m high and occur, principally in the proximal reach, where cores show gravelly and coarse sandy turbidites. They are not apparent in high amplitude reflectors buried below the channel axis and are inferred to be thin, transitory, surface, sand bodies that migrated across coarser substrates, perhaps during the last, turbidity current. Their proximal, channelised location, their wavelength, and their steeper up-current faces indicate that these sediment waves formed as antidunes in high-velocity ($4-11\text{ms}^{-1}$), self-perpetuating, “autosuspension” turbidity currents that were about 500 m thick, so that the main flow over-spilled the 250-300 m deep channel.

On overbank slopes beyond the channel levées, sediment waves are up to 50 m high and have migrated up the levée backslope towards the channel at rates of 3–20 m/ka, during aggradation of nearly half a kilometre of turbidites. The stratigraphy of Barnes and Mercier de Lepinay (1997) suggest that they have been developing since about the start of the Pleistocene. These sediment waves are inferred to form in lee waves, in the upper, “overspill” parts of turbidity currents, in the lee of the linear perturbation of the levée crest. They are best developed on the outsides of bends, where centrifugal outflow of “overspill” is concentrated. They are particularly well-developed at right-hand bends on the left-bank, where centrifugal and southern hemisphere Coriolis effects combine. Poorly developed sediment waves on the inside of bends on the left-bank may be the result of Coriolis effects only. Overbank sediment waves decrease in height and wavelength away from the channel and continue into the depression along the slope-toe deformation front at the landward edge of the turbidite plain. Their trend suggests that overbank flows re-enter the channel axis where it approaches the deformation front. This implied return-flow, which may have eroded fine sediment as well as depositing a turbidite, may be critical in maintaining density and autosuspension in turbidity currents along the 2000 km Hikurangi Channel

At the toe of the Chatham Rise, sediment waves up to 5m high (and 2-5 km in wavelength) migrate away from the channel and towards a slope-toe “moat”. They are inferred to be part of a drift deposit, perhaps associated with a branch of the Pacific’s Deep Western Boundary Current.

Reference: Barnes, P.M., Mercier de Lepinay, B., 1997. Rates and mechanics of rapid frontal accretion along the very obliquely convergent southern Hikurangi margin, New Zealand. *Journal of Geophysical Research* 102, 24,931-24,952.

MANAGING ENVIRONMENTAL IMPACTS OF COAL MINING AND COAL COMBUSTION ASH: THE GEOLOGICAL AND GEOCHEMICAL APPROACH

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Awareness over possible environmental impacts of coal combustion and combustion products has increased over the past two decades. An outcome of this awareness has been a better understanding of the behaviour of trace elements during coal mining as well as combustion. As a preventative measure, stringent regulations have been enacted on some potentially hazardous air pollutants' (HAPs). The US 1990 Air Pollution Act Amendments specifically identified As, Be, Cd, Cr, Co, Hg, Mn, Ni, Pb, Sb, Se and U as potential HAPs.

In order to understand the behaviour of HAPs in the Greymouth coalfield, a total of 184 samples were collected as part of a broader study. These samples consisted of coal and inorganic partings as well as roof and floor rocks. The HAPs spatial distribution trends in relation to seam geometry were also investigated as was the modes of occurrence of HAPs using SEM-EDX and sequential leaching tests.

It is important to know both the distribution of HAPs and their behaviour upon combustion. For example, Pb concentration reaches 121 ppm at one horizon of the Strongman coal E seam, although Pb is at low concentration overall the seam. If further analysis shows this interval to be of concern, it could selectively mined, thus mitigating environmental impacts *in situ*. However, understanding how HAPs behave during combustion requires a level of more complex analysis.

For example, in order to understand the trace element behaviour during combustion, laboratory scale combustion tests were performed on three composite samples from the E seam (high volatile bituminous coal). After each combustion test, samples of bottom ash and cyclone ash were recovered and weighed. The major and trace elements from sub-samples of: (a) feed coal, (b) bottom ash, (c) fly ash and (d) flue gas were analysed by ICP-MS, XRF and SEM-EDXA. The trace elements were categorised into five groups in terms of their different partitioning behaviours. Finally the partitioning of the HAPs in different combustion ash types was quantified. Hg and S are predominantly partitioned in the flue gas fraction whereas Co, Cr, F and Ni are chiefly retained in the bottom ash. In contrast As, B, Cd, Pb and Se were enriched in the fly ash fraction. Characterisation of these types of behaviours for HAPs during combustion allows better assessment of environmental risk for the disposal or utilisation of combustion ashes.

DYNAMICS OF THE HIKURANGI SUBDUCTION MARGIN AS RECORDED BY RIVER TERRACES IN THE EASTERN NORTH ISLAND

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The presence of widespread flights of river terraces in the eastern North Island is indicative of regional as well as localised uplift, and thus provide a readily accessible data source with which to better understand deep-seated processes of the Hikurangi Subduction Margin. Through systematic and comparative study of the terrace data, the influences of base-level, climate, and upper plate versus deep-seated deformation processes should be able to be identified and quantified. In particular the distribution and elevation of the last aggradation terrace (probably Ohakean equivalent) provides a datum that can be compared in multiple catchments along the margin, and thus can delineate along-strike variations.

Preliminary results from the Waipawa/Tukituki Catchment in southern Hawkes Bay are presented here. Aerial photograph analysis and field mapping indicate the widespread preservation of two Otiran age terraces, with additional, higher, terraces preserved only in the very upper and lower reaches. Of the two Otiran terraces, the lower is the best preserved, and can be traced for 70 km upstream from the mouth of the Tukituki River. Based on the lack of cover beds, and the widespread distribution, this terrace is interpreted as the Ohakean terrace. The higher terrace is tentatively assigned a Ratan correlation based on the presence of a single loess sheet cover, which contains Kawakawa Tephra in isolated localities. The elevation of the Ohakean terrace has been surveyed using GPS, allowing construction of a longitudinal profile.

Existing data from the Mohaka and Waipaoa catchments, from Northern Hawkes Bay and eastern Raukumara Peninsula respectively, along with the data from the Waipawa/Tukituki catchment presented here, allow some initial regional comparisons to be made. Longitudinal profiles show remarkably different elevations of the Ohakean terrace above present river level, indicating significantly different rates of down-cutting since c. 15 ka. Variation in the shape of the profiles is considered likely to be a function of the different effects of local versus regional uplift.

SUBSURFACE STRUCTURE OF THE TAMA LAKES ERUPTION CENTRES, TONGARIRO VOLCANIC COMPLEX

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The Tama Lakes eruption centres, part of the Tongariro Volcanic Complex, are two of a series of vents active c.10 ka ago that lie on a NNE trending alignment within a major regional graben. Detailed gravity, magneto-telluric and aeromagnetic data at two elevations have been collected across the Tama Lakes Saddle providing a well-integrated geophysical data set. Gravity data show a broad asymmetric negative anomaly that suggests a significant change in basement level below the volcanic axis with shorter wavelength components indicating density variations within the volcanic pile. The aeromagnetic data define a broad, slightly asymmetric anomaly with a complex central magnetic high flanked by magnetic lows.

An iterative model consistent with all three potential field data sets shows an extensive low density body; the upper part, with moderate magnetisation, represents volcanic rocks, whilst the lower part appears to have no significant magnetisation and may represent Tertiary sediments. In the centre of the profile there is a denser, more magnetic body which coincides with the extent of the mapped lavas. This body has a two-pronged form at depth, extending to the basement interface at two locations which coincide at the surface with the lineament of the 10 ka eruption centres and faults mapped X km to the west of the eruption centres. Inversion of the TM mode magneto-telluric data shows a similar two-pronged form in resistivity structure but paradoxically with low resistivity zones coinciding with the denser, more magnetic zones. Low resistivity in the upper 1 to 2 km also extends to both the north-west and the south-east of Tama Lakes and is consistent with the existence of Tertiary sediments. The modelled magnetisations indicate that this low-resistivity material cannot be due to present-day high temperatures (eg due to shallow magma) or a well developed hydrothermal system but it may indicate enhanced groundwater flow in fracture zones.

IMPACTS OF VOLCANISM ON EARLY MAORI SOCIETY IN NEW ZEALAND

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This paper (see Lowe *et al.* 2001) discusses various interactions between volcanism and early Maori society in New Zealand. 'Early' Maori society is defined for our purposes to date from initial settlement *c.* 1250–1300 AD until the catastrophic Tarawera eruption of 10 June, 1886, that resulted in at least 108 deaths. We firstly summarize in detail the record of volcanic activity in New Zealand's North Island since the Taupo eruption of *c.* 200 AD. We then examine the likely effects and impacts that such volcanism and associated events had on early Maori society, as far as can be determined. Next, we describe the benefits and exploitation of volcanic features and products by early Maori, and then discuss aspects of Maori mythology and spirituality associated with volcanism. Finally, we use one of the main products of volcanism, tephra deposits, to date and correlate the palaeoenvironmental impacts of early Maori with archaeological records via tephrochronology.

It is likely that early Maori witnessed only one rhyolitic eruption (Kaharoa, 1314 ± 12 AD), two basaltic eruptions (Rangitoto, *c.* 1400 AD; Tarawera, 1886 AD), and numerous andesitic eruptions (dozens to possibly hundreds) from the frequently active volcanoes of Tongariro Volcanic Centre, Whakaari (White Island), and Taranaki (Mt Egmont). Early Maori had a strong awareness of volcanism generally and may have developed a spiritual 'disaster culture' to reduce the impacts of eruptions in proximal locations. The application of tephrochronology to the issue of New Zealand's settlement history is now well established, and the Kaharoa Tephra in particular provides a key 'settlement' marker enabling both archaeological and palaeoenvironmental sites (which record the earliest forest clearances accompanying settlement) to be dated. That the extremely powerful and devastating Taupo eruption of *c.* 200 AD is unregistered in Maori culture and folklore is consistent with the accepted model of late settlement of New Zealand. The beneficial and spiritual aspects of volcanism to early Maori are numerous and range from preferential occupation of volcanic cones as fortified villages to the use of volcanogenic iron oxides as pigments for functional and ceremonial purposes, amongst many other examples.

Lowe, D. J.; Newnham, R. M.; McCraw, J. D. 2001. Volcanism and early Maori society in New Zealand. *In* J. Grattan & R. Torrence (eds), "The Archaeology of Natural Disasters", Routledge, London (in press).

VOLCANIC GEOLOGY OF THE SOUTHERN MAMAKU PLATEAU

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The Southern Mamaku Plateau is a complex feature of the western Taupo Volcanic Zone (TVZ) that has been constructed by a series of thick welded ignimbrites, intercalated with a sequence of plinian fall deposits with associated paleosols and loess, and lensoidal fluvial sands and gravels. There have been successive periods of erosion which have modified the landscape, and periods of deposition of pyroclastic density currents as either valley ponded or veneer types, that have complicated the stratigraphy.

Deep U-shaped valleys that have been incised into the Southern Mamaku Plateau, expose a sequence of ignimbrites comprising the Whakamaru Ignimbrite (0.32 ± 0.02 Ma), Waimakariri Ignimbrite (age unknown), Waihou Ignimbrite (age unknown), Pokai Ignimbrite (age unknown) and Mamaku Ignimbrite (0.22 ± 0.01 Ma). In the southern part of the plateau in the Matahana Basin, an older sequence of pre-Whakamaru ignimbrites are exposed, that include the Tikorangi Ignimbrite (0.89 ± 0.04 Ma), Rahopaka Ignimbrite (0.77 ± 0.06 Ma), and Waiotapu Ignimbrite (0.71 ± 0.06 Ma).

The post-Whakamaru ignimbrites were derived from the Rotorua and Kapenga volcanic centres, and indicate a interval of intense ignimbrite production during this time, and that the volcanic histories of these centres is more complex and productive than previously documented.

RESERVING OPENCAST COAL MINES WITH PREVIOUS UNDERGROUND WORKINGS

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Historic underground workings pose major uncertainty for modelling and reserving coal-in-ground. At the Rotowaro Opencast coal mines, near Huntly, extensive underground workings, mined from 1916 to mid-1970's, are present. The two major seams have been "first worked" by the bord and pillar method, which extracted approximately 20% of in situ coal. In some areas, the seams were then "pillared" (i.e. the pillars were extracted), increasing extraction rates to 45-50%.

Drillholes provide the raw data for building a geological resource model. Holes are sited to avoid old workings in order to report reliable unworked seam thicknesses and yield complete cores for coal quality analysis. At Rotowaro, the exact location of drives (bords) in first worked areas is complicated by the past use of different survey origins, which necessitate an offset correction to the drive positions. Drilling in first workings has an 80% success rate of hitting solid coal. In pillared workings, poor survey records and lost circulation in collapsed ground above the workings, reduce the success rate to 20-30%. Consequently, good data is often sparse in the areas where the seams were well developed, leading to less structural and quality control in the model.

The geological model aims to represent in-situ coal prior to underground mining. The mine model is then created by removing areas considered too thin to mine (< 0.5m), merging seam splits too close to be separated by mining, and applying adjustments for underground workings and roof/floor mining losses. First working adjustments are made by reducing the level of the seam roof grid by a thickness equivalent to the volume of coal in the drives. This has a relatively low degree of uncertainty due to relatively good survey records and known drive dimensions. However, sometimes split pillars are not surveyed, drives are occasionally missing from old mine plans and roof recovery can be erratic. Pillared working adjustments are far less certain due to varied mining methods, seam thickness and variable extraction. A recovery factor of 25% is currently applied to the seam thickness grids in the pillared areas based on reconciling actual coal recovery performance.

To maximise reserves recovery from workings, contaminated coal is processed through a coal washing plant, which yields 70% product. In first workings, 20% run-of-mine coal is processed to the washery. This can rise to 50% from pillared workings. Advance cleaning of first worked drives increases clean coal recovery and reduces processing costs.

Despite cleaning, there is always some residual contamination of clean coal, which increases the ash content of the coal significantly. Run-of-mine factors are applied to in-situ ash values to ensure contract specifications can be met and penalties avoided. A factor of +0.7% is applied in first workings and +2-4% in pillared workings, depending on the degree of extraction.

INCIPIENT DEFROSTING OF A SUBVOLCANIC GRANITIC PLUTON, VINALHAVEN, MAINE, U.S.A.

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The Vinalhaven intrusion, approximately 10 km in diameter, is one of several bimodal plutonic complexes along the Maine coast, emplaced at about 420 Ma. While the bulk of the intrusion is a two feldspar, biotite granite, many basally chilled layers of mafic and hybrid rocks occur within the granite. These layers grade upward through hybrid dioritic rocks to coarse-grained granite, dip inward beneath the center of the granite, defining a basin, and display depositional and compactional features which indicate that they were produced by injections of basaltic magma which spread out across the aggrading floor of a silicic magma chamber. Some large bodies of fine-grained granite cut sharply through the mafic sheets and have irregular to gradational contacts with overlying granite. These appear to represent silicic replenishments to the chamber. The pluton has been tilted gently northward, exposing a roof, above which occur apparently coeval, bimodal volcanic rocks consisting of silicic ash flows, breccias and domes along with basaltic flows and sills compositionally similar to mafic rocks in the pluton. Angular blocks (up to km-scale) of country rock identical to roof rocks are associated with the largest mafic sheets. This association suggests that the chamber roof was disrupted at the same time large volumes of basaltic magma intruded into the silicic chamber, perhaps recording a major eruptive event. Mineral assemblages in metasedimentary blocks indicate that pressures at the base of the chamber were 1-2 kbars. All of these relations suggest that the Vinalhaven plutonic complex provides a stratigraphic record of events within an episodically replenished magma chamber beneath an active volcano.

The youngest intrusion of basaltic magma into the still active pluton produced an ENE-trending, 2 km long, sheet-like body of mafic and hybrid intermediate rocks that locally grade upward to fine-grained granitic rocks in sharp contact with a roof of coarse-grained granite. Based on apparent 20° northward dips of internal layering, this body is roughly 150-200 m thick. Steep bodies of massive gabbro with chilled margins occur along the base in contact with coarse-grained granite and appear to feed mafic and hybrid sheets within the lower part of the intrusion. The matrix in contact with the chilled mafic material is continuous with a substantial amount of a fine-grained hybrid rock containing quartz and feldspar "xenocrysts" apparently derived from the coarse-grained granite. These xenocrysts are corroded and show structures such as rapakivi feldspars and rims of mafic minerals around quartz, implying remelting and disequilibrium within the chamber. Rounded blocks of coarse-grained granite with gradational boundaries occur in the hybrid rocks. Upward in this body, the matrix becomes increasingly silicic and the proportions of xenocrysts decrease and are locally absent. Along the western side of the body, crystal content increases continuously from these xenocrystic porphyries, grading continuously back to normal granite. Here xenocrysts clearly come from what was locally solid granite. These relations suggest that mafic magma was emplaced into a largely crystallized interior of a nearly solid pluton, remelted much of the adjacent granite and mixed with it to produce hybrid rocks that accumulated on the floor, permitting granitic melt to collect toward the roof of the small chamber.

NUMERICAL SIMULATION OF DEBRIS AVALANCHE HAZARDS AT RUAPEHU

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The use of computer models of a range of gravity-driven flows to determine areas vulnerable to volcanic hazards is a growing trend in the earth sciences. One such model is the LAHARZ programme developed by Richard Iverson and Steve Schilling at the United States Geological survey (Iverson et al., 1998; Schilling, 1998). This application runs in the ArcView GIS-environment and simulates inundation of a digital topographic model by a debris avalanche. Debris avalanches are a low frequency/high consequence hazard at cone volcanoes, occurring when gravitational collapse of the upper part of the edifice triggers massive landslides involving many cubic kilometres of debris that can travel for tens of kilometres at velocities exceeding 200 km/hr. They occur globally on average four times a century, most recently at Mount St. Helens in 1981.

In this poster, we have simulated debris avalanche generation at Ruapehu volcano using topographic information in the LINZ digital database. Our worst-case scenario, small by world standards, involves the collapse of Pyramid peak (2640.6 mASL) and the release of a full Crater Lake ($9 \times 10^6 \text{ m}^3$) into the upper Whangaehu catchment. Bifurcation of the debris avalanche on the southeastern ring-plain is modelled by directing 75 % of the flow volume into the Whangaehu River and 25 % into a northern tributary of the Whangaehu, from where it spontaneously avulses into the upper Waikato Stream. The resulting debris avalanche (volume 0.18 km^3) travels up to 24 km, not including long-run out lahars directed along impacted river valleys, and buries an area of $> 70 \text{ km}^2$. While the inability to model flow velocity limits simulations involving the over-topping of topographic barriers by highly mobile flows, the technique is capable of quickly, objectively, and reproducibly generating maps of lahar-inundation hazard.

