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Earthquakes – the Alpine Fault

Teaching high-ability science students

Non-native birds

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A forum for the exchange of views on science and science policy

Editor: Allen Petrey
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Contents

Cover: Deep Fault Drilling Project (DFDP-2) drillsite, where a cohort of geologists, geophysicists, and seismologists have been drilling into the Alpine Fault to discover the physical processes that generate earthquakes on the Australian-Pacific plate boundary (*see article on p 27*).

Photo by J Townend

Instructions to Authors

New Zealand Science Review provides a forum for the discussion of science policy. It also covers science education, science planning, and freedom of information. It is aimed at scientists, decision makers, and the interested public. Readability and absence of jargon are essential.

Manuscripts on the above topics are welcome, and should be emailed to the editor (editor@scientists.org.nz).

As well as full papers, short contributions, reports on new developments and conferences, and reviews of books, all in the general areas of interest detailed above, are invited. The journal may also accept reviews of a general nature and research reports.

Full manuscripts (with author's name removed) will be sent for peer review, and authors will be sent copies of the reviewer's comments and a decision on publication. Manuscripts should not normally have appeared in print elsewhere, but already published results discussed in the different, special context of the journal will be considered.

Manuscripts should be accompanied by biographies of not more than 100 words on each author's personal history and current interests. Authors are also expected to supply a suitable high-definition passport-size photograph of themselves. This will be published with the article.

Articles may be submitted in MS Office Word, rich text format, or plain text. Diagrams and photographs should be on separate files (preferably eps, tif, jpg, at 300 dpi), not embedded in the text.

All tables and illustrations should be numbered separately – Tables 1, 2, 3, 4, etc., and Figures 1, 2, 3, 4, etc. – and be referred to in the text. Footnotes should be eliminated as far as possible. Diagrams and photographs will be printed in black and white, so symbols should be readily distinguishable without colour, and hatching should be used rather than block shading. However, colour may be used if the author or the author's institute is willing to pay for the added cost.

References should preferably be cited by the author–date (Harvard) system as described in the Lincoln University Press *Write Edit Print: Style Manual for Aotearoa New Zealand* (1997), which is also used as the standard for other editorial conventions. This system entails citing each author's surname and the year of publication in the text and an alphabetical listing of all authors cited at the end. Alternative systems may be acceptable provided that they are used accurately and consistently.

In this issue

In 1941, geologists Harold Wellman and Richard Willett traversed the length of Westland, mapping what would become known as New Zealand's Alpine Fault[1]. Their work relied on surface observations.

Carolyn Boulton and her colleagues in their article, A *window into thousands of earthquakes: Results from the Deep Fault Drilling Project* (DFDP**)** describe how a cohort of geologists, geophysicists, and seismologists drilled into the Alpine Fault to discover the physical processes that generate earthquakes on the Australian–Pacific plate boundary.

The project has provided researchers with unparalleled opportunities to understand the mechanisms that generate earthquakes on the Alpine Fault. Results show that fluids play a fundamental role in explaining the weakness during earthquakes.

The new underground observations arising from DFDP are motivating current researchers to discover the physics that underpin these dramatic displacements and the as-yet unpredictable earthquakes that accompany them

With many countries relying on science and technology for their future economic prosperity, science educators must nurture curiosity and encourage high-ability science students to become creative and innovative scientists of the future.

In the exploratory case-study, *If only I had time: Teachers' perceptions of teaching high-ability science students,* Jenny Horsley and Azra Moeed employ semi-structured interviews to investigate how four award-winning science teachers identified and addressed the learning needs of their high-ability science students. The research was underpinned by a constructivist theory of learning.

Their findings suggest that these teachers were not aware of mandated policies for Gifted and Talented students[2]. Rather they used English and mathematics standardised tests for identifying high-ability science students, and supplemented these with their own approaches. Additionally, although the literature identifies the importance of student-led science inquiry, the authors found no evidence of the teachers engaging their students in authentic scientific inquiry to enable them to investigate their own questions. These findings are discussed in the light of extant literature.

In *The lark descending: Are non-native birds undervalued in New Zealand?* Lincoln University ecologist Stephen Wratten, while acknowledging that bird species that are native to New Zealand are in trouble, also notes that recent data shows that introduced bird species are also disappearing[3]. Stephen warns that this could be yet another warning of New Zealand biodiversity loss.