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FIRE, PUMICE AND WATER: RESPONSE OF THE WAIKATO RIVER TO THE 181 A.D. TAUPO ERUPTION

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One of the most dramatic processes in physical sedimentology and geomorphology is the post-eruption readjustment of landscapes to major explosive volcanic eruptions. New landscapes can be formed in a geologic instant over areas of tens of thousands of square kilometres by large ignimbrite-forming eruptions from rhyolitic caldera volcanoes. New depocentres are created in volcano-tectonic collapse structures while existing topography and drainage systems are buried beneath up to hundreds of metres of pyroclastic material. Subsequent remobilisation of this pyroclastic material constitutes a widespread and enduring hazard, as demonstrated by studies of the sedimentary aftermath of late Quaternary caldera-forming eruptions in the central North Island of New Zealand. The most recent such event, the A.D. 181 eruption from the Taupo Volcanic Centre, destroyed hydrologic systems over an area of 20 000 km² when emplacement of the climactic ignimbrite filled valleys and depressions with up to 70 m of pyroclastic material and blocked the outlet to the intracaldera basin. Post-eruption, large-scale remobilisation of this material in the Waikato River catchment occurred in association with re-establishment of the axial stream. Vertical, lateral, and proximal-to-distal changes in volcanoclastic lithofacies preserved along the main valley reflect evolving sediment transport and depositional systems in the eruption aftermath, and may be used to reconstruct the interplay between evolving hydrographs, sediment yields, and local sub-environments. Following an initial period dominated by mass flows, re-establishment of fluvial systems began with the headward erosion of box canyons through the ponded ignimbrite deposits. Streams developed in these channels evolved from shallow, ephemeral, flashy sediment-laden flows to more permanent braided rivers as drainage networks re-integrated and sediment yields declined through revegetation and depletion of the reservoir of easily remobilised material. After c. 20 years, the ignimbrite barrier at the outlet to Lake Taupo was breached by the refilling intracaldera lake, triggering the release of 20 km³ of floodwater down the Waikato valley. Brief rejuvenation of tributaries followed, before stabilisation of local base levels and flows effectively terminated the period of post-eruptive landscape response.

PALAEOSHORELINES, DEFORMATION TRENDS, AND CALDERA UNREST AT LAKE TAUPO

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The Taupo Volcanic Zone is a region of ongoing active volcanism, deformation, and seismicity in the central North Island of New Zealand. At Taupo Volcanic Centre, a major young caldera system, currently occupied by a large lake, coincides with the Taupo Fault Belt, a zone of Late Quaternary extensional normal faulting. Intracaldera Lake Taupo forms a highly sensitive datum against which to measure active deformation trends around the margins of the lake. Modern short-term (< 20 years) vertical deformation rates measured using geodetic and lake-leveling techniques reveal complex and episodic deformation trends related to active faulting and seismicity, overlaying a broader regional pattern. Medium-term deformation trends, defined relative to an isochronous paleolevel formed by a highstand shoreline developed ~15 years after the 1.8 ka Taupo eruption are broadly similar to these historic patterns. However, warping and offsetting of a high-stand shoreline developed ~140 m above modern lake level in the immediate aftermath of the 26.5 ka Oruanui eruption indicates rather different long-term deformation trends. Relative offsets on this paleoshoreline are only double those of the 1.8 ka shoreline, despite being 15 times older, except where subsidence has been concentrated on a single, highly active fault. Furthermore, the 26.5 ka shoreline reaches its highest elevation in the middle of an inferred graben in the Taupo Fault Belt: extrapolation of modern deformation rates at this site would place it *below* modern lake level. A number of inferences may therefore be drawn:

Nearby extra-caldera faulting associated with the Oruanui caldera collapse was completed prior to the lake refilling to its highstand level.

The Taupo Fault Belt immediately north of Lake Taupo is largely isostatically compensated, with short-term patterns ($10^0 - 10^2$ years) of episodic uplift and subsidence cancelling out over longer time periods ($> 10^4$ years).

Use of short-term, fault-related, deformation trends and seismicity to indicate caldera unrest at Taupo Volcanic Centre may be inappropriate, as such phenomena may simply represent elastic responses to long-term horizontal extension, highlighted by the presence of Lake Taupo as a horizontal datum.

FOSSIL BEETLES AS INDICATORS OF LAST INTERGLACIAL CLIMATE AT PALLISER BAY, SOUTHERN NORTH ISLAND, NEW ZEALAND

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The technique of examining fossil insect assemblages for information about past environments is a well-established methodology in the Northern Hemisphere. In UK and northern US fossil beetles have not only been used to detect short-term climatic oscillations and to track climate changes over time, but also to precisely calculate the rates and degrees of Quaternary climatic fluctuations. Reconstruction is achieved by comparing fossil taxa with the ecological requirements of extant taxa. The strength of this approach comes from the insects themselves in that they are able to respond quickly to environmental change, have very stable evolutionary forms and preserve well as fossils. This method is long overdue in New Zealand as a Quaternary reconstruction tool and may provide the quantification of elusive paleoclimatic parameters here.

A total of 63 fossil beetle species belonging to 15 families were extracted from two Last Interglacial lake deposits at Palliser Bay. Two beetle assemblages are provisionally prescribed to MIS5e and MIS5 (younger than e). Both fossil assemblages contain taxa including *Novitas nigrans*, *Eucossinus setiger* and *Macroscytalus parvicornis* that host specific to flax, cabbage trees and tree fern.

The lower sample (MIS5e) is a species-rich, swamp forest assemblage dominated by weevils. This Assemblage contains species with northern affinities. Eight taxa including *Lorelus crassicornis*, *Dasytes* *laticeps*, *Cryptobius nitidius*, *Stenomalius* *sulcithorax*, *Psilocnaeia nana*, *Microbrontes lineatus* and *Philonthus* have modern day distributions that range between Tairua to the far north of New Zealand. This assemblage indicates climate at time of deposition was similar to northern present day conditions.

The upper sample (younger than MIS5e) is also a swamp forest assemblage but contains no species that indicate climate was different than present day conditions. This assemblage relatively species poor and is also dominated by weevils including over 600 individuals of the weevil *Macroscytalus parvicornis*. The difference between the two assemblages is consistent with a rapid decline from warm conditions at MIS5e.

MICROZONING FOR EARTHQUAKE EFFECTS IN THE SOUTH AUCKLAND AREA

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Although the south Auckland area is outside of the main seismic zone in New Zealand it does contain Quaternary faults and has experienced strong ground shaking in historic times. It can therefore be argued that given there is a seismic hazard (albeit small) and that there are vulnerable structures there is a consequent risk in the area. This risk needs to be properly evaluated in the interests of public safety and long term planning. However, to understand risk the hazard must first be estimated.

Microzoning for strong ground shaking has been undertaken previously in Auckland by converting surface geological units into various ground classes and calibrating with microtremor analyses. This provides us with a relative hazard map. Our study advances this work by producing a subsurface model from a developing drillhole database. We have also obtained additional microtremor data to provide a more evenly spaced coverage. The combination of data allows us to determine the critical thickness where soft material overlying stiff material begins to resonate and amplify waves. This critical thickness is used to define zones of relative amplification on a map. It shows that the previous microzoning attempt was much too conservative (over-estimated the hazard) near the margins of the soft material and over a buried basement high in the Manurewa area.

The natural period of the ground as determined from the microtremor data shows considerable variation over the area. One use of this dataset is to identify vulnerable structures that have a similar period to the underlying ground. We have also used the period and the thickness of soft material to estimate an average shear wave velocity. Knowledge of the shear wave velocity may make it eventually possible to better determine relative amplification at any site.

A SEQUENCE STRATIGRAPHIC MODEL FOR SIXTH ORDER (41 K.Y.) CYCLOTHEMS IN THE MANGAPANIAN AND NUKUMARUAN SUCCESSION OF WANGANUI BASIN

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A new model sequence is presented that illustrates the geometry and distribution across the contemporary shelf of facies within typical mid-late Pliocene Wanganui Basin cyclothems. The model is based on three sequences of Mangapanian and Nukumaruan age, which have been mapped and described across the basin from outcrop sections. These reference sequences include the Mangapani Shell Conglomerate, Wilkies Shellbed and Hautawa Shellbed (Kuranui Limestone). Collections of fossil molluscs from these shellbeds reveal cross-shelf paleoecologic and paleobathymetric trends, all of which indicate accumulation on the eastern flank of the Patea-Tongaporutu High. Particular attention is focused on the microstratigraphy of shellbeds, which reveal both lateral and vertical facies variations. Correlation of carbonate facies and their bounding contact surfaces allow classification of shellbeds into distinctive *onlap* and *backlap* parts. Onlap shellbeds result from winnowing of sediment from shoreface wave-action. They occur above an erosive sequence boundary, and mark a paleoshoreline. The landward migration of the paleoshoreline during transgression means that when present, the onlap shellbed will occur as a thin (< 1 m) layer of reworked and disarticulated shell material at the base of a sequence. An example of an onlap shellbed is the Kuranui Limestone at Okiwa. Backlap shellbeds either conformably overlie the onlap shellbed, or mark the base of a sequence when the sequence boundary is a conformable contact. Backlap shellbeds accumulate in inner-mid shelf conditions, on a sediment-starved shelf. Distinctive characteristics of backlap shellbeds are the occurrence of well-preserved, *in situ* epifaunal molluscs, usually within a siltstone matrix, often overlying an onlap shellbed. Above the shellbed/s, the associated siltstone and sandstone members within a sequence also exhibit consistent cross-shelf lateral facies distribution, with sandstone normally occurring above the onlap shellbed when no backlap shellbed is present. Siltstone occurs above backlap shellbeds. Where present, sandstone members mark the top of the sequence, and extend basinward to about the same vicinity as the basinward extent of the backlap shellbed. Siltstone members pinch out landward, to about the same position as the shallowest extent of the backlap shellbed.

Thus, the constituent members of a sequence are distributed in a predictable manner across the shelf, and the stratigraphic architecture of a sequence is genetically related to its paleoshelf position. Comparison of stratigraphic columns of other sequences within the Mangapanian succession to the model cyclothem give an indication of where they accumulated on their respective paleoshelves. This obviates the necessity for exhaustive molluscan paleoecology and paleobathymetry to determine the positioning of a sequence on a paleoshelf.

**ORBITALLY-INFLUENCED TERRESTRIAL PALYNOFORM RECORD IN
PLEISTOCENE DEEP-SEA SEDIMENTS (ODP SITE 1123) , OFFSHORE EASTERN
NEW ZEALAND**

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Pollen analysis of Pleistocene deep-sea sediment from ODP Site 1123 (Leg 181), located 1100 km offshore from eastern New Zealand and in a water depth of 3300 m, reveals marked variations in warm (*Cyathea* + *Prumnopitys/Podocarpus* + *Dacrydium cupressinum*) and cold (*Nothofagus fusca* + *Phyllocladus* + *Halocarpus* + *Coprosma*) climate indicator taxa at Milankovitch-scale periodicities. Near-synchronicity between Northern Hemisphere glaciations and New Zealand terrestrial climate is indicated by the close correlation between SPECMAP-derived ages for glacial terminations and peaks in the warm/cool pollen ratio and tree fern (*Cyathea* spores) abundance. Time series analysis indicates that the vegetation record is covariant with local marine climate indicators and is strongly coherent at the 41- and 100-kyr orbital frequency bands. A gradual change from more mesothermal taxa (*Brassospora*), in the Pliocene and early Pleistocene, to less mesothermal (*Fuscospora* and podocarp conifers) taxa in the middle and late Pleistocene reflect a general decrease in humidity and cloud cover over time

In deep sea sediments, uncertainty surrounds the degree to which variation in palynomorph abundance is a real reflection of changes in vegetation on land or is an artefact of changes in the marine environment which may affect transport and sorting processes. Despite long distance from land and significant water depth, terrestrial palynomorphs are relatively abundant at Site 1123. Overall, the assemblage indicates a North Island podocarp/hardwood forest source which, coupled with lack of an obvious South Island signature, implies that westerly winds and the east-flowing East Cape Current (ECC) are the primary source of palynomorphs at this site. It is possible that increases in the dominant warm climate indicators (robust *Cyathea* spores and bisaccate pollen from *Prumnopitys* and *Podocarpus*) are concentrated by increased winnowing during intensification of the ECC in interglacials. A plot of the cold climate indicators listed above, with relative abundance recalculated to exclude bisaccates, reveals a much weaker correlation with glacial cycles. This suggests that ocean currents and winds may be more important than terrestrial climate in modulating the terrestrial palynomorph record in the open ocean.

UNDERSTANDING ACID MINE DRAINAGE

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Acid mine drainage (AMD) from old as well as current extraction activities exists throughout New Zealand. Understanding the physical and geochemical processes of AMD facilitates sensible remediation. Indeed, a full comprehension of these processes allows pre-mining risks to be adequately assessed and post-mining liabilities to be minimised.

In an effort to develop a methodology of AMD assessment and a protocol for remediation, the closed underground Sullivan Mine (Denniston Plateau, West Coast) is being investigated. A multidisciplinary approach is being taken, utilising:

Source Analysis

(Geological mapping, geochemical and water analyses, and GIS integration)

Risk Analysis

(Ecological risk assessment, ie. stream invertebrate studies)

Remedial Action Plan

(Evaluation of remedial options based on results of source and risk analyses)

Currently acid waters are being discharged from the Sullivan Mine's western two portals into Rapid Creek. Upstream of these portals pH is approximately 4.5, which is also the natural background of other unaffected streams in the area. However, pH at the discharge source is 2.8 and even 5km downstream from the source pH is still approximately 3.5. Most biota are absent from the stream compared to other unaffected waterways. In addition, throughout Rapid Creek, iron precipitate has formed as a coating on practically all rock surfaces.

Although it is clear that the Sullivan Mine is the source of the acidic discharge, it is not clear which strata are generating the acidity. Moreover, geochemical constraints and factors affecting changes in acid generation over time are unknown. Therefore, a geological-geochemical model is being prepared which will identify distinct and mappable rock units, their geochemical signature and acid generating capabilities, their intersection with faults and groundwater, and their position in relation to the mine cavity. In this way, a three-dimensional risk model can be generated to identify source of acidity and change in acidity over time. The outcome of this model will facilitate and direct the most effective and cost beneficial remediation plan. In addition, the protocol can be used prior to mining in other places to minimise post-mining acid generation.

ACCUMULATION OF MERCURY IN PLANTS GROWN ON HG-TREATED MINE TAILINGS

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Considered a potent systemic toxic agent, mercury has been shown to affect not only the neurological tissues of humans but also other systems such as kidney, liver, and developing fetuses (Chang, 1979). In spite of this, mercury is still used in artisanal gold mining in Latin American, South East Asia and Africa countries, where gold is extracted through amalgamation in a very effective, simple and cheap process that culminates with Hg emissions to the environment in the order of hundreds of tonnes/year. Such discharges rates have resulted in Hg-contaminated sites in mining areas spread around the world. In the Amazon Region (Brazil), for instance, the problem is aggravated by the fact that people in some locations are occupying and building houses in former open pits and as well as on top of Hg-contaminated tailings (Hinton, unpublished report).

Different remedial procedures (dredging procedures, liming, re-suspension of sediments) have been proposed both to amend the Hg contamination and to minimize Hg bioaccumulation, but the cost has become a major impediment for application of these methods in developing countries (Veiga, 1997). Phytoextraction, that involves the accumulation of heavy metal contaminants in plants tissues, however, may be a viable solution to the Hg pollution problem. In such operations, heavy metals have been shown to accumulate in the above-ground foliage of hyperaccumulator species, facilitating their removal from a contaminated site upon harvesting. A recent advance in this technology is related to the fact that plant species can be induced to take up soluble metal complexes from soil solutions upon addition of suitable solubilizing agents to the soil. Induced accumulation of gold in plants has been shown to occur when ammonium thiocyanate is added to the soil (Anderson et al., 1999), but little is known about the potential for inducing mercury accumulation in plants from Hg-contaminated soils.

This poster presents results from a greenhouse experiment that investigated the effects of plants species (*Atriplex canescens* and *Berkheya coddii*) and soil Hg concentrations on the uptake of a soluble form of Hg. These are the preliminary results from a research that is investigating the geochemical aspects of Hg bioavailability with the purpose of developing a plant-based remediation system to counteract Hg pollution in contaminated sites around the world.

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TERRANES AND BATHOLITHS: THE 4D BUILDING BLOCKS OF NEW ZEALAND

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It is 25 years since the publication of the seminal paper on the Dun Mountain Ophiolite Belt and New Zealand terranes by Coombs *et al.* (1976). What progress has been made in understanding the nature and origin of New Zealand's Cambrian to Early Cretaceous rocks since then? This question can be answered in two parts: how the rocks are described (their nature) and how they are interpreted (their origin).

DESCRIPTION. Most of the terrane names used by Coombs *et al.* (1976) are still in use today. GNS's QMAP programme is currently providing us with our most detailed view, and consistent national classification, of basement rock units. Many units have demonstrable offshore correlatives. New Zealand basement igneous, sedimentary and metamorphic rocks can currently be described in terms of four batholiths, at least 10 terranes, and areas of at least three regional metamorphic-tectonic overprints. This simple yet powerful classification provides a conceptually useful framework within which resource, environmental and hazard-related aspects of New Zealand geology can be analysed.

INTERPRETATION. In 1970s publications on New Zealand regional geology, Gondwanaland is barely mentioned. Nowadays, almost all papers discuss NZ in a Gondwanaland context, although only small areas of autochthonous Gondwana sequences have been found in the South Island. Considerable effort continues to be expended on understanding just how far-travelled are the various terranes and batholiths, when they were mutually amalgamated and accreted to Gondwanaland and when they were exhumed. A consensus of opinion on New Zealand paleogeography, even in the Early Cretaceous time interval, remains elusive.

Description and interpretation are not mutually separate activities. Each influences the approach of the other and, in the last 25 years, both have been affected by available technology (e.g. PCs, GIS, databases, geochronology). Our increasingly sophisticated view of the New Zealand basement owes much to the efforts of previous generations of geologists, and to fruitful recent and ongoing collaboration with overseas geologists and their analytical facilities.

**THERMAL ISOLATION OF CAMPBELL PLATEAU, NEW ZEALAND:
PERMANENT CONSTRICTION OF THE ANTARCTIC CIRCUMPOLAR CURRENT
OVER THE PAST 130 KA**

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Campbell Plateau, off southern New Zealand, occupies a key position in the Southwest Pacific sector of the Southern Ocean. The flanks of Campbell Plateau have constricted the Antarctic Circumpolar Current (ACC) for at least the last 130 ka. As a result flow is intensified, disrupted into large eddies and diverted northwards as far as $\sim 50^{\circ}\text{S}$. The role of the ACC in affecting water masses and circulation patterns during paleoclimatic fluctuations has been the subject of much debate. It is proposed that the northern boundary of the ACC, the Subantarctic Front (SAF) remained bathymetrically locked to the edge of Campbell Plateau, which raises the question - Would a "locked" ACC affect the water masses over Campbell Plateau by, perhaps, thermally isolating the plateau interior?

New sediment cores from Campbell Plateau provide a record of watermass stratification during glacial and interglacial periods. Oxygen and carbon isotope records, based on *Globigerina bulloides* and *Globorotalia inflata*, enable the reconstruction of temperature and carbon isotope composition within the surficial waters. During glacial climates constriction and intensification of the SAF/ACC circulation resulted in waters about the Plateau flanks being deeply mixed and $\sim 2^{\circ}\text{C}$ cooler. However, waters of the plateau interior retained a stratified nature and were isolated from the cold southern waters as a result of the vigorous ACC.

The western plateau cooled markedly ($\sim 3^{\circ}\text{C}$) during the last glaciation as a result of reduced entrainment of Tasman Sea waters and intensification of the SAF. At this time marked cooling on the southern flank of Chatham Rise is potentially influenced by increased entrainment of cool Polar waters through Pukaki Saddle into the Bounty Gyre. The ACC was retained on the flanks of Campbell Plateau during the last interglacial with warmer ($\sim 1^{\circ}\text{C}$) stratified waters on the plateau interior supporting phytoplankton blooms while Bounty Plateau was influenced by waters sourced from the Subtropical Front region. Thus, temporal and spatial changes in watermass structure and circulation during the changing climate of the past 130ka are defined over Campbell Plateau and the attendant SAF/ACC system. Hence, providing a new perspective of paleocirculation southeast of New Zealand.

STRONTIUM ISOTOPE DATING OF THE NEW ZEALAND OLIGOCENE: SOME PRELIMINARY RESULTS

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Interpretation of Earth history from the sedimentary rock record is necessarily dependent on having good age control. One of the least well resolved portions of the New Zealand Cenozoic time scale is that centred on and about the Oligocene period, internationally regarded as spanning an interval of c. 10 m.y. from 33.5 to 23.8 Ma. This is mainly because the New Zealand Oligocene currently includes only two biostratigraphic stages (a long Whaingaroan [Lwh] and a short Duntroonian [Ld]), while historically a third biostage (Waitakian [Lw]) has fluctuated from being entirely within, to partly within, to wholly younger than, the Oligocene.

The Oligocene heralds remarkable development of widespread nontropical limestone formation throughout New Zealand, along with several global paleoclimatic and paleoceanographic changes associated with rapid buildup of ice sheets on Antarctica and transition into an icehouse world. A prompt for this strontium isotope study was to refine the absolute chronology of the local mid-Tertiary biostages to allow better age control of paleoenvironmental events recorded within New Zealand Oligocene sections, and to assist with regional and global correlations.

$^{87}\text{Sr}/^{86}\text{Sr}$ values were obtained for 77 brachiopod, pecten, and oyster fossil shells, all stable low-Mg calcite secretors, from several mid-Tertiary sections of highly calcareous mudstones, sandstones, and limestones in the South Auckland and North Otago regions. Ages were derived from look-up tables provided by Howarth and McArthur (1997; *Journal of Geology* 105: 441-456). The site specific stratigraphic implications of our new ages remain to be assessed. Some preliminary broader age implications for the New Zealand Oligocene biostages are as follows:

1. The new Sr ages suggest the following approximate stage boundary ages: Ar/Lwh = 35.0 Ma; early Lwh/late Lwh = 31.0 Ma; Lwh/Ld = 28.5 Ma; Ld/Lw = 26.0 Ma; Lw/Po = 22.0 Ma. These values appear to be about 0.5-3 m. y. older than certain formerly assigned ages, and the duration of the stages differs considerably (Lwh = 6.5 m.y.; Ld = 2.5 m.y.; Lw = 4 m.y.).
2. The early Lwh Stage, traditionally held to be entirely within the Oligocene, may extend back across the Eo-Oligocene boundary at 33.5 Ma into the Late Eocene by up to 1.5 m.y.
3. The Lw Stage, formerly included entirely in the Early Miocene, starts in the Oligocene (in agreement with Graham et al. [2000] *NZJGG* 43: 335-347), so that the Oligocene-Miocene boundary (23.8 Ma) lies about mid-way within the Lw Stage.
4. The Lwh/Ld boundary approximates the international Early-Late Oligocene one (28.5 Ma).
5. The Haq et al. (1987) suggested sea-level fall of ~100 m in the mid-Oligocene (c. ±29 Ma) should be developed in deposits of late Lwh or near Lwh/Ld boundary age in New Zealand.
6. From recent Oligocene stable isotope records (Kominz & Pekar [2001] *BGSA* in press), one could anticipate ^{18}O maxima as follows: 3 in early Lwh; 2 in late Lwh; 1 in Ld; and 3 in Lw.
7. The main period of widespread shelf limestone formation in New Zealand occurred from c. 28-22 Ma, spanning latest Oligocene – earliest Miocene time.

REREWHAKAAITU TEPHRA – A LAND-SEA MARKER FOR THE LAST TERMINATION IN NEW ZEALAND, WITH IMPLICATIONS FOR GLOBAL CLIMATE CHANGE

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The Rerewhakaaitu Tephra, erupted from Okataina Volcanic Centre, North Island, New Zealand, at $14,700 \pm 90$ ^{14}C yr BP (ca. 17,600 cal. yr BP), was deposited at a time of rapid re-organisation of Earth's climate system at the end of the last glacial maximum (Termination I). It provides a distinctive isochron in a range of different environments in North Island and in adjacent Pacific Ocean sediments. Terrestrial evidence, based on fluvial aggradation and downcutting relationships, loess accumulation rates, palaeovegetation patterns, and buried soil development and mineralogy, shows that marked amelioration of climate occurred shortly before the Rerewhakaaitu Tephra was deposited. Similarly, marine evidence from around this time shows major changes in accumulation rates of sediment and aeolian quartz and in the abundance of various marine organisms, while foraminiferal oxygen and carbon isotope records show that the arrival of the glacial meltwater signal occurred close to or just after the deposition of the Rerewhakaaitu Tephra.

These changes are discussed in relation to controls on climate by oceanic and atmospheric mechanisms. The re-organisation of climate commencing at ca. 15,000–14,500 ^{14}C yr BP (ca. 18,000–17,400 cal. yr BP) is detected elsewhere in the Southern Hemisphere and evidently was linked to orbitally-forced Oldest Dryas warming which is thought to have initiated ice retreat in both hemispheres. Southern Hemisphere records of subsequent changes show variable coherence with Northern Hemisphere records, which may reflect current inadequacies in these records or, alternatively, a complicated pattern of response to insolation forcing and ice, oceanic, and atmospheric processes.

**MOVING VIEWS FROM A SHIFTING OUTCROP 1950-1985:
ANOTHER CHAPTER IN THE HISTORY OF THOUGHT ABOUT
THE NEW ZEALAND GREYWACKES**

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Between 1950 and 1985, the way in which geologists visualised the Late Paleozoic and Mesozoic paleogeography of the New Zealand region underwent a radical change. This was driven by the plate tectonic revolution in which their understanding of the behaviour of the earth's crust was transformed.

In 1950, the Late Paleozoic and Mesozoic rocks belonging to what later became known as the Torlesse and Waipapa terranes, their daughter terranes, the Caples terrane, and the Murihiku terrane were arranged into a single 'layer cake' stratigraphic column with the Otago schists seen as by far the oldest rocks. Great difficulty was experienced in relating the dissimilar but coeval facies characteristic of the 'Hokonui System' (Murihiku terrane) and the New Zealand greywackes (Torlesse and Waipapa terranes).

The introduction and elaboration of the quickly accepted and very successful Late Paleozoic-Mesozoic New Zealand Geosyncline model (1952, 1956) permitted explanations of the contrasting petrographies and paleontological styles between the Hokonui System and the New Zealand Greywackes, and the presence of turbidites and 'ophiolites', diagenesis and metamorphism.

The geosynclinal model could not explain the characteristic deformational styles of 'eugeosynclinal greywackes, nor could it account for a transcurrent Alpine Fault or how a theoretical structure such as a geosyncline could be formed and later everted during postulated mountain building episodes.

During the late 1960s and early 1970s many New Zealand geologists began re-interpreting the character and distribution of New Zealand rocks, including the Late Paleozoic and Mesozoic greywackes, in terms of the fast-developing network of hypotheses that underpinned the new theory of plate tectonics. However, acceptance of the new theory was uneven, sometimes controversial, and the well-established old geosynclinal model and its associated terminology (e.g. marginal facies) continued to be used until after 1980. Nevertheless, the old New Zealand Geosyncline continued to be modified by the addition of an oceanic trench, an active subduction zone and an accretionary prism until it was transformed into a mobile Mesozoic plate boundary.

The unifying and integrating effect of the theory of plate tectonics brought the previously separate geological specialties together, permitting geologists to offer a range of novel, credible, and sometimes competing explanations of problems to do with the New Zealand Greywackes especially those concerning their structure and the unexpected relationship between the characteristic deep-water turbidites, pillow lavas and red cherts.

FAULT GROWTH BY REPEATED EARTHQUAKES

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Deformation in the earth's upper crust is most often accommodated by faults which grow during repeated earthquakes. In circumstances where faults remain active for millions of years they can accommodate 100's or 1000's of earthquakes. Exactly how displacements during individual earthquakes, or earthquake cycles, sum to produce the patterns of faulting we see today is the subject of much debate. Examination of faults from the geological record reveals that in general longer faults have greater displacements than shorter faults, from which it has been inferred that they increase in length as they accumulate displacement (e.g., Walsh & Watterson 1988, Cowie & Scholtz 1992). Accordingly, structures that are now 10's or 100's of kilometres long (e.g. Alpine Fault or Wellington Fault) were once much shorter and had considerably less displacement. If slip during earthquakes scales proportionally with fault length, as is the case for historical earthquakes (e.g. Wells & Coppersmith 1994), then the favoured growth model requires that the size of earthquakes on a fault increases as it grows. To test this basic model we have charted the evolution of active normal fault systems in New Zealand and the Timor Sea.

The results are preliminary and somewhat surprising in that they indicate a significant departure from the accepted model of fault growth. The present data sets suggest that some faults initially increase rapidly in length and reach their final lengths at an early stage of their movement history. Subsequent fault growth is mainly achieved by increases in total displacement. The early rapid increase in fault lengths appears to have arisen because the fault systems studied were reactivated and inherited their lengths from underlying Mesozoic structures. Near-constant lengths during subsequent growth are attributed to intersections and interactions between faults, which retarded, or stopped, lateral propagation of their tips.

These results have significant implications for the general stability of earthquakes through time. For example, our data suggests that the maximum size of earthquakes on a fault (i.e. earthquakes that rupture the entire fault surface) may be fixed from an early stage in its movement history. Therefore, the largest earthquakes on these faults may be characteristic, with general patterns of displacement which are similar from one earthquake to the next, rather than progressively increasing in size through time.

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BIOGEOCHEMICAL COUPLING BETWEEN SURFACE AND DEEP OCEAN PROCESSES

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Atmospheric carbon dioxide is absorbed by the ocean via physical processes or is fixed from the atmosphere by processes of photosynthesis by marine plants (phytoplankton) and calcification by oceanic organisms. Organic matter, composed primarily of carbon, nitrogen, phosphorus and silica, is, therefore, produced in surface waters of the ocean and is transferred to the deep ocean by these physical and biological pumps, either as solid particles or as dissolved constituents of seawater via passive (sinking/diffusion) or active transport (using animals as mediators/vertical mixing). The chemical composition of this organic matter is modified by interactions within the biological food web, principally in the upper ocean, but also as the organic matter sinks into the ocean interior where the organic constituents are remineralised and transformed. The organic matter descends to the seafloor, where it is the principal source of food and energy for deep ocean benthic organisms. Organic matter may ultimately be incorporated and buried in seafloor sediments, where it will become locked away until the sediments are uplifted, eroded and washed back into the sea or the preserved organic matter is released back into the atmosphere as carbon dioxide during fossil fuel combustion.

The National Institute of Water and Atmospheric Research (NIWA), with collaborators from New Zealand universities and overseas institutions, has been studying the oceanic carbon cycle over the last 8 years. One of the principal components of this research has been several studies designed to determine the factors controlling oceanic biological productivity and degree of coupling between the surface and the deep ocean to the east of New Zealand and in the Southern Ocean. A significant portion of this work has focused on the Chatham Rise, where the circum-global Subtropical Front separates warm, saline, nutrient-poor subtropical surface waters from cold, nutrient-rich, though iron-limited, subantarctic waters. The frontal zone and subtropical waters host relatively enhanced levels of algal biomass and primary production, which contributes substantially to this region being identified as significant biologically mediated regional sink for atmospheric carbon dioxide at least on seasonal time-scales. NIWA has recently installed two biophysical moorings in subtropical and subantarctic waters that will be maintained for the next 5+ years to allow us to ultimately detect the impact of climate shifts on surface production, the export of organic material to the seafloor and hence changes in the strength of the biological pump in these water masses. In addition, instruments to determine the response of benthic biological communities to influxes of organic matter over seasonal time-scales have been deployed recently, in collaboration with the Netherlands Institute for Sea Research. Aspects of these studies will be addressed in the presentation.

EARTHQUAKE RUPTURES ON THE SOUTHERN SECTION OF THE ALPINE FAULT

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Detailed mapping of the Alpine Fault trace between the Haast and Arahata Rivers, together with excavation of five trenches across the fault trace and investigation of a small deep swamp in a rapidly subsiding pull-apart between two fault strands, allow identification of prehistoric earthquake ruptures and place constraints on their timing.

The fault has a relatively straight trace from the Haast to the Turnbull Rivers but multiple traces occur to the south. Horizontal offsets of features are consistent with an average slip of c. 8 m for each of the last two events. Trenches excavated at Haast and Okuru in 1998 provide clear evidence for three ground rupturing events. Total horizontal displacement due to these events is 25 m, also suggesting an average of c. 8 m per event. Radioarbon ages on small seeds within displaced soils exposed in these trenches indicate uplift and stabilisation of the terrace by 1220 ± 50 AD, probably following the first rupture event. The penultimate event can only be bracketed sometime between 1400 and 1600 AD and the last event after 1665 AD. A trench excavated across the trace at the Turnbull River also contains evidence of three events. Dating of wood constrains the first event to post-dating 1105 ± 85 AD. Unfortunately, contamination of organic matter by an unknown source of old carbon prevented further age constraints being obtained on the penultimate and last event.

The South Turnbull swamp lies in a pull apart between two slightly discordant overlapping traces of the Alpine Fault. The swamp is protected from flooding from the Turnbull River by a sand barrier. Subsidence during coseismic displacement on the fault will render it vulnerable to flooding by the river until the barrier is re-established. A sequence of six swamp-wide incursions of river sediment occur since 880 ± 110 AD. Not all of these can be necessarily correlated with seismic rupture, however, as it is also possible for more than one incursion to relate to the same event. Two robust dates can be established: the first is the establishment of the swamp by rapid subsidence at 880 ± 110 AD and the other is a massive incursion of river sand accompanying sudden subsidence immediately prior to 1260 ± 55 AD. This latter date is consistent with the first event recorded in the trenches. After this inundation, three further units of silt occur. The lower two appear to be close in time, occurring sometime soon after 1350 ± 50 AD. The last horizon returned a modern age. The average rate of subsidence of the swamp of 5.9–7.3 mm/yr is consistent with that expected from coseismic fault displacement.

The Alpine Fault in the south appears to have broken on average every 250–300 years. This is consistent with a fault slip rate of 27 mm/yr and an 8 m displacement. Comparison with the rupture chronology established on more northern sections of the Alpine Fault strongly suggests that the fault broke along its whole length at these times. Whether this occurred in a single M8 event or whether by two or more smaller events over a short time period cannot be determined within the time constraints available. An 8 m displacement suggests a rupture length of at least 150–200 km. Nevertheless, the northern and southern records differ in the number of events recognised, suggesting that, at least on occasions, the two fault sections behave independently.

SEDIMENT TRAPS DEPLOYED IN SOUTHERN OCEAN REVEAL SEASONAL TRENDS IN FORAMINIFERAL FLUX

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First time deployments of time-incremental sediment traps in New Zealand's Southern Ocean provided a continuous one-year record of foraminiferal flux from May 1998 to July 1999. Trap locations were: (1) The Campbell Plateau, north of the Subantarctic Front (SAF), where the waters are weakly stratified and quiescent; (2) the eastern Plateau margin, where the waters are well mixed by the intense and eddied flow of the SAF marking the northern boundary of the Antarctic Circumpolar Current.

The composition and timing of microfaunal productivity is distinctly different between these two sites. From early spring to early summer the Subantarctic surface waters over Campbell Plateau supported a seasonal foraminiferal community dominated primarily by *Globorotalia inflata* and to a lesser extent *Globigerina* species. This period of high productivity ceased rapidly for all micro-organisms and remained low for the rest of the year, suggesting a collapse of the ecosystem. Hence, long term sedimentary records on the Plateau may be primarily represented by spring deposition.

The SAF bathed Plateau margins exhibited a slightly later spring flux dominated by *Globorotalia inflata* and to a lesser extent *Globigerinita glutinata* as well as *Globigerina* species. Large numbers of *Globorotalia truncatulinoides* dominated early autumn to mid-winter, while a significant radiolarian flux occurred in summer. The higher flux rate and increased species diversity on the Plateau margin compared to that of the Plateau, suggests that a large proportion of the production on the margin is likely transported in consort with the turbulent waters of the SAF.

These data, together with concomitant ocean observations, will be used to evaluate the seasonal and spatial variability of microfaunal production as a pre-cursor to assess future changes. Known seasonal variations in living assemblages of foraminifera will also help to assess the applicability of annual cycle temperature estimates as well as sea-surface temperature estimates based on fossil assemblages of foraminifera.

CUMULATE ROCKS OF THE LUXMORE COMPLEX: PETROLOGY AND GEOCHEMISTRY

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The Luxmore Complex (LC) is a complicated array of arc-derived ultramafic and mafic cumulate rocks located to the west of Te Anau on the eastern edge of Fiordland, New Zealand. The LC forms part of a belt of ultramafic-mafic cumulate rocks located in Southland that represent the root zone of an island arc active in the Triassic-Jurassic. The cumulate rocks of the LC form an elongate body with a rough concentric zonation from ultramafic rocks (The Ultramafic-mafic Series) to altered gabbroic rocks (The Gabbro Series). The rocks of the Ultramafic-mafic Series are amphibole-bearing, olivine and plagioclase cumulates that are characterised by significant localised heterogeneity at outcrop and microscopic scale. This feature, and the presence of numerous plagioclase cumulate pods, injection layers, sills and veins are best explained by the movement of basaltic magmas through a porous cumulate pile during and subsequent to consolidation. Fine-grained mafic sills consisting of amphibole, plagioclase, pyroxenes, olivine and chrome spinel are interpreted as the products of water-saturated melt moving through the main cumulate body during cooling.

Ultraviolet laser ablation inductively coupled plasma source mass spectrometric (LA-ICP-MS) analyses of the sills reveal trace element patterns similar to Recent SW Pacific island arc basalts. Using published partition coefficients for crystalline phase-magma equilibration, selected LA-ICP-MS analytical data for cumulate phases have been inverted to calculate parent magma compositions. The resultant trace element patterns display the same features as those for the fine-grained sills.

The crystallisation sequence is olivine + chrome-spinel > plagioclase > clinopyroxene > Fe-Ti oxides > orthopyroxene > amphibole. The crystallisation of plagioclase before clinopyroxene in the Luxmore cumulates is unusual in arc cumulates (and contrasts with the Greenhills Complex; Spandler et al., 1999) and is indicative that: 1) the parent magma of the Luxmore cumulates was relatively anhydrous compared with typical arc magmas; or 2) there were marked spatial and temporal variations in H₂O content within the magma reservoir during emplacement. High water content in the later evolution of the magma is indicated by significant amounts of postcumulus amphibole in the cumulates, and amphibole-rich sills intruding the complex. The presence of multi-phase coronas, consisting of orthopyroxene, amphibole and spinel, roughly constrains the depth of emplacement of the Luxmore cumulates to 0.5-0.8 GPa (18-24 km depth).

NEW SEDIMENT PATHWAYS ON THE POVERTY BAY CONTINENTAL SLOPE THAT BYPASS THE MAJOR SUBMARINE CANYON SYSTEM

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The seabed off Poverty Bay is the repository for sediment from the Waipaoa River, New Zealand's fourth largest river in terms of sediment yield (~9 Mt/yr). Post-glacial riverine sediment output has been largely trapped in a mid-shelf subsiding basin, which is boarded along the shelf edge by two growing anticlines, formed by compression along the nearby plate boundary. However, some sediment leaks through a 13 km-wide gap between the anticlines and cascades into a large re-entrant in the slope, heavily incised by the Poverty submarine canyon system. An estimated 20 km³ of sediment has deposited in the mid-shelf basin since 18 ka BP, with an additional 3 km³ of post-glacial detritus forming an apron up to 38 m thick along the shelf edge. Preliminary ²¹⁰Pb mass accumulation profiles indicate that the modern (last 100 years) sedimentation rate of around 1 cm/yr on this outer shelf apron is approximately double that recorded for the mid-shelf basin. Hence, the modern sediment accumulation appears to be inconsistent with the post-glacial sediment thicknesses, that clearly show the largest volume accumulating on the shelf. This might suggest a higher frequency of hyperpycnal flows from the Waipaoa River with the ability to transport sediment seawards, or a change in the storage pattern within Poverty Bay. Accumulation rates on the slope are an order of magnitude less, around 0.1 cm/yr.

The Poverty Canyon was considered to be the dominant offshore pathway for sediment, but recent evidence from cores and multibeam bathymetry suggests it might be inactive today. However, this conclusion is problematic. The mouth and floor of Poverty Canyon are composed of very stiff mudstone (?bedrock), overlain by a drape <40 cm thick of unconsolidated mud. Backscatter and multibeam data show the mouth of the Poverty Canyon has a highly reflective and eroded character, and is devoid of a submarine fan. These features might indicate little or no modern sediment flux down the canyon. Alternatively, sediment is being efficiently flushed through the canyon and removed to the trench. Unconsolidated sediments along the structural trench appear to be turbidites with multiple discrete ash beds. Elsewhere on the slope, seismic, acoustic backscatter, and multibeam data show massive avalanches on the slope and several generations of slumps are clearly visible (see Lewis & Orpin, this volume). Limited seismic evidence suggests there is minimal sediment drape/ponding over this irregular landslide terrain. New turbidity current pathways emanating from the Poverty Bay sedimentary system flow along and around avalanche deposits, cascading downslope and accumulating in a lower-slope basin.

During lowstand, the point of discharge of the ancient Waipaoa River is likely to have been the gap between the anticlines and significant turbidity current activity in one upper slope canyon suggests it could have tapped into the lowstand riverine sediment supply. However, aggradation in the subsiding coastal plain (now the mid-shelf basin) might have occurred.

IMPROVING GEOSCIENCE TEACHING AND LEARNING: FINAL DATA FROM THE *EARTHWORKS* STUDY

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The simulations at the *Earthworks* exhibition featured models of different characteristics, presenting causal and dynamic earth science processes.

Analysis of observations of 118 students and 8 adult visitors to the earth science exhibition *Earthworks*, content analysis of focus group interviews with 47 students and 37 teachers, and analysis of questionnaires conducted with 156 teachers, 26 of which replied in a post-attendance questionnaire, provided a rich source of information about the impact of earth science simulations on teacher and student knowledge of and confidence in earth sciences.

Findings of the investigation showed that students can construct good mental models of complex systems. Students were able to apply their knowledge to new information, based on their experiences with the simulations. In a similar way that pictures assist a person learning to read, the interactive exhibit has a “visual impact” which appears to have a supportive function. Several factors that enhance the ability of a simulation to effectively communicate ideas about earth sciences were identified.

Surveys of participating teachers showed that their confidence in teaching earth sciences correlates with their formal training in this area (Figure 1). Similarly, teacher confidence is correlated with their awareness of the availability of earth science resource material. In a further small scale study 59 % of 93 first year university students reported that they had no prior introduction into earth sciences at their secondary schools by their teachers which supports the findings that earth sciences are only taught by teachers who have a personal interest in this area.

The study showed that the use of physical models (including computer simulations) helps to overcome limiting factors like the process duration or spatial limitations of earth science processes. Such applications can then be linked with the more traditional teaching techniques in earth sciences like going on fieldtrips in order to provide sufficient information.

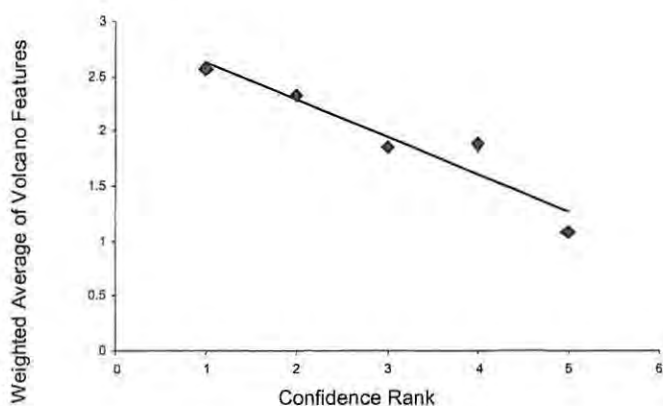


Figure 1: Comparison of weighted average of the number of volcano features with the confidence ranking showing those with confidence also demonstrated better knowledge.

MANAGING OUTBURSTS OF COAL AND GAS IN A NEW MINE, THE MOUNT DAVY EXPERIENCE

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Mount Davy Mine on the West Coast of the South Island of New Zealand, was developed between 1995 and 1999 to exploit high fluidity, low sulphur coking coal.

During the development of access tunnels and the initial pit bottom layout, Mount Davy mine experienced 21 outbursts of coal and gas. Observation of the outburst cavities and geological structures indicated that the outbursts were associated with faulting, folding and bedding plane shear. Sections of the mine workings were developed in intensely faulted ground without experiencing outbursts.

Attempts to manage the outburst problem using pre-drainage of gas and stress relief drilling were not successful. Ultimately, uncertainty with regard to the presence of outburst structures in the deposit and uncertainty concerning the maximum upper size of outburst events led to the project being abandoned.

TOWARDS A REGIONAL LITHOSTRATIGRAPHY OF THE PLIO-PLEISTOCENE ROCKS IN EAST COAST BASIN, NORTH ISLAND, NEW ZEALAND

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The sedimentary rocks of Plio-Pleistocene age in the East Coast Basin (ECB) have been described by numerous geologists since the days of von Hochstetter, McKay, and Hector. They accumulated in a predominantly shallow-marine forearc basin setting inboard of the actively convergent Pacific-Australia plate boundary. Comprising a wide range of siliciclastic, mixed siliciclastic-carbonate, and carbonate facies, involving an equally wide range of textures from mudstone to rudstone, the basin-fill successions are spatially diverse and characterised by often rapid vertical and lateral facies changes. The most prominent lithology, and the focus of attention of several researchers, are the widespread sheets of temperate-latitude skeletal limestones that form conspicuous outcrop ridges in the topography and potential hydrocarbon reservoirs in the subsurface. Because the limestones are laterally discontinuous, sheets of the same age have been given different names in different parts of the basin. An important attempt to clarify what was developing into a confusing lithostratigraphic nomenclature was recently made by Beu (1995; GNS Monograph 10) and again by Field et al. (1997; GNS Monograph 19). However, both presentations continue to use different names for rather similar units in different parts of the basin, and their syntheses failed to present an array of stratigraphic columns in support of their schemes.

The basis of the present work is a stratigraphic, sedimentologic, and diagenetic study of the Plio-Pleistocene temperate limestone and calcareous sandstone sheets in the northern part of the basin. First it was necessary to devise a practical facies scheme that would account for the lithological variation in the area. Then for mapping purposes, and to better understand the origins and interrelationships among facies, it was necessary to place the succession of rock units/facies into a sound lithostratigraphic framework. Having done this for the Plio-Pleistocene units in northern Hawke's Bay, the question arose as to whether or not the scheme, in full or in part, might be more widely applicable to other regions of the ECB.

To develop this theme, the poster shows several measured stratigraphic profiles for the Plio-Pleistocene deposits between Wairoa in the north and Wairarapa in the south. It also attempts to rationalise previously published group, formation, and member names for these stratigraphic sections, and their possible relationships to the northern Hawke's Bay scheme. For example, in the north the rocks of late Miocene (Kapitean) to middle Pliocene (Mangapanian) age generally show no, or weak, signs of a glacio-eustatic sea-level signature, probably because of tectonic masking, whereas rocks of late Pliocene to early Pleistocene (Nukumaruan) age feature much clearer discernment of glacio-eustatic sea-level changes. This dual pattern has led to the differentiation of two major groups (Maungaharuru and Petane), and within these the recognition of several formations and members (see Bland 2001 and Graafhuis 2001, both unpublished MSc theses, University of Waikato), where formation names extend laterally as far as possible, and members correspond to distinctive lithofacies. A comparable first-order dual pattern of rock successions is evident in many other Plio-Pleistocene columns throughout the ECB. Our ideas concerning development of a regional stratigraphic nomenclature are evolving, and far from complete. The approach may prove to have too many shortcomings for it to be practical or desirable. We welcome direction, suggestions, and input from other ECB workers.

MIOCENE–PLIOCENE FAULTING IN WESTERN TARANAKI: IMPLICATIONS FOR THE EVOLUTION OF THE QUATERNARY TARANAKI VOLCANIC SUCCESSION

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The Miocene–Pliocene section underlying the Quaternary Taranaki Volcanic Succession is dissected by southwest-northeast trending normal faults. Many of these faults propagate into the overlying Quaternary sedimentary and volcanic deposits. Three faults – Oaonui, Norfolk and Inglewood – have mapped surface traces. Faults with similar trend are presumed to lie beneath the entire volcanic succession. Structural evidence tends to support the concept that active extensional tectonism facilitated movement of magma to the surface via a dyke system (Locke and Cassidy 1997) that played a major role in edifice construction and subsequent edifice collapse. Volumetrically significant clasts and megaclasts of Miocene and Pliocene marine strata are preserved within the Pleistocene Maitahi Formation, a unit of complexly interstratified debris-avalanche and debris-flow deposits exposed along the Taranaki coastline between New Plymouth to near Okato. These deposits were preferentially directed to the NW from Pouakai Volcano during Castlecliffian time. Intermixing of these Miocene–Pliocene strata with volcanoclastic flank material suggests that the failures that produced the Maitahi Formation were deep-seated. Flank failures likely propagated along or were enhanced by slip along the interface between the Quaternary volcanics and underlying marine strata.

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MID PLEISTOCENE ARID SHIFT IN SOUTHERN AUSTRALIAN TERRESTRIAL SEQUENCES, DATED BY MAGNETOSTRATIGRAPHY, BUT WHAT ABOUT NEW ZEALAND?

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Between 600 and 900 ka, oxygen isotope fluctuations in deep sea cores show a pronounced change in frequency, from a 40 ka (obliquity dominated) to a 100 ka (eccentricity dominated) pattern. At the same time, glacial-interglacial amplitudes increased, with a marked enrichment of glacial $\delta^{18}\text{O}$ values consistent with larger continental based ice-sheets. Terrestrial environmental responses to this major paleoclimatic shift are yet to be fully documented.

In South Australia, in coastal sections near Adelaide, and on Kangaroo Island, the Brunhes/Matuyama (B/M) polarity transition (0.78 Ma) is identified in the strongly oxide-mottled Ochre Cove Formation, which is overlain by calcareous, grey-green aeolian clay (Ngaltinga Clay) and younger calcareous sediments (Christies Beach and Taringa Formations). The marked change from an oxide-dominated weathering regime to a carbonate weathering regime is estimated to have occurred at about 500 to 600 ka, and is interpreted as a major arid shift in regional climates (Pillans & Bourman 2001, *Aust. J. Soil Res.* 39, 89-98). Similar arid shifts are inferred from the Murray Basin in southeastern Australia and Lake Lefroy in southern Western Australia, where changes from lacustrine clays to evaporites and dune sediments are estimated to have occurred between 400 and 700 ka. An increase in aeolian dust input to Tasman Sea sediments also occurs in the last 400 ka.

Long terrestrial sequences extending back to the B/M boundary are apparently lacking in New Zealand, or are they? Loess/paleosol sequences are continuous back to at least 500 ka on Taranaki-Wanganui marine terraces (Pillans & Wright 1990, *Quat. Res.* 33, 178-187). Weathered tephra sequences, with interbedded loess in the western North Island (e.g. Kauroa and Hamilton Ash Formations) extend beyond the B/M boundary, but paleoclimatic interpretations of such strongly weathered sequences are difficult to make. Loess/paleosol sequences in the eastern South Island may offer better prospects, particularly in the Timaru area, where Timaru Basalt (c. 2.6 Ma) is overlain by up to 20 m of loess. New luminescence dating results, coupled with paleomagnetic data, from the Timaru area will be presented and discussed.

LITHOSTRATIGRAPHY AND GENERAL GEOLOGY OF CAMERON GROUP METASEDIMENTS, CENTRAL SOUTHERN FIORDLAND

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Geological mapping in the Heath and Cameron Mountains and the Dark Cloud Range, central Southern Fiordland, New Zealand, discloses the existence of a coherent, areally-extensive succession of metasediments and associated metavolcanics. These rocks are named here **Cameron Group**. This lithostratigraphic unit is bounded to the west by the Dark Cloud Fault, beyond which lies the Edgecumbe Group, which has previously been shown to lithocorrelate with the Haupiri Group of West Nelson. The eastern limit of Cameron Group is the Grebe Fault, east of which are the mostly undeformed intrusive rocks making up the batholith formerly known as the Median Tectonic Zone.

Cameron Group rocks of central Southern Fiordland are unfossiliferous and of high metamorphic grade but structurally are not very complicated. They can be mapped in five units, each of formation status. These are: **Chankly Bore Formation** (structurally uppermost, at least 440 m thick, top lost to erosion); **Long Sound Calc-silicate** (thickness undetermined); **Parakiore Pelite** (450 m); **Sea View Psammite** (450 m); and **Kathryn Metavolcanics** (structurally lowermost, at least 750 m thick, base not exposed). Most of these units can be subdivided into mappable members and beds or flows.

Rock units of probable Cameron Group affinity have been identified outside central Southern Fiordland: a distinctive hyalophane-sillimanite pelite from Long Sound represents Member 2 of the Chankly Bore Formation approximately 15 km south of its type section in the Dark Cloud Range. The largely undifferentiated, mostly gneissose metasediments of central Fiordland are probably Cameron Group correlatives. Metabasic, quartzofeldspathic and pelitic gneiss units of the Fraser Complex, Westland, are probably equivalents of the Kathryn Metavolcanics, Sea View Psammite, and Parakiore Pelite respectively.

All known Cameron Group rocks are of amphibolite facies. Cameron Group pelites from central Southern Fiordland contain sillimanite pseudomorphs after andalusite and underwent mid-Paleozoic metamorphism at approximately 665°C, 3.0 kbar. A higher-pressure overprint is sporadically recognisable in central Southern Fiordland. This younger metamorphic episode probably corresponds to the Early Cretaceous event during which the granulite facies Western Fiordland Orthogneiss of Northern Fiordland underwent recrystallisation at pressures in excess of 12 kbar.

COURSES IN ENGINEERING GEOLOGY AT THE UNIVERSITY OF AUCKLAND – A REVIEW AND SOME RECENT DEVELOPMENTS

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Engineering geology is offered as an elective course for both final year BSc students in Geology and for final year BE students in Civil and Environmental Engineering. This course, Geology 372, has evolved over many years into an interdisciplinary learning experience, which is taken by some 50 students with more or less equal numbers from Geology and Engineering. The course is designed around case histories, both successes and failures. It is designed to show the contribution of engineering geology to geotechnical engineering projects in a range of diverse geologic and geomorphic settings with emphasis being placed upon weak rock and volcanic terrain of the North Island.

The in-course assignments provide “hands-on” site experience in geotechnical logging and rock mass characterisation with engineering applications. Students are encouraged to work as interdisciplinary teams on realistic engineering problems and using methods and guidelines, which match those in the modern professional situation. Aerial photo interpretation, map and literature research and initial feasibility studies are built into the assignments. There is an emphasis on problem identification and the development of engineering geological models.

A new course, Geology 701 “Engineering Geological Mapping” follows on at graduate level and is also an elective taken by students from both departments and by practising geotechnical professionals. Entirely field-based, this course is an intensive 9 day experience in geotechnical mapping at a range of scales and in a variety of situations in the Auckland region. The course takes students through the stages of development of engineering geological models from their own field data, with the aim of identifying and assessing geologic hazards, foundation conditions and slope failures. As part of this process the course has contributed some new data and different interpretations of geomorphic development, landslides, faulting and hazard assessment at a number of localities in the Auckland region.

Both of these courses form part of a larger offering for diplomas and degrees in Applied Geology and Geotechnical Engineering.

GEOLOGY OF THE SOUTH EASTERN FLANK OF RUAPEHU VOLCANO: A GIS APPROACH

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The objective of this project is to map and interpret the Wahianoa Formation geology of the planeze located between the Wahianoa and Whangaehu Rivers on Mt Ruapehu using a Geographic Information System to interpret the spatial data in two and three dimensions. This area lies between 1300m and 2100m elevation. The stratigraphic units were identified through field observations and the distribution of each unit was then mapped using aerial ortho photos, topographic maps and a GPS receiver.

The stratal sequence of the area is typical of the effusive and explosive activity that has taken place at Ruapehu Volcano over Quaternary time. The area is dominated by blocky, andesitic lava flows and associated volcanoclastic breccias. Pyroclastic deposits identified as of both block and ash flow and tephra origin can be found but are confined to small areas; lower in the stratigraphic sequence pumiceous diamictons are also present. These mantle the topography and form valley fills.

A geological map was created using ArcView by digitising the extent of each unit based on field observations and converting the units to individual themes or layers. At the same time a GIS was created, containing a database with fields of relevant information about each unit.

A digital terrain model was created using aerial photograph stereo images. They were projected using Image Station Stereo Display and a digital terrain model was created using Microstation and MGE terrain analyst. This data was then used in E.R. Mapper to create a 5m gridded digital terrain model (DTM). The field data is then incorporated and individual geological units extracted and displayed in 3D.

The use of the DTM, the geological map and 3D models of the individual geological units provides a detailed, visual model about the spatial relationships of the volcanoclastic units and their related topography. The data may also provide information about flow behaviour in relation to topography that could be used to better understand volcanic hazards at Ruapehu Volcano.

QMAP - THE NEW 1:250 000 GEOLOGY MAP OF NEW ZEALAND “HALF WAY THERE”

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The QMAP 1:250 000 Geological Map of New Zealand updates and replaces the original “4-mile” map series completed in the late 1960s. QMAP comprises a series of 21 map sheets covering New Zealand and incorporates the wealth of geological data and new understanding that has accumulated since then. The new maps are produced via a Geographic Information System (GIS), which will by the end of the project hold a seamless digital geological database for the whole country. Each full colour, lithoprinted map is accompanied by an illustrated A4 format text summarising the geology, tectonic development and geological resources of each region, and discussing aspects of engineering geology and potential geological hazards.

Since the programme began in 1994, seven maps have been published, one is in press and two are close to publication:

Published:	Dunedin	In press:	Waitaki
	Kaitaia		
	Nelson		
	Wellington	<u>Publish in 2002:</u>	Greymouth
	Wakatipu		Wairarapa
	Raukumara		
	Auckland		

Compilation is well advanced on a further four map sheets (Waikato, Kaikoura, Aoraki and Murihiku), and work will start on Rotorua and Fiordland in 2002. Digital coverage now exceeds 50% of the country and additional areas have been compiled on 1:50 000 base sheets in preparation for digital capture. The QMAP series will be completed in 2009 with publication of the challenging Fiordland sheet (provided funding is maintained).

Map compilation has drawn on a wide range of existing published and unpublished data held by GNS, other CRIs, universities and exploration companies. The co-operation of university geology and earth science departments in particular has been critical to QMAP success and is gratefully acknowledged. A considerable amount of new field mapping and air photo interpretation has also been undertaken by the QMAP team, to give a reasonably consistent level of detail across sheets.

The digital data are stored and organised using ArcInfo GIS software. The database consists of a number of themes or layers such as geological map units and boundaries, faults, folds, structural data and data sources. Each layer is linked to a range of attribute tables which contain detailed information on features within the layer. Data layers can be queried, singly or in combination, to provide made-to-order maps. For instance, the database can be used to produce maps showing all Cenozoic limestones, or all Paleozoic strike-slip faults with over 1 km of offset. As each map sheet is published, the digital data are archived and are available for use by universities and other users under licence. QMAP data will soon be available via the GNS web site and it is planned to make the printed maps available on CD-ROM.

QUATERNARY GEOLOGY AND LANDFORM DEVELOPMENT OF COASTAL BAY OF PLENTY, NORTH ISLAND, NEW ZEALAND

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The Quaternary deposits of the coastal Bay of Plenty represent the product of a dynamic system involving volcanic, geomorphic, and tectonic processes. Geological mapping and stratigraphic studies were undertaken within an area of ~250 km² along the central Bay of Plenty coastline. The field area extends from Matata in the west to Pukehina Beach in the east, and inland ~10 km from Pongakawa to Manawahe. The study, part of a wider research project being undertaken in collaboration with Environment Bay of Plenty, aims to document the stratigraphy and geomorphology, produce a 1 : 25 000 geological map, and to interpret the development of landforms in the study area.

Much of the study area is underlain by several extensive rhyolitic ignimbrite sheets that originated in the Okataina Volcanic Centre, including Matahina Ignimbrite (*c.* 0.28 Ma) and Rotoiti Ignimbrite (*c.* 55 cal. ka). Overlying these units are thick pyroclastic deposits of the Mangaone Subgroup (*c.* 43–31 cal. ka), Aokautere Ash (*c.* 26.5 cal. ka) and tephric loess of Marine Oxygen Isotope Stage (MOIS) 2, and pyroclastic deposits (tephras) of the Rotorua Subgroup (<*c.* 26.5 cal. ka). Many of the deposits commonly support buried soils (paleosols).

Geomorphic development is expressed by a series of terraces, defined by their distinct geology. Terrace development is controlled by several factors relating to lithology, tectonics and climate change. Subsidence in the central and western Bay of Plenty began in the early Quaternary, and was accentuated during the mid-late Quaternary when subsiding areas were rapidly infilled with both primary volcanic materials and extensive volcanoclastic deposits (debris flows, fluvial sands and conglomerates). Tectonic movement is still evident with subsidence occurring in the west and uplift to the east. Nairn and Beanland (1989) calculated uplift rates of ~1 mm/yr at Matata. Uplift along the Matata Fault has resulted in exposure of greywacke gravels that were deposited during MOIS 16 (Manning, 1996). Overlying these gravels are marine and estuarine sands intercalated with tephras estimated at approximately 0.7–0.6 Ma. The Matahina Ignimbrite caps these deposits. After the Rotoiti eruptive episode (*c.* 55 cal. ka), a new phase of increased volcanic activity in the Okataina Volcanic Centre began, and resulted in the deposition of thick, nonwelded Mangaone Subgroup plinian fall and ignimbrite units across the field area. Stratigraphic relationships indicate that several major episodes of erosion occurred, most notably after the deposition of the Rotoiti eruptives, and also during MOIS 2 after deposition of the Mangaone Subgroup, resulting in localised valley infilling and the formation of thick, reworked volcanoclastic units.

Manning, D.A. 1996. Middle-Late Pleistocene tephrostratigraphy of the eastern Bay of Plenty region, New Zealand. *Quaternary International*, Vol. 34 – 36: 3 – 12.

Nairn, I.A. and Beanland, S. 1989. Geological setting of the 1987 Edgecumbe earthquake, New Zealand. *New Zealand Journal of Geology and Geophysics*. Vol. 32: 1 – 13.

MODELLING REGIONAL LANDSLIDE SUSCEPTIBILITY USING GIS

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Reliable assessment of landslide susceptibility requires knowledge of a number of factors including slope angle, rock strength, rock defect intensity and orientation, groundwater conditions, and extent of vegetation. The interactions between these factors is very complex, and the relative contribution of individual factors to landslide susceptibility varies. For many of these factors little data are available on a national or regional scale, but two of the more significant factors, slope and an approximation of rock strength, can be derived from existing national digital datasets.

We have been using Geographic Information Systems (GIS) software to develop a national landslide susceptibility model utilising a digital terrain model (DTM) and digital geological map data. The DTM has been generated from digital 20 metre contours and spot heights supplied by Land Information New Zealand. A slope model is straightforward derivative of a DTM using GIS.

Two methods have been employed for incorporating digital geological map data as a proxy for rock strength. The first method is knowledge-driven in the sense that each geological rock unit is assigned a qualitative estimate of mean rock strength on the basis of experience and expert knowledge of rock condition and behaviour. The rock strength classes and weighted slope angle classes are then combined to create a preliminary slope-rock strength model. The second method is data-driven in the sense that a slope angle frequency analysis of each geological rock unit is used to determine threshold slope angles for the range of landslide susceptibility classes. For example a 15° slope in a Late Miocene central North Island mudstone-dominated unit is steep compared to the 8° mean for the unit and therefore attains a relatively high landslide susceptibility rating. Compare that to a 15° slope in a South Island Triassic greywacke sandstone-dominated unit which is gentle compared to the 22° mean for the unit and consequently attains a relatively low landslide susceptibility rating.

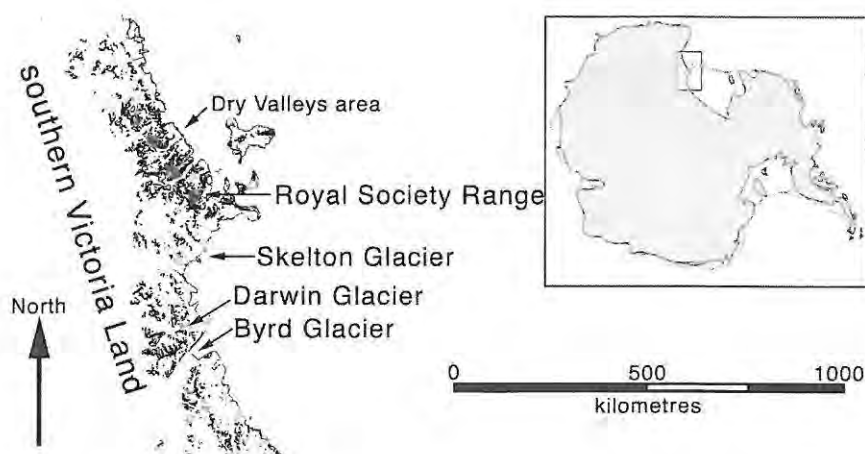
Close proximity to steep ground is also a factor in landslide susceptibility, either through landslide runout (across a valley floor for instance) or through ridge collapse or undercutting (for example at the top of a steep cliff). Using topographic tools available in the GIS software and the digital terrain model we have identified zones at risk of runout or collapse that are adjacent to steep slopes. These zones have been combined with the preliminary slope-rock strength model (from either of the above methods) to produce a national landslide susceptibility model.

The effectiveness of the landslide susceptibility model is limited primarily by the quality of the data available. Significant improvements to the model are expected once higher resolution digital topography and geological map data (for example QMAP) become available. In addition, incorporation of rock defect, groundwater conditions, and vegetation factors will improve the model's resolution. GIS modelling methodologies are also evolving with recent emphasis on artificial intelligence techniques.

HILLARY GRANITOIDS OF THE KOETTLITZ GLACIER ALKALINE PROVINCE, ANTARCTICA

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The Koettlitz Glacier Alkaline Province, Antarctica, is "the area of southern Victoria Land that is dominated by alkaline rather than calc-alkaline igneous rocks" (Read et al., 2001). It extends southwards from the southern end of the Royal Society Range at least as far as the Darwin Glacier area (Simpson, 2001), a distance of approximately 300 kilometres along the Hillary Coast of southern Victoria Land.



In the Royal Society Range area, alkaline igneous plutonic rocks include A-type granite and quartz syenite, nepheline syenite, carbonatite, gabbro and monzodiorite that intrude Late Proterozoic marble and schist of the Skelton Group. In the Skelton Glacier further south, A-type granite and quartz syenite, gabbro and monzodiorite intrude Skelton Group metasediment. In the Darwin Glacier area A-type granite is intruded by calc-alkaline granitoid (Simpson, 2001).

A new name, **Hillary Granitoids**, is proposed to include all A-type granitoids in the Koettlitz Glacier Alkaline Province. Glee Granitoids, Penny Hill Granite, Cocks Granitoids and the Foggy Dog Granite (Simpson, 2001) are members of the **Hillary Granitoids**. Ages of all dated **Hillary Granitoids** lie within the range 551-517 Ma.

Geochemical discrimination diagrams indicate that **the Hillary Granitoids** belong to the A₂ group of A-type granites and the Continental Epeirogenic Uplift Granite group of anorogenic granites. This suggests a period of broad crustal extension coupled with magma generation from 551 to 517 Ma, pre-dating the onset of Ross Orogeny subduction by c. 35 Ma.

Read, S.E., Cooper, A.F., and Walker, N.W., 2001, Geochemistry and U-Pb geochronology of the Neoproterozoic-Cambrian Koettlitz Glacier Alkaline Province, Royal Society Range, Transantarctic Mountains, Antarctica. 8th International Symposium on Antarctica Earth Sciences, The Royal Society of New Zealand Bulletin 35.

Simpson, A.L., 2001, The Foggy Dog Granite Suite, Darwin Glacier region, southern Victoria Land, Antarctica., GSNZ Annual Conference: Hamilton, New Zealand.

ADAKITIC MAGMATISM IN THE KOETTLITZ GLACIER ALKALINE PROVINCE, SOUTHERN VICTORIA LAND, ANTARCTICA

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Field relations, petrology and geochemistry indicate the presence of at least eight adakitic plutons, in the area extending from the southern end of the Royal Society Range to the Darwin Glacier, along the Transantarctic Mountains. The plutons are generally unfoliated, medium to coarse grained and holocrystalline hypidiomorphic. Generalised mineralogy comprises oligoclase, quartz, orthoclase, biotite, \pm hornblende, \pm pyroxene with accessory titanite, zircon, apatite, allanite, ilmenite and magnetite.

	KGAP ¹	Darwin ²	Teall ³	Saddle ⁴	DV1b ⁵	Andean ⁶
SiO ₂	68.04	65.23	71.27	72.43	70.37	64.77
TiO ₂	0.41	0.60	0.22	0.19	0.29	0.57
Al ₂ O ₃	16.41	17.32	15.23	15.26	15.54	17.17
Fe ₂ O ₃ *	2.69	3.23	2.14	1.30	2.18	4.47
MgO	0.93	1.41	0.43	0.41	0.49	2.35
CaO	3.27	4.88	2.14	2.54	2.46	5.33
Na ₂ O	4.30	3.95	3.98	4.07	3.69	4.07
K ₂ O	2.97	2.37	3.63	3.20	4.00	1.52
Cr	7	8	6	2	4	26
Sr	588	775	281	554	548	704
Y	11	17	13	4	10	10
Yb				0.55		1.07
Sr/Y	66	46	127	139	59	95
⁸⁷ Sr/ ⁸⁶ Sr	0.7096		0.7083	0.7110	0.7095	0.7045
¹⁴³ Nd/ ¹⁴⁴ Nd	0.5116		0.5117	0.5114	0.5119	0.5127

1 - Koettlitz Glacier Alkaline Province averages

2 - "Nun 1", Darwin Glacier Region

3 - "TI", Teall Island, Skelton Glacier

4 - "2006", Saddle Granite, Dromedary Glacier

5 - DV1b Suite (Allibone et al., 1993; Cox et al., 2000)

6 - Andean Austral Zone, South America (Stern & Kilian, 1996)

Geochemically the group ranges from quartz monzonite to granite though individual plutons tend to have a restricted range of compositions. Both peraluminous and metaluminous compositions are present. A strong depletion in HREE is coupled with a small positive Eu anomaly. The largest pluton, at Hooper Crags, spans the range from quartz monzonite to granite.

On the Sr/Y vs Y discrimination plot of Drummond & Defant (1990) the adakitic and often very strong adakitic affinities of these granitoids is evident (Sr/Y ratios up to 184). There is considerable variation in the Sr/Y ratios within some plutons.

On the Rb vs Y+Nb plot of Pearce (1984) the granitoids fall exclusively within the Volcanic Arc Granite field. Preliminary interpretations of U-Pb data suggest that several of the plutons crystallised at around 490 Ma.

The adakites that crop out in the Koettlitz Glacier Alkaline Province (KGAP) are similar in age, chemistry and isotopic systematics to the Dry Valleys DV1b suite to the north. However, the KGAP adakites are more primitive, possibly due to earlier crustal attenuation in this province, as indicated by older alkaline magmatism in this area (Read et al. 2001).

Allibone, A.H. et al. 1993. *NZ Journal of Geology and Geophysics* 36: 299-316.

Cox, S.C. et al. 2000. *NZ Journal of Geology and Geophysics* 43: 501-520.

Drummond, M.S.; Defant, M.J. 1990. *Journal of Geophysical Research* 95: 21503-21521.

Pearce, J.A. et al. 1984. *Journal of Petrology* 25 (4): 956-983.

Read, S.E. et al. 2001. 8th ISAES, Royal Society of New Zealand Bulletin, 35.

Stern, C.R.; Kilian, R. 1996. *Contributions to Mineralogy and Petrology* 123: 263-281.

**PLIOCENE TO RECENT DEFORMATION OF THE EAST COAST FOREARC
BASIN REVEALED BY SEISMIC SEQUENCES BENEATH HAWKE BAY,
NEW ZEALAND**

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Pliocene to Recent strata beneath Hawke Bay constitute part of the active forearc accretionary prism in East Coast Basin, North Island. Reflection seismic profiles (part of the New Zealand CQX series, 1988-1991) have been examined to decipher: (1) the seismic stratigraphy of post-Miocene strata; and (2) the record of deformation in these, the youngest deposits of the forearc basin.

Four 3rd-order sequences (SB1 to SB4) are identified that are of regional extent, based on the presence of onlap, downlap, and erosional discordances. The sequences range in age from earliest Pliocene to the most recent sediments. The top of SB1, identified in the offshore Hawke Bay-1 well as top of the Waipipian (earliest Late Pliocene), is the only established time-line in the offshore area; therefore, SB1 spans about 1.5 million years. The duration of the other three sequences is not established, although SB4 is probably Late Pleistocene to Recent. SB1 has a maximum thickness of 1200 m (along profile CQX 90-07), resulting from an average sedimentation rate of about 80 cm/ky.

Stratigraphic and structural associations indicate that deformation was not synchronous across Hawke Bay, and that faulting and folding-uplift may become progressively younger towards the northern part of the region. Faulting as young as Late Pleistocene displaces strata in the northern half of Hawke Bay.

Uplift of Lachlan Ridge probably began late in the Miocene, continuing into the Pliocene. Some differential uplift of Lachlan Ridge is evident during the Waipipian and even later. Lachlan Ridge had positive relief for most of this period, as evidenced by thick, west-prograding clinofolds in sequences SB1, SB2, and SB3.

The onshore occurrence of Pliocene Te Aute limestones has previously been linked to the development of skeletal carbonate factories atop growing antiformal ridges within and/or bounding the wider forearc basin. The seismic identification beneath Hawke Bay of spatially diverse regions involving "linear" growth faults and folding-uplift within the Pliocene successions is consistent with such a model. It also supports an initial tectonic control on the development, location, and geometry of at least some of the Te Aute limestone occurrences.

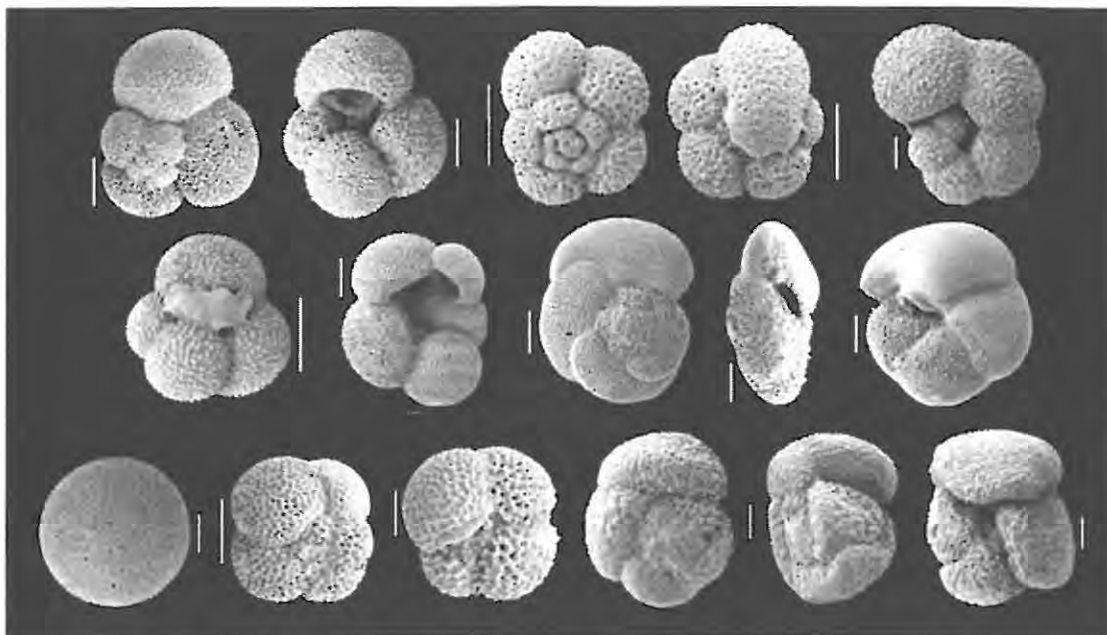
PLIOCENE FORAMINIFERAL BIOSTRATIGRAPHY AND PALEOCEANOGRAPHY OF ODP SITE 1125, EASTERN NEW ZEALAND

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Fourteen planktic foraminiferal datums (bioevents) were recognised in a high resolution study of the Pliocene (4.0-2.39 Ma) in Ocean Drilling Program Site 1125, north side of Chatham Rise. Pliocene sea-surface temperatures for summer and winter were estimated from planktic foraminiferal census data using modern analog technique. A general trend toward warmer climate is indicated up through this interval, with 3 major cold periods (c. 3.38-3.28 Ma, 3.02-2.97 Ma, and 2.84-2.79 Ma) and 2 minor cool periods (c. 2.69 Ma and 2.43 Ma).

Comparison between estimated Pliocene sea-surface temperatures and modern isotherms show that although the modern position of Site 1125 is just north of the Subtropical Front, it experienced temperatures typical of the modern Subantarctic Zone during cold periods in the Pliocene. Comparison between sea-surface temperatures of the Pliocene and Last Glacial Maximum shows that some intervals during the Pliocene were colder than Last Glacial Maximum especially in summer seasons.

All the first appearance datums occurred within the warm periods and many of the last appearance datums occurred during times of cooling. Dextral coiling of *Globorotalia oceanica* is strongly correlated with warmer climate, and sinistral coiling of *Neogloboquadrina pachyderma* is strongly correlated with cooler climate. Generally, cold periods are characterised by lower diversity, lower absolute abundance of planktic foraminifera per gram of sediment and lower carbonate dissolution (may be because of lower productivity).



Pliocene planktic foraminifera from ODP Site 1125

**LATE GLACIAL TO HOLOCENE WARMING IN AUCKLAND
(THE SEARCH FOR THE YOUNGER DRYAS CONTINUES!)**

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Glacier advance in New Zealand is commonly cited as evidence for the global extent and synchronicity of an abrupt climatic cooling in the North Atlantic, the Younger Dryas cooling event, at c. 13,000 to 11,500 cal yr BP. Many palaeoecological records from New Zealand are limited in chronology and resolution, and conflicting climatic results have been presented. We present a pollen record from continuously deposited lake sediments in a maritime setting, constrained by well-dated tephra beds. The gradual establishment of forest with warm taxa provides no evidence for significant climatic reversal or cooling. This pattern is consistent with other Southern Hemisphere pollen records and is typical of the Southern Hemisphere vegetation response during this time.

DISTAL RECORD OF MULTI-SOURCED TEPHRA IN ONEPOTO BASIN, AUCKLAND: IMPLICATIONS FOR VOLCANIC CHRONOLOGY, FREQUENCY AND HAZARDS

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A 61 m long core of paleolake and estuarine sediments was collected from Onepoto basin, North Shore, Auckland. Onepoto basin is a phreatomagmatic basaltic explosion crater that was occupied by a lake following eruption. The crater was breached by rising sea level at the early Holocene and became an enclosed estuary. Twenty-five m finely laminated paleolake sediments (> 9.5 cal ka) contain at least 78 tephra layers representing large plinian and subplinian eruptions from central North Island and local events from the Auckland Volcanic Field (AVF). The distal record comprises 14 events from Okataina Volcanic Centre (OVC), 4 from Taupo Volcanic Centre (TVC), 38 from Taranaki and 2 from Tongariro Volcanic Centre (TgVC). In addition, there are 11 pre-Rotoehu age rhyolitic layers (>50-60 ka) from uncertain source(s) in the Taupo Volcanic Zone (TVZ). Eight events from the local Auckland Volcanic Field (AVF) are identified. Age control is provided by the identification of rhyolitic tephra of known age. Fallout from all rhyolitic eruptive episodes in the OVC during the interval 24 – 9.5 ka are recognised. In addition, several events from the OVC Mangaone Subgroup are identified (Te Mahoe, Hauparu, and ?unit G), greatly extending their known dispersal ranges into northern North Island. Four layers with a heterogeneous low-Si rhyolite composition and chemical affinity to the older Mangaone Subgroup tephra occur, and do not match previously documented events. Tahuna tephra of uncertain source and Rotoehu tephra from OVC constrain the stratigraphy at the base of the Mangaone Subgroup sequence.

Taranaki tephra are trachytic to rhyolitic in composition. Some are compositionally homogeneous, while other display variability in SiO₂ content up 7 wt %. All are high K₂O (>3 wt %), and there are no temporal trends. This contrasts proximal volcanoclastics and lavas from Taranaki where only post-30 ka magmas are high-K₂O varieties.

By combining the Onepoto tephra record with that of the previously documented Pukaki crater in South Auckland, minimum event frequencies can be estimated for macroscopic tephra fall at Auckland during the interval 28 – 9.5 ka for the following volcanoes: OVC (1 per 2200 yrs), TVC (1 per 5800 yrs), Taranaki (1 per 830 yrs), TgVC (1 per 2900 yrs), and AVF (1 per 2900 yrs). The combined Onepoto-Pukaki record includes 15 basaltic fall events at 34.6 ka, 30.9 ka, 29.6 ka, 29.6 ka, 25.7 ka, 25.2 ka, 24.2 ka, 23.8 ka, 19.4 ka, 19.4 ka, 15.8 ka, 14.5 ka, and 3 pre-50 ka events. This provides some of the best age constraints for the AVF. However, chemical heterogeneity of basaltic glass presently prevents correlation to particular vents.

PACIFIC TERRANE MODELS APPLIED TO EUROPEAN GONDWANA

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The Hercynian (Variscan) Orogen of Europe developed in the Carboniferous when the Rheic Ocean closed between Laurentia-Baltica-Avalonia and Gondwana (Africa and South America), forming Pangea. In some plate reconstructions the two continental masses collided more or less orthogonally; in others, Laurentia moved from a Devonian position close to the northwestern edge of present day South America to its position in Pangea by a massive dextral translation along the northern edge of Gondwana.

Gondwanan France and Iberia are characterised by a large number of disparate terranes separated by important dextral shear zones, and there are major problems in explaining the geological relationships by orthogonal collision. For instance, regions characterised by very high pressure (>20kbars) subduction zone metamorphism and associated island arc volcanics are juxtaposed against regions characterised by stable Gondwanan shelf sedimentation of the same age. Other workers have sought to explain these relationships by the opening and closing of oceans, but the paleontological and stratigraphic evidence is incompatible with the development of such oceans.

We have used tectonostratigraphic terrane modelling from the Pacific rim region to explain the geological relationships of Gondwanan France and Iberia. We developed first a general model, and have now progressed to being able to show in much greater detail how the various terranes could have moved into place. We are able to show how an area previously described as an intermontane sinistral pull apart basin should be reinterpreted as a dextral exotic duplex, and the high pressure oceanic terranes are, we suggest, slices of the Rheic Ocean, shuffled in amongst slices of the Gondwanan shelf.

Our modelling provides strong support for those plate reconstructions which have Laurentia on the NW tip of South America in the Devonian, and it shows that the Orogen is better described as having developed in a strike slip plate boundary setting, with some convergence, than as a result of a continental collision.

FLUID INCLUSION EVIDENCE OF NEAR LITHOSTATIC PRESSURE AND ANOMALOUS CO₂ CONCENTRATIONS IN HYDROTHERMAL QUARTZ FROM THE BROADLANDS-OHAAKI GEOTHERMAL FIELD

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The partial pressure of CO₂ in geothermal fluids is controlled by the pressure gradient and the CO₂ source. In many TVZ geothermal fluids, the hydrostatic gradient is a limiting factor. Here, we provide fluid inclusion evidence from a single quartz crystal for the past existence of anomalous CO₂ concentrations requiring a near lithostatic gradient in the Broadlands-Ohaaki geothermal system. Preliminary microthermometric results are available from two generations of fluid inclusions that occur in a doubly polished plate of quartz (3-4 mm diameter) from well 25-1258 m depth.

The earliest generation of inclusions occupies the core of the crystal, where there are more than 100 primary and pseudosecondary inclusions ranging from <10 to 20 μm across. About 95% of these comprise liquid-rich two-phase inclusions, while about 5% comprise vapour-rich inclusions. Their coexistence in the same generation indicates vapour-saturated conditions at the time of trapping. Heating runs in which liquid-rich inclusions homogenise to a liquid phase indicate trapping temperatures that range from 330 to 345° C. During freezing runs, both ice and CO₂ clathrates are observed, with ice-melting temperatures (T_m ice) of -1.9° C and clathrate melting temperatures of 7.1 to 9.8° C (4 inclusions measured). Solid CO₂ appears to have formed during these same cooling runs to -90° C in the vapour-rich inclusions. These data suggest that this ancient geothermal liquid contained about 2 molal CO₂ (~9 wt %), which is more than 4 times the amount found in the modern parent liquid. At 330° C, the calculated *p*CO₂ is 104 bars and the *p*H₂O is 128 bars, so the total fluid pressure is 232 bars. For comparison, the hydrostatic pressure at 1258 m depth is 96 bars, while the lithostatic pressure is 260 bars (rock density =2.1 g/cc). The buildup of *p*CO₂ under vapour-saturated conditions thus requires extraordinary conditions whereby fluids were unable to ascend to the surface probably due to silica sealing of fluid conduits in the upper 1000 m of the system.

The later generation of fluid inclusions also comprises liquid-rich and vapour-rich inclusions of primary origin. Liquid-rich inclusions homogenise at 300 to 310° C and have T_m-ice values of -0.4° C (two measurements). These liquids are similar in temperature and composition to the modern fluids and suggest CO₂ concentrations of 0.1 to 0.2 molal (<1 wt %). At 300° C, the calculated *p*CO₂ is 14 bars and the *p*H₂O is 86 bars, so the total fluid pressure is 100 bars.

It appears that the fluid conditions allowing near lithostatic pressures and anomalous CO₂ concentrations were relatively short-lived and possibly relieved by a catastrophic release of steam and gas, generating hypersaline inclusion fluid found elsewhere in the same geothermal system.

THE FOGGY DOG GRANITE SUITE, DARWIN GLACIER REGION, SOUTHERN VICTORIA LAND, ANTARCTICA

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The **Foggy Dog Granite (FDG)** suite is exposed in several locations between the Darwin and Carlyon Glaciers in southern Victoria Land, Antarctica. Field relations indicate that the FDG suite is the oldest granitoid exposed in the Darwin Glacier Region. The suite is intruded by calc-alkaline granite and granodiorite, adakitic granodiorite and several generations of dykes and pegmatites. The suite shows major and trace element compositions and elemental ratios diagnostic of A-type (alkaline, anorogenic, anhydrous) granites. These characteristics include high average values for SiO₂ (76 wt %), Na₂O + K₂O (8 wt %), FeOt/MgO ratios (30), Ga/Al ratios (2.8), Y (46 ppm), Zr (167 ppm), Ba (409 ppm), Ce (101 ppm) with low CaO (1 wt %). The suite has a typical primary granite assemblage of quartz, potassium feldspar, plagioclase, biotite and hornblende with accessory titanite, zircon, apatite, allanite, barite, fluorite, magnetite and ilmenite. The suite displays distinctive mineral chemistries, including ferrotschermakitic hornblende (31–33 wt % FeOt), iron-rich annite (average Mg number < 14), albite to oligoclase (An₈ - An₂₁) and aluminium-rich titanite (< 6 wt % Al₂O₃).

The suite has an interpreted U-Pb zircon/titanite crystallisation age of 536 ± 5 Ma, comparable to other alkaline granites in the Transantarctic Mountains (Read et al., in press). The suite is interpreted to have been emplaced at 5.4 ± 0.7 kbar (equivalent to ~18 km depth), which is consistent with depths calculated for metamorphism of the Koettlitz Metasediments. A magmatic temperature of 757 ± 42°C has been calculated. The suite has an initial ⁸⁷Sr/⁸⁶Sr ratio of 0.7095 and an initial ¹⁴³Nd/¹⁴⁴Nd of 0.51195 (ε_{Nd} value of -4), indicating that the suite is more primitive than calc-alkaline suites in the region.

The presence of A-type granites as far south as the Darwin Glacier indicates that the Koettlitz Glacier Alkaline Province (KGAP) (Read et al., in press) extends at least 300 km from the Royal Society Range area to the Darwin Glacier Region. The KGAP encompasses areas in southern Victoria Land that are dominated by alkaline rather than calc-alkaline rocks.

This alkaline magmatism is inferred to result from high temperature, low H₂O activity, partial melting of lower crustal rocks. Asthenospheric upwelling during an extensional tectonic environment may have resulted in this heightened heat flow, however, the environment under which extension took place is poorly understood.

Read, S.E., Cooper, A.F. and Walker, N. In Press: Geochemistry and U-Pb geochronology of the Neoproterozoic-Cambrian Koettlitz Glacier Alkaline Province, Royal Society Range, Transantarctic Mountains, Antarctica. 8th International Symposium of Earth Sciences.

GEOHERMAL ACTIVITY AND HAZARD IN KUIRAU PARK, ROTORUA CITY: RECENT HYDROTHERMAL ERUPTIONS AND MONITORING OF GEOTHERMAL FEATURES

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The Rotorua Geothermal Field lies at the southern end of Lake Rotorua, within the Rotorua Caldera. Kuirau Park is located to the NW of the Rotorua Central Business District, west of Rotorua Hospital Hill (Pukeroa).

Concerns were raised in the mid 1970s regarding the 'quieting' and possible extinction of Rotorua's geysers and hot springs. Central government initiated the closure of many geothermal wells in 1986, with the purpose of restoring pressure and water levels in the geothermal aquifer. Rotorua's geothermal field has since responded with rejuvenated levels of activity.

The Rotorua Caldera was formed 230,000 years ago following the large eruption that produced the Mamaku Ignimbrite. Following its formation, several rhyolite domes (Rotorua Rhyolite) were extruded within the caldera margins. The Mamaku Ignimbrite, and Rotorua Rhyolite domes act as aquifers beneath the city, and the latter has good fracture permeability. Hot water rises into the rhyolite and flows laterally through the aquifer. Less permeable sedimentary sequences overlying the rhyolite act as an aquitard. Faults allow thermal fluids to penetrate through them, and discharge at the surface.

The Kuirau Fault runs along the eastern side of Kuirau Park and the thermal features within the park and at Ohinemutu to the north are fed from the Pukeroa dome rhyolite aquifer cut by this fault. Geothermal activity manifests as acid-sulphate and alkali-chloride pools, fumaroles and steam heated ground.

Hydrothermal eruptions are another thermal manifestation and are geotechnical hazards. On Friday 26th January 2001, the largest hydrothermal eruption since 1966 took place in the park. Mud and blocks were ejected up to 100m high and deposited as a thick carpet that extended 120m from the vent. Five types of deposits produced by the eruption have been recognized within the eruption deposits and an order of events is proposed. The geotechnical character of the eruption deposits is being examined to assess their relationship to possible eruption mechanisms.

An inventory of all the geothermal features within the park has been compiled with a number of parameters being recorded. Size, shape, physical characteristics, surrounding deposits and the condition of vegetation adjacent to the features were mapped. Temperature, pH, water levels, ebullition height, gases, and the smell of features are being measured and recorded. Ground Penetrating Radar, hand augers and penetrometers will be used to determine the extent of sinter and near surface stratigraphy throughout the park. Hazard analysis using GIS will combine locations of past events and coverages of surface geology, sinter, geothermal features, faults, temperature, pH, and areas of recent activity.

The Rotorua Geothermal Field is dynamic and fast changing. Reactivation of geothermal features in Kuirau Park, and its hydrothermal eruptions may result from increases in pressure in the aquifer as a consequence of the bore closure and reinjection of used geothermal fluid back into the field.

A REASSESSMENT OF THE K-H RELATIONSHIP IN VOLCANIC ARC MAGMAS

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The apparent relationship (K-h) between the K_2O content of magmas erupted in volcanic arcs and the depth to the underlying Wadati-Benioff Zone led to the paradigm that links subduction zone processes to the petrogenesis of arc-type magmas. Although it is widely accepted that subduction does play an important role in the production of such magmas the K-h relationship is not a fundamental characteristic of volcanic arcs. Northern New Zealand andesite volcanoes and those of the Sunda Arc in Indonesia were among those used to establish the original K-h correlation. Egmont Volcano is a high-K calc-alkaline volcano that lies to the rear of the North Island subduction system and magmas erupted in the Holocene fit the K-h correlation. However, the early stages of the Egmont system produced medium-K magmas and it was only in the later stages that high-K magmas were produced. Merapi Volcano occupies a frontal position in the Sunda Arc and is very similar in its petrological characteristics to Egmont Volcano. A first order conclusion is that position in the arc and therefore relative to the underlying Wadati-Benioff Zone, has no correlation with K_2O content at least for these two volcanoes.

At both Merapi and Egmont Volcanoes there are two clear trends in the geochemical evolution of their respective magmatic systems. On relatively short time scales K_2O increases with SiO_2 ; at longer time scales there is an increase in K_2O that is independent of SiO_2 . The processes responsible for these two trends are logically shallow and deep respectively. The evolution of each of these volcanoes toward higher K_2O at a particular SiO_2 content with time is thought to be related to the thermal evolution of the arc such that in the later stages there is recycling of early underplated material. What is intriguing about these two volcanoes is that they appear to have involved the same processes(s) although at different positions in their respective arcs. The trends observed at Egmont and Merapi are not observed at Ruapehu, which is in a frontal position in the New Zealand arc system. We suggest that it may be possible to geochemically fingerprint magmatic systems in arcs, and correlate particular evolutionary patterns with tectonic/thermal environments.

ION-PROBE DATING TVZ IGNIMBRITES: CONSTRAINTS ON MAGMA TIMESCALES AND SOURCES

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An understanding of the timescales involved in the storage of silicic magmas at shallow levels in the crust is critical to determining the timing of catastrophic explosive eruptions from caldera volcanoes. The timescales on which TVZ (and other) silicic caldera systems operate are at present very poorly constrained. In the TVZ there is the additional enigma of the source(s) of the prodigious volumes of rhyolite magma generated at very high rates for perhaps the last 2 Ma. U-series dating by ion microprobe of individual zircons extracted from ignimbrites is emerging as a powerful and instructive tool for quantifying the crystallization histories of silicic magma systems, and provides some insight into the temporal evolution of caldera volcanoes.

The ion-probe enables the rapid determination of ages for individual zircon grains within a large sample population. The ability to resolve accurate ages on 10-20 μm spots within individual grains also allows for specific zircon growth zones to be dated, from which detailed chronologies of crystallization can emerge. This approach has recently been applied at Long Valley caldera, USA and on the Whakamaru-group ignimbrites (0.34 Ma) where minimum magma residence times in excess of 0.25 Ma were suggested. These apparently long intervals contrast with the very short residence times recently indicated by isotopic studies of Tongariro andesite magmas (10^1 - 10^2 years), and by U-Th studies of small to moderate sized rhyolite magma batches at Taupo volcano ($<10^4$ years).

In this pilot study we are examining zircons from the Ongatiti Ignimbrite (1.2 Ma), a large volume ($>300 \text{ km}^3$) welded ignimbrite erupted from Mangakino caldera after a c. 0.2 Ma quiescent period. Preliminary analyses by ion-probe and cathodoluminescence imaging have yielded two distinct populations of Ongatiti zircons:

a dominant population of weakly to moderately zoned euhedral grains with rim ages of 1.2 Ma and core ages of 1.3-1.5 Ma;

a subordinate population of euhedral grains with very well defined cores with resorbed boundaries that give ages of 280-320 Ma, rimmed by weakly zoned material which give ages of 1.2 Ma.

The ranges of core and rim ages suggest prolonged crystallization within a sub-caldera magmatic system prior to the Ongatiti eruption. The much older xenocrystic cores provide unequivocal evidence for the assimilation of crustal material in the age range of the local basement metasedimentary rocks. Further work is to be carried out on older and younger Mangakino eruptives to determine the legacy of zircon crystallization and constrain to what extent large batches of silicic magma have been discrete or overlapping in time and space.

THE TE RERE (21 KA) AND ROTOMA (9 KA) ERUPTIVE EPISODES, HAROHARO VOLCANIC COMPLEX, OKATAINA VOLCANIC CENTRE

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The Okataina Volcanic Centre is the most recently active rhyolitic volcanic centre in the Taupo Volcanic Zone. Activity within the Okataina Volcanic Centre during the past 21 ka has occurred from the Haroharo and the Tarawera volcanic complexes. All the eruptions from these volcanic complexes have been fissure eruptions from linear vent zones. The Haroharo linear vent zone extends for 28 km from Okareka basin through to the Rotoma Caldera. The lava flows and domes erupted from the Haroharo linear vent zone are associated with at least four major eruptive episodes from multiple vents: Te Rere (21 ka), Rotoma (9 ka), Mamaku (7 ka) and Whakatane (5 ka).

The Rotoma eruptive episode (9 ka) includes numerous widespread deposits that erupted from a 12 km long series of vents. The many eruptive phases during the Rotoma eruptive episode include: (a) a large plinian eruption from the Rotoma Caldera; (b) numerous lava flows including the Rotoma, Te Pohue and possibly the Waiti and Kaipara lava flows; and (c) pyroclastic flows and surges most likely associated with a northeastern blast which breached the side of the Pukerimu tuff cone. The pyroclastic fall and flow deposits are compositionally homogeneous, both vertically and laterally. Glass variability is comparable to analytical uncertainty (SiO_2 77.4-78.4 wt. %, K_2O 3.3-3.6 wt. %). Most phenocryst phases also lack variation between beds: cummingtonite (FeO 18.0-20.5 wt. %, MgO 18.0-19.5 wt. %), orthopyroxene (En_{40} - En_{45}) and plagioclase (An_{25} - An_{40}). Temperature calculations also suggest the magma batch lacked a thermal gradient (715-775°C from Fe-Ti oxides). This indicates that the numerous vents tapped a single magma batch. However, differences are observed in Sr and Zr in trace element data from whole pumice analysis. These differences appear to be related to differences in mineral abundance; this varies between vents.

The Te Rere eruptive episode (21 ka) comprises a series of eruptions from vents extending over 20 km. The Te Rere eruptive episode comprises: (a) pumice falls and associated pyroclastic flows from vents near the northern edge of the complex; (b) the Tapuaeharuru and Te Haehaenga obsidian rich pyroclastic flows; and (c) the Haumingi, Tuarae, Northern Dome and Lava A lava flows. Glass analyses from the Te Rere deposits indicate three magma batches:

SiO_2 (wt. %)	K_2O (wt. %)
76.5 - 77.3	2.7 - 3.2
77.4 - 78.3	3.0 - 3.5
77.3 - 77.8	3.6 - 4.0

These sub-populations of shards are mixed within the individual fall units suggesting simultaneous eruption. Phenocryst phases are also heterogeneous: plagioclase (An_{25} - An_{50}), orthopyroxene (En_{43} - En_{65}) and hornblende (Al_2O_3 5.5-9.0 wt. %). Temperature data calculated from Fe-Ti oxides also displays wide ranges (770-950°C) indicating that some of the magma batches were at different temperatures and some had thermal gradients.

**PETROLOGY AND GEOCHEMISTRY OF THE GREENHILLS COMPLEX OF
SOUTHLAND, NEW ZEALAND AND SOME IMPLICATIONS FOR THE SOURCE
AND MAGMATIC EVOLUTION OF PRIMITIVE ISLAND ARCS.**

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The remains of a Permian (~265Ma) intrusive complex that formed as a magmatic feeder reservoir to an immature island-arc volcano are fortuitously exposed on the Bluff Peninsula, South Island New Zealand. Known as the Greenhills Complex, this intrusion was emplaced at shallow crustal levels and consists of two layered intrusions that were intruded by a variety of dykes. Cumulate rock-types include dunite, olivine clinopyroxenite, olivine gabbro, and hornblende gabbro-norite, and are related products of parent-magma fractionation. Both primary (magmatic) and secondary platinum-group element (PGE) minerals occur within chromian spinel-rich dunite at one locality. These PGE minerals are suggested to be the source of alluvial PGE deposits found on beaches to the east of the complex. Using the composition of cumulus minerals, mafic dykes and melt inclusions hosted within cumulus chromian-spinel grains, we have determined that the parent magmas of the complex were hydrous, low-K island-arc tholeiites of ankaramitic affinities. Such magmas are not expected to have been generated by melting of mantle peridotite, but may have formed by high-degree partial melting of either ultramafic cumulates at the base of the crust or mantle-derived pyroxenites. Progressive magmatic differentiation generated fractionated melt of high-alumina basalt composition, now only preserved as dykes that cut the Complex. Field evidence and cumulus mineral profiles reveal that the magma chambers experienced turbulent magmatic conditions during cumulate-rock formation. Recharge of the chambers by primitive magma is likely to have coincided with eruption of residual melt at the surface. Similar processes are inferred to account for volcanic-rock compositions in other parts of southern New Zealand and in modern island-arc systems.

EVOLUTION OF THE OKATAINA VOLCANIC COMPLEX

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Okataina volcanic centre is one of two currently active centres within the Taupo Volcanic Zone, and the recent history (post 65ka) has been well studied and documented. Older deposits are generally less well exposed and, as a result, the early evolution of the centre is less well understood. The Haroharo Caldera is the current topographical expression of a more complex system of multiple collapse, in which individual phases of collapse are masked by more recent volcanism.

Events are commonly divided into caldera-forming (pre 65ka) and caldera-filling (post 65ka) episodes, but this subdivision is likely erroneous due to the preferential preservation of large landscape-modifying ignimbrites, and the removal of caldera-fill by subsequent eruptions and associated collapse. Units such as Pokopoko, Onuku, and Bonisch pyroclastics may represent all that remains of significant parts of inter-caldera eruptive history.

Lithic component analysis and drill-hole data have identified ignimbrite lithologies not known to outcrop at the surface, and other units (e.g. Hongi's Bluff, Tikitere, Millers Rd, and Quartz-Biotite Ignimbrites), exposed close to the caldera complex, do not feature in the current models of eruptive history, supporting a hypothesis that Okataina caldera complex may have been active for longer than the accepted 250ka, and that the stratigraphy is more complicated than previously thought.

The study of the structure and evolution of young calderas such as those in the Taupo Volcanic Zone, without the benefit of uplift and erosion, requires a broad approach, incorporating diverse techniques. Through lithic component analysis, mineral and whole pumice chemistry, satellite and geomorphologic analysis, we hope to constrain both the magmatic and landscape evolution of Okataina Caldera Complex.

This poster indicates the current level of knowledge about the early evolution of the Okataina Caldera Complex, and provides a mechanism for discussing how it relates to the broader Okataina volcanic centre, and younger Haroharo Caldera.

THE POST-GLACIAL LAVA FLOWS OF TONGARIRO VOLCANO - NEW INSIGHTS FROM AIRBORNE INTERFEROMETRIC RADAR

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In the last 15,000 years, Tongariro volcano has erupted blocky lava flow-fields from various summit vents. Despite their age, the surface features of these flow-fields are well preserved in comparison with older lavas at Tongariro, because they were erupted after the last glacial maximum. High resolution, three-dimensional measurements of the shape and surface features of lava flows would allow inferences to be drawn about emplacement conditions in lavas for which no co-eruptive field observations were made. Such investigations have been hindered to date by a lack of high-resolution topographic data of the area.

In November 1996 and August 2000, the topography of the Tongariro Volcanic Centre was mapped by the airborne NASA C-band topographic interferometric synthetic aperture radar system (TOPSAR). This provided a digital elevation model (DEM) data of Tongariro volcano in a 10 km wide swath, at 10 m spatial resolution, with a calculated root mean squared vertical accuracy of 1-3 m.

The TOPSAR DEM provides a new opportunity to investigate the morphology of lava flows at Tongariro volcano. The resolution is detailed enough to map the surface features preserved in the flow-fields (e.g. flow lobes, drained channels, levées, tectonic fault scarps and fluvial valleys). The detailed topographic data of the lava margins and their heights enabled measurements of the gross morphology of the lava flows to be obtained (e.g. surface area, volume, length, mean margin depth etc).

This paper presents an on-board tour of the NASA DC-8 that carried the TOPSAR instrument. The measurements derived from the TOPSAR DEM are used in parallel with existing empirical relationships to constrain understanding of the lava emplacement behaviour during eruption. The TOPSAR data thus provide new insights into lava emplacement behaviour and long-term effusive magma budget at Tongariro volcano.

THE SENSITIVITY OF A VOLCANIC FLOW MODEL TO DIGITAL ELEVATION MODELS FROM DIVERSE SOURCES

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A growing trend in the field of volcanic hazard assessment is the use of computer models of a variety of flows to predict potential areas of devastation. The accuracy of these computer models depends on two factors, the nature and veracity of the flow model itself, and the accuracy of the topographic data set over which it is run.

All digital elevation models (DEMs) contain innate errors. The nature of these depends on the accuracy of the original measurements of the terrain, and on the method used to build the DEM. We investigate the effect that these errors have on the performance of a volcanic flow model designed to delineate areas at risk from lahar inundation.

The model was run over two DEMs of southern Ruapehu volcano derived from (1) digitised 1:50,000 topographic maps, and (2) airborne C-band synthetic aperture radar interferometry obtained using the NASA AIRSAR system. On steep slopes of $\sim 4^\circ$ or more, drainage channels are more likely to be incised deeply, and flow paths predicted by the model are generally in agreement for both DEMs despite the differing nature of the source data. Over shallow slopes ($\sim < 4^\circ$), where channels are less deep and are more likely to meander, problems were encountered with flow path prediction in both DEMs due to interpolation errors and forestry. The predicted lateral and longitudinal extent of deposit inundation was also sensitive to the type of DEM used, most likely in response to the differing degrees of surface texture preserved in the DEMs.

A technique to refine contour-derived DEMs and reduce the error in predicted flow paths was tested to improve the reliability of the modelled flow path predictions. The suitability of forthcoming topographic measurements acquired by a single-pass space-borne instrument, the NASA Shuttle Radar Topography Mission (SRTM) are also tested.

TECTONICS OF NORTHLAND FROM NEW STRUCTURAL STUDIES IN THE MT CAMEL TERRANE

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Houhora Complex units between Henderson Bay and Rarawa mostly dip to the SE and consist of 1. Henderson Pt type turbidites and mudstones (oldest unit, equivalent to the Tokerau Formation elsewhere) 2. thin-bedded mudstone-rich units, and monomict conglomerates (both also equivalent to Tokerau Formation) with intercalated pillow lavas which are correlated with the Rangiawhia Volcanics, and 3. polymict conglomerates and sandstones of the Ngataki sequence (youngest unit, possibly equivalent to the Whatuwhiwi Formation). Black mudstones may be correlatives of the Waiari Formation. No unconformities have been recognised. The stratigraphy is repeated in a number of imbricated thrust slices and undergoes facies variations in a basin with a possible shelf area to the west.

Deformations is extremely complex and consists of the following phases: D₁: accretionary tectonics (folding, disruption by broken formation, imbrication) indicating subduction to the W; D₂: back-folding to the SW, causing wide-spread overturning; D₃: westward thrusting; D₄, D₅: sinistral shearing and folding; D₆: southwestward thrusting; D₇: intrusion of E-W striking dikes; D₈: sinistral down-to-the-E faulting; D₉: E-W striking, down-to-the-N faults; D₁₀: intrusion of E-W and NW-SE striking dikes (?subduction related Miocene Karikari Plutonics)

These structures can be integrated with those elsewhere in the Mt Camel terrane, including those at Whatuwhiwi, where Tertiary rocks are involved in a D₂ fold. This indicates that all the structures are of Tertiary age and therefore associated with the formation and emplacement of the Northland Allochthon rather than the Early Cretaceous 'Rangitata Orogeny'.

This area records (?Late Cretaceous) formation of an extensional basin at the eastern edge of Northland, into which the (?intraplate) Rangiawhia Volcanics were extruded, followed by accretionary tectonics (?immediately) prior to westwards overthrusting during Northland Allochthon emplacement. Subsequent phases were sinistral shear, southwards thrusting (?of the Allochthon), further sinistral shear and final N-S extension. The recurring sinistral shear is compatible with recent reconstructions of plate movement in the region.

DEFORMATION AND UPPER CRUSTAL FLUID FLOW IN THE OUTBOARD FOLD AND THRUST BELT, EASTERN SOUTHERN ALPS

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Continental collision creates an orogen consisting of two oppositely facing wedges whose form are a result of rheology, erosion and the relative plate motion. The geometry of the main backbone of the Southern Alps is broadly predictable from the known plate vector, the asymmetric orographic erosion regime of the South Island and crustal rheology. To the east of the main ranges, the structure of the outboard fold and thrust belt is less well understood.

This study focuses on the Two Thumb Range and surrounding basins, the Mackenzie Basin, the Fairlie Basin and the Rangitata/Lake Heron Basin. A NE striking fault system runs for at least 60 km, from Lake Tekapo, through Coal River, Neutral and Forest Creeks to the Rangitata River. The N striking Fox Peak/Butler Creek system in Forest Creek intersects this system. In the central Two Thumb Range, both the NE and N striking systems consist of two closely spaced oppositely dipping thrust faults. In the Fairlie Basin the east-dipping strand of the Fox Peak Fault evolves into a broad antiformal fold in the south.

All faults have been active in the late Cenozoic and thrust older greywacke basement over Tertiary and younger rocks. Uplift was initiated on N to NNE striking faults with the prominent NE striking faults that now cross oblique to the trend of the range forming after the initiation of the N trending range. The intersection of the two sets of faults is currently responsible for the continuing uplift of the Two Thumb Range. Active structures within the northeastern Mackenzie Basin include the Irishman Creek Fault and the Coal River Fault, both of which strike NE-SW. Sub-bottom profiling of Lake Tekapo showed that recent movement on both the Irishman Creek Fault and the Coal River Fault decreases to zero within the lake basin, suggesting the existence of a N-S trending structure within the lake basin.

Fluid flow in an actively deforming system is coupled to the deformation. In the outboard region, we have investigated fluid movement and source using carbon and oxygen stable isotopes. Isotopic analyses of calcites hosted within fault zones reflect mixing of three parent fluids: meteoric, basinal and minor deeper rock-exchanged fluids, in the upper 3-4 km of the crust. These, combined with other results, imply the existence of two fluid regimes within the upper crust of the outboard region. First, leading to the vertical conductor is leakage of rock-exchanged fluid from beneath the brittle-ductile transition. This leakage is slow, continuous and buoyancy-driven. A second flow regime exists in the top few km of the crust. It is episodic, related to faulting, and leads to precipitation of fault-hosted calcite.

Unlike many outboard fold and thrust belts worldwide, which form in sedimentary strata eroded from the growing main ranges, the eastern Southern Alps consist of basement rocks, argillites and greywackes which were metamorphosed and then uplifted and extended in the Mesozoic. Two sets of structures, formed during Mesozoic extension and oriented NE-SW and NW-SE, create a pre-existing fabric to the rocks forming the fold and thrust belt. Only the NE-SW set is utilised by the current tectonic regime, reactivated as thrust faults, but it appears that they were not favourable oriented until the N-S trending ranges had been uplifted. Thus form of the outboard fold and thrust belt in the eastern Southern Alps, and the related fluid flow regime, result from a combination of crustal rheology, driving forces, and pre-existing structure.

ACTIVE FAULTING AND FOLDING IN AND AROUND LAKE TEKAPO, MACKENZIE BASIN

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The outboard fold and thrust belt of the Southern Alps is dominated by N-S trending mountain ranges oblique to the main backbone of the Alps, and NE-SW trending intermontane basins, cut by N-S oriented glacial valleys and lakes. Uplift of the N-S trending ranges was initiated along N to NNE striking thrust faults followed by movement along NE-SW striking faults, which run oblique to the trend of the ranges. Movement along these two sets of active faults is currently responsible for the continuing uplift of these basement ranges at rates of $1-1.5 \text{ mma}^{-1}$ (James, 1998, Upton et al., submitted). Faulting occurs on the flanks of the ranges while folding dominates within the basins. This study focuses on the northeastern Mackenzie Basin and, in particular, on the structure of Lake Tekapo.

Active structures within the northeastern Mackenzie Basin include the Irishman Creek Fault west of Lake Tekapo, and the Coal River Fault east of the lake, both of which strike NE-SW. Extremely low lake levels this winter have enabled detailed mapping of the lakeshore along strike from the Irishman Creek Fault. A ~100m wide fault zone, dipping to the SE, was found on both shores of the lake, but, there is no evidence to suggest that recent movement has occurred along it.

Sub-bottom seismic reflection profiling of Lake Tekapo revealed several regions of deformation within the lake basin. The profiles show flat lying lake sediments in the northwest and southeast quarters of the lake. Along the northeastern edge of the lake basin, where the Coal River Fault projects into the lake, an anticline that folds the lake bottom is imaged. In the southwest corner, another anticline is imaged at the northern end of the Irishman Creek Fault Zone. Basement highs are observed beneath each of the anticlines. There is no evidence on the profiles for movement within the last 5-10 ka along the extension of the Irishman Creek Fault zone that cuts the lake basin, deformation of the lake sediments occurs as a fold 3 km north of this structure. These profiles suggest that the NE striking faults die out into anticlines within the lake basin.

I suggest that west of Lake Tekapo, the Irishman Creek Fault Zone is taking up contractional movement. East of the lake, the shortening is taken up along the Coal River Fault, leading to the uplift of the Two Thumb Range. The amount of relative uplift reduces markedly across the lake and some sort of transfer structure is inferred to exist within the lake. The profiling did not image such a transfer feature, but this may just mean that this structure has not moved within the last 5-10 ka, the approximate time span represented by the sediments imaged on the profiles.

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GEOLOGICAL DEVELOPMENT OF THE LATE MIOCENE-EARLY PLIOCENE SUCCESION (MATEMATEAONGA AND KIORE FORMATIONS), EASTERN TARANAKI PENINSULA

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The stratigraphic development of eastern Taranaki Peninsula through the Late Miocene and Early Pliocene is best understood in terms of a major progradational continental margin, which has subsequently been uplifted, tilted to the southwest and partially eroded. This succession is exposed in eastern Taranaki Peninsula and in Wanganui Basin, and is encountered in the subcrop beneath Taranaki Peninsula.

The paleoshelf strata in eastern Taranaki Peninsula are represented by the Matemateaonga Formation (Late Kapitean to Early Opoitian; c. 5.5-4.7 Ma). It comprises a 1000 m thick succession characterised by the cyclical repetition of lithofacies (sequences) driven by 6th or 7th order glacio-eustatic sea-level oscillations. Each sequence comprises transgressive (TST), highstand (HST) and regressive (RST) systems tracts. Most sequences contain onlap and backlap shellbeds, which are often superimposed to form compound shellbeds (=TSTs). These are typically overlain by massive aggradational siltstone (=HSTs) and regressive sandstone (RST). Most of the sequence boundaries are unconformable. Individual sequences of the Matemateaonga Formation have been geologically mapped across eastern Taranaki Peninsula and into the vicinity of exploration wells Rotokare-1, Ahuroa-1, Standish-1, Kiore-1, Huiroa-1 and Huinga-1.

The paleo-uppermost slope strata are represented by the Kiore Formation (latest Tongaporutuan to Early Kapitean; c. 7-5.5 Ma). It comprises a predominantly sandy siltstone lithofacies punctuated by discontinuous channels, infilled with shell hash and conglomerates. The formation is approximately 500 m thick. It is distinguished from the overlying Matemateaonga Formation principally by the absence of continuous shellbeds with tabular geometry; while the underlying Urenui Formation is distinguished by the higher frequency of channel occurrences, the slightly coarser texture of the siltstone lithofacies and the occurrence of wavy-bedded interbeds of very fine sandstone and siltstone. These differences, noted in previous exploration reports, has led to this unit sometimes being named the Lower Matemateaonga Formation.

The Matemateaonga Formation has been correlated across Wanganui Basin at the scale of individual cyclothems. This provides very detailed constraints on the contemporary paleogeography. The shelf represented by the Matemateaonga formation prograded earlier and further to the north in the vicinity of the Wanganui River than it did in eastern Taranaki Peninsula. In the Taranaki Peninsula area, the Patea-Tongaporutu High clearly influenced the northward progradation of the shelf as there are a greater number of shelf cyclothems over the High than the areas to the east and west, and the cyclothems have a higher proportion of sandstone than to the east.

DEVELOPMENT OF FLUID CONNECTIVITY, GRAIN-BOUNDARY DILATION, AND GEOPHYSICAL CHARACTERISTICS OF ALPINE FAULT TECTONITES, NEW ZEALAND

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As mid- to deep-crustal rocks are ramped upwards along crustal-scale faults, nearly-isothermal decompression will cause sequential overpressuring of smaller and smaller fluid inclusions. The expanding fluid will leak outwards, forming growing tubular extensions (spiderlegs) and films along developing fractures, causing interfacial (wetting) angles to decrease below $\sim 60^\circ$. Eventually the combination of fault movement, fluid overpressuring, and progressive autodecrepitation of smaller and smaller fluid inclusions produces a zone of interconnected fluid that is not located above the orogenic root where metamorphic devolatilization occurs, but instead is offset along the fault to higher crustal levels. Results of seismic velocity and electrical resistivity studies undertaken as part of the South Island Geophysical Transect (SIGHT) Programme show such an offset zone of fluid connectivity associated with the Alpine Fault, South Island, New Zealand. In this and other collisional orogenic belts where nearly isothermal decompression follows the metamorphic peak ("clockwise" P-T-t path), the development of the large-scale fluid connectivity necessary for vertical fluid escape can be delayed $\sim 1-2$ m.y. after the metamorphic peak.

EXTENSION ACTIVITIES FOR THE 'WATERWAYS' BOOKLET OF THE BUILDING SCIENCE CONCEPTS SERIES

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The 1993 New Zealand Science Curriculum is written in terms of Achievement Objects, Learning Contexts, Learning Experiences and Assessment Examples, however it provides no background knowledge nor practical activities to assist/guide teachers in delivering the programme. In 1999, "Making Better Sense of Planet Earth and Beyond", was published. This was explicitly designed to provide background information on topics from Planet Earth and Beyond (it covers Landforms, Weather and Astronomy) and to furnish practical activities relevant to these topics. Subsequent to these publications a series "Building Science Concepts" (at this stage partially published):

- (a) identifies the "Big Ideas" associated with a topic,
- (b) provides teachers' explanatory notes, and
- (c) outlines activities that demonstrate the "Big Ideas".

To date Building Science Concepts that relate to Planet Earth and Beyond have been published on Volcanoes, Weathering and Erosion, Waterways, The Moon, and Soil Animals.

A major theme running through the Planet Earth and Beyond strand is to understand our landscape. This involves:

- (a) observing/investigating the processes that shape the land,
- (b) coming to an understanding that Earth has a long history, and
- (c) realising that Earth's surface is continually changing.

Some of these can be investigated with class room activities (as shown in "Making Better Sense of Planet Earth and Beyond" and the Waterways booklet) but the best way to appreciate and study the landscape is to go out into it on a field trip. On field trips it is possible to see real examples of modifications of the landscape and to ponder on the processes involved. Often, though, the size of a real landscape means that it is not possible to "see" the whole picture and understand the inter-relatedness of many of the features. Also, it is not possible to manipulate the landscape to investigate various parameters. At this point it is helpful to have a model where the natural processes still occur (though on a smaller scale) but where the whole "river" system can be seen, and manipulated.

During this session I will demonstrate:

- (a) an activity to demonstrate the sedimentation process and stratigraphy,
- (b) a series of activities using stream trays to demonstrate river processes
- (c) techniques to investigate how substrate parameters change along a river.

These activities are best undertaken both before and after the field trip. If the stream tray is "run" for a while at the end of the unit and then the water is turned off, the resulting "stationary" stream-tray-landscape can be used for assessment. Alternatively, posters of landscapes can be used in assessment.

EBSD DETERMINATION OF CRYSTALLOGRAPHIC PREFERRED ORIENTATION IN THE ALPINE FAULT MYLONITES

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The Electron Backscatter Diffraction (EBSD) technique provides absolute orientations of crystallographic axes for given mineral grains or areas within grains. During ductile deformation, randomly oriented grains respond to imposed stresses by rotation of their crystallographic axes relative to the compression direction (Passchier and Trouw 1996). By combining a population of such measurements, we can define a statistically valid crystallographic preferred orientation (CPO) of deformed grains within a tectonite. CPOs of deformed rocks are crucial to understanding the deformation processes and kinematics involved in strain accumulation (Prior and Wheeler 1999).

A CPO measurement from a deformed rock potentially allows us to define the physical conditions of deformation. This is because the CPO is a product of the deformation mechanisms and individual slip systems that have contributed to the finite strain of that rock. These deformation mechanisms are highly dependent on physical and chemical conditions operating within the deforming zone. CPO data, from experimentally deformed monomineralic aggregates, provide constraints on deformation mechanisms and slip systems operative during specific conditions of deformation/metamorphism. Therefore, in theory, such data can provide information on deformation (eg. differential stress, temperature, strain rate, shear-sense). However, in reality, such experimental data are currently available for relatively few minerals (eg. quartz, calcite), and can be difficult to interpret.

In most studies of mylonites, microstructure is used in conjunction with metamorphic petrology in order to try to infer the deformation conditions under which the rocks formed. The relative youth (<5 Ma) of the Alpine Fault mylonites provides a unique opportunity to reverse this and to test the effectiveness of CPO as a tool for determining deformation conditions. This is because the mylonites that are currently uplifted and exhumed on the hanging wall are thought to have formed in approximately the same tectonic regime as those currently being deformed at depth within the fault zone. Deformation and kinematic conditions for this tectonic regime are well constrained, independently of microstructure. For example, P/T conditions are known from metamorphic petrology (amphibolite facies), strain rate is understood from paleoseismology and geodetics (eg. late-Quaternary strike-slip rate = 27 ± 5 mm/yr (central section), (Norris and Cooper 2000)). Finite shear strain values of 200-300 have been reported by Norris and Cooper (1999). By comparing these and other data to the deformation conditions suggested by CPOs from experimentally deformed rocks, we may be able to assess the validity of extrapolating such experimental data to natural conditions.

EBSD has been used to determine the CPOs of monomineralic quartz and calcite mylonites exhumed along the hanging wall of the Alpine Fault. Preliminary interpretation of these data suggest deformation by dynamic recrystallisation under conditions of dominant non-coaxial deformation at temperatures of 500°C, with some suggestion of temperatures as high as 700°C. Lack of evidence for basal <a> slip systems in quartz suggest that low-temperature ductile deformation was unimportant, possibly due to rapid uplift rates. Kinematics are consistent with field observations. Further interpretation and data processing is in progress.

ELECTRON BACKSCATTER DIFFRACTION (EBSD) AS A TOOL IN MICROSTRUCTURAL ANALYSIS OF TECTONITES

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Microstructure can be defined as the joint analysis of texture and fabric in a deformed rock. Texture is based on crystallographic preferred orientation (CPO) whereas fabric refers to dimensional preferred orientation. Fabric can easily be described using optical microscopy, however CPO analysis of rock texture requires specialised equipment. The universal stage has been employed for well over a century as a means of determining c-axis orientations of crystallites, however this method of fabric analysis is slow and fails to quantify the complete crystallographic orientation of a mineral grain.

Electron backscatter diffraction (EBSD) is a relatively new scanning electron microscope (SEM) based technique of assessing the orientations of crystalline materials. In the EBSD method a stationary electron probe is focussed onto a small (<1 μ m) region of a crystal. The angular distribution of back-scattered electrons (BSEs) emerging from the specimen is recorded as an electron backscatter pattern (EBSP) by placing a phosphor screen into the path of the BSEs (Wilkinson and Hirsch 1997). As with all diffraction images, the symmetry of the crystal under observation is reflected in the EBSP and therefore its full crystallographic orientation can be directly determined. The EBSP is a complex optical image consisting of intersecting Kikuchi bands of variable width. The particular pattern geometry observed is dictated by the crystallographic symmetry of the specimen under observation and its orientation with respect to the specimen surface and a chosen reference frame.

The CamScan Crystal Microprobe X500 housed in the Department of Earth Sciences, University of Liverpool, has been specifically designed for EBSD work. The resultant EBSP is imaged using a low-light video camera. Software then uses the SEM parameters, and databases of crystallographic symmetry for the particular material under consideration, to index the EBSP (assign Miller indices). Assessment of whether the software has indexed a pattern correctly requires a comparison of the observed EBSP with a suggested simulation. A good fit requires that all the visible bands are simulated and that there are no bands in the simulation that are not observed (Prior et al. 1999). In the case of most minerals, an operator needs to check that the software has achieved this. However, in the case of calcite and quartz, indexing is so accurate that it is now possible to automatically scan a specimen over a predefined grid at grid-space resolutions of as low as 1 μ m. Such scans are highly efficient (eg. 1 million measurements over a weekend).

The orientation data can be plotted in various ways, the most common for geological applications being the pole figure. The pole figure is essentially a composite stereographic projection of orientation data for a given crystallographic axis. In the case of automated scans, a variety of colour coded orientation maps can be produced to display crystallographic orientations, phases and textures. A variety of boundary types can also be displayed. Statistical analyses such as distribution functions can be applied to the data set. Since the orientations of neighbouring grains can be determined using EBSD, it follows that misorientation between the two grains can also be readily calculated. The resolution of EBSD enables complex orientation analysis within single grains and allows the quantification of grain boundary misorientations and boundary plane types.

PROVENANCE OF THE PAHAU TERRANE, SOUTH ISLAND, NEW ZEALAND

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The New Zealand Eastern Province terranes comprise portions of a volcanic arc, arc-related basins, slope basins and an accretionary complex which originated along the margin of Gondwana. The Torlesse superterrane, the accretionary complex, comprises an enormous volume of quartzo-feldspathic sandstones and mudstones with subsidiary conglomerates plus minor oceanic assemblages. Two terranes in the South Island are recognised, the Permian to Late Triassic Rakaia terrane and the Late Jurassic to Early Cretaceous Pahau terrane. The Torlesse superterrane is widely accepted as allochthonous and not derived from the continental crust of western New Zealand. Recent studies in detrital petrology and geochemistry have established the broad type of source, and point to derivation from a continental magmatic arc or active continental margin.

New SHRIMP U-Pb zircon ages of 16 igneous clasts analysed from 3 conglomerates from the Pahau terrane indicate that the igneous activity in the source area of the clasts was predominantly of upper Late Jurassic to Early Cretaceous age. The samples dated are undeformed, metaluminous to evolved metaluminous I-type rocks of mainly volcanic origin. Most plutonic clasts display hypersolvus textures, but subsolvus clasts have also been analysed. Some rhyolite samples from the Mount Saul conglomerate are of peralkaline composition and some clasts from Kekerengu have adakititic affinities. Geochemistry, SHRIMP-ages and Sr and Nd isotope ratios strongly suggest that igneous clasts of the Pahau terrane conglomerates have very strong resemblance to rocks of the Median Tectonic Zone of the New Zealand and Antarctica sectors of the Gondwana margin. New SHRIMP U-Pb detrital zircon ages are presented. Two Rakaia terrane samples analysed each contain a major zircon detrital age group in the range of 220 – 360 Ma (Middle Triassic – Devonian). The major peak of the Permian Kurow sample at *ca.* 270 Ma is indistinguishable from the ages of other published Permian Rakaia sandstone rocks. The Middle Triassic Balmacaan Stream detrital zircon age distribution has a main peak at 265 Ma. The Lower Cretaceous Pahau terrane sample from Ethelton, the matrix to the conglomerate, has a prominent peak at *ca.* 235 Ma. This peak strongly coincides with peaks recognised in Triassic Rakaia, Waipapa/Caples, and Western Province detrital zircon age distributions. A second pronounced peak at *ca.* 130 Ma, and a minor Jurassic peak in the Ethelton sample are recognised.

Detrital zircon age distributions and igneous clast zircon ages demonstrate that the igneous source provided detritus to the Pahau Basin, deposition and igneous activity are contemporaneous, and that the older, uplifted Rakaia terrane is recycled into the Pahau basin. The recycling of the older terrane is supported by new sandstone clast petrography, major and trace element, and Nd isotope geochemistry.

THE 26.5 KA ORUANUI ERUPTION AND ITS AFTERMATH

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The 26.5 ka Oruanui eruption is the latest of the 'large' ($>100 \text{ km}^3$, magma) caldera-forming events in the Taupo Volcanic Zone. It generated 430 km^3 of fall deposits, 330 km^3 of pyroclastic density current (PDC) deposits (mostly ignimbrite) and 420 km^3 of primary intracaldera material, equivalent to $\sim 530 \text{ km}^3$ of magma. Erupted magma is 99% rhyolite, mostly within a narrow compositional band that shows no systematic changes with time in the eruption, and 1% mafic compositions. The latter vary in abundance to define 3 'spikes' that link coeval fall and PDC deposits. The 10 phases of the eruption produced 9 mappable fall units, from 0.8 to 85 km^3 , totalling 165 km^3 , and a tenth, poorly preserved unit of 265 km^3 ; all are of wide to extremely wide dispersal. Fall deposits show a range of deposition states, from dry to water saturated, reflecting both magma:water interaction at vent and/or pyroclast:water ratios on deposition. Multiple fall bedding and normal grading show that the first third of the eruption was spasmodic, with bursts of activity separated by breaks of up to several weeks to months. PDC activity in the form of both dilute and concentrated currents occurred throughout the eruption. PDC deposits range from cm-thick veneers to $>200 \text{ m}$ thick proximal ignimbrite. The farthest travelled ($\sim 90 \text{ km}$), most energetic PDCs (velocities $>100 \text{ m/s}$) occurred in phase 8, but the most voluminous occurred in phase 10. Physical variations in PDC deposits are complex, with vertical changes in the thick, proximal accumulations being greater than lateral changes out to distal deposits. Modern Lake Taupo partly fills the Oruanui caldera; the lake outline reflects coeval marginal and volcano-tectonic collapse, while a 140 km^2 structural collapse area is concealed beneath the lake. Unusual features of the Oruanui eruption include its episodic nature, the wide range of depositional conditions in fall deposits of very wide dispersal, the complex interplay of fall and PDC activity, and the lack of systematic rhyolite compositional variations with time.

The eruption occurred 2-3 ka before the peak of the Last Glacial Maximum, under dry and cool/periglacial conditions. Of the eruption products, deposition of the ignimbrite had the greatest impact on the landscape, leading to a major convulsive sedimentation event. Ignimbrite emplacement destroyed the lake that had occupied the Taupo-Reporoa structural graben for $>100 \text{ ka}$, and buried interfluvial creating a new surface. The newly formed caldera re-filled post-eruption to a temporary highstand $\sim 140 \text{ m}$ above modern level. Fluvial erosion surfaces along outlet channels at intermediate elevations demonstrate episodic stillstands during lake level fall, while coarse fluvial deposits $60\text{-}100 \text{ km}$ downstream imply catastrophic releases of water. Around Taupo, most ignimbrite dissection was accomplished prior to the onset of deglaciation, as marked by preservation of the $\sim 21 \text{ ka}$ Okareka Tephra above the erosion surface, while by this time also Lake Taupo had fallen to near its current level. After 26.5 ka the Waikato River constructed a major fan surface along its pre-eruption course through the Hauraki Plains. However, continued aggradation caused overtopping of a drainage divide and avulsion into its modern course via the Hamilton Basin prior to $\sim 21 \text{ ka}$, where fan-building persisted until climatic warming at $\sim 17 \text{ ka}$ led to re-afforestation and a decline in sediment yields. Subsequent entrenchment of the Waikato and its tributaries caused a final phase of distal aggradation before landscapes stabilised at $\sim 12 \text{ ka}$. Catastrophic sedimentation was triggered by the eruption, but prolonged for several thousand years by the Last Glacial climate.

GEOCHEMICAL INVESTIGATIONS OF PRIMITIVE MEMBERS OF THE TAKITIMU ARC COMPLEX

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The Takitimu Mountains (~ 700 km²) are located in Western Southland, some 60 km north-northwest of Invercargill. The Takitimus are predominantly composed of a steeply easterly dipping (~60 to 80°), 14 to 16 km-thick, Permo-Triassic series of calc-alkaline volcanic and volcanogenic sediments of basaltic to andesitic composition. This sequence has been assigned to the Brook Street Terrane, and has been interpreted as the remnants of an intra-oceanic arc (Houghton, 1981; Frost & Coombs, 1989). Ultramafic to mafic plutonic rocks, interpreted as roots of volcanic centres, are intruded along the length of the terrane (Ballard, 1989).

While the Takitimus are located in the catchment area (e.g., Waiau River) of alluvial platinum group mineral (PGM) deposits, the volcanic-plutonic rocks of the mountains themselves are not known to be hosts of PGM. However, recent sampling has revealed a number of previously unreported lithologies, such as chrome spinel-bearing ankaramites and clinopyroxenites, that are known to be associated (e.g., the Permo-Triassic age Greenhills Complex, south of Invercargill; Spandler et al., 1999) with PGM-bearing lithologies. The Mg numbers (i.e., $100 \cdot \text{Mg}/(\text{Mg} + \text{Fe}^{2+})$) of the clinopyroxene ranges up to the high nineties, indicative of equilibration with primitive, mantle-derived basaltic magma. Several samples also contain chromites with chrome numbers (i.e., $100 \cdot \text{Cr}/(\text{Cr} + \text{Al})$) in the high eighties, some spinel with $100 \cdot \text{Fe}^{3+}/(\text{Fe}^{3+} + \text{Cr} + \text{Al})$ in excess of 10, and magnesium numbers in the fifties (see Figures below). All of these characteristics are typical of equilibration with relatively oxidised, primitive arc-type magmas. Trace element analytical studies including UV laser ablation inductively coupled plasma source mass spectrometric analysis of clinopyroxene and spinel in ankaramite hosts has revealed arc-type equilibration signatures and the presence of Ru and Rh, respectively.