Finally in this issue there are two book reviews. The first, Brian Gill's *The Unburnt Egg – More stories of a museum curator,* is reviewed by Hamish Campbell and the second, Richard Prum's *The Evolution of Beauty: How Darwin's Forgotten Theory of Mate Choice Shapes the Animal World – and Us,* is reviewed by Geoff Gregory.

Allen Petrey
Editor

[1] Wellman, H.W., Willett, R.W. 1942. The geology of the west coast from Abut Head to Milford Sound, Part I. *Transactions of the Royal Society of New Zealand 71*: 282–386.

[2] Education Review Office. 2008. *Schools' provision for gifted and talented students.* Wellington, NZ: Education Review Office. http://www.ero.govt.nz/National-Reports/Schools-Provision-for-Gifted-and-Talented-Students-Good-Practice- June-2008

[3] http://www.landcareresearch.co.nz/science/plants-animals-fungi/animals/birds/garden-bird-surveys

President's column

This President's Column comes to you from just after the 2017 election while we wait for MMP to deliver our next government. It has certainly been an interesting month or so, with some very dynamic changes in fortune for various political parties and ideas. Throughout this there has been a modest focus on science, but climate change and river water quality have certainly played a role in the conversation. As promised at our annual conference in June[1] the Association, in conjunction with the PSA, held a public forum where science spokespeople for most of the political parties gave a brief statement on their policies and then responded to questions from the audience. Issues like expectations around allowing greater access to scientific views, open data, climate and support for early-career science were all touched on. It was too brief to drill down as to what the future will hold for science. Time will tell.

As I've noted in earlier columns, I think there is a real need to put science more squarely in the political frame. In order to secure things like more science funding and better perspectives on science careers, science has to make the benefits clear, and there is no better way than to do this directly. The Speaker's Science Forum at Parliament, supported by the Royal Society Te Apārangi, is a pathway for presenting science ideas. Worthy as it is, the sector needs something disruptive, to use the parlance of innovation-speak. Imagine a day-long session where we get a diverse range of scientists into Parliament – to be coached in how the political process works and, in exchange, to give politicians free access to some of the brightest minds in the land. It can't fail. It is, of course, an idea stolen from the Australians[2], but think of it as fair exchange for Phar Lap/Pavlova/Crowded House. At the other end of the spectrum, when it comes to injecting science into society, I must point to the Unlocking Curious Minds initiative driven by the present ministry funding science. This seeks to expose young New Zealanders and their families to science ideas and concepts, and surely sets the scene for a society better grounded in scientific ideas.

One of the annual science funding milestones recently was passed – the announcement of MBIE Endeavour results. Behind the stories of great science ideas given a lease of life, lies a dreadful story of wasted effort with little meaningful feedback. With a success rate of around 17% (although complicated because there is a split between economic and environmental outcomes), it is absolutely vital for a transparent and accountable system that seeks to minimise wasted productivity, that there be clear feedback on proposals. In future initiatives the Association will continue to promote better systems for decision-making around funding.

A number of previous columns have dedicated space to the issue of speaking out[3] and the role of university academics being the critic and conscience for society[4]. A new award, the Critic and Conscience Award, supported by the Gamma Foundation and administered by Universities New Zealand, has been instigated in recognition of this key role for society. The inaugural award was made to Dr Mike Joy, a freshwater scientist based at Massey University.

The Association was proud to support a public talk on Suffrage Day (18 September) exploring how we can reach equity for all scientists. I had the pleasure of introducing Dr Zuleyka Zevallos, an applied sociologist and an Adjunct Research Fellow with Swinburne University. She developed and managed Science in Australia Gender Equity (SAGE), an initiative of the Australian Academy of Science. This was based on the Athena SWAN Charter, an evaluation and accreditation programme that has been running successfully for over a decade in the UK[5]. Dr Zevallos reflected on national approaches to improving the hiring, promotion, retention, recognition, and participation of all women, specifically including Indigenous and transgender women, as well as other under-represented minorities in science. Panellists Joanna Kidman, Izzy O'Neil, Di Tracey, and Richard Blaikie gave a local perspective on the ideas, and NZAS past-President Nicola Gaston closed the evening. The audience got a sense of what has been achieved and what goals remain. In the applied sciences one often talks of enabling activity through development of a social licence to operate. This applies equally to science itself and, if science wishes to build a stronger foundation for our society, it needs to reflect that society.

Craig Stevens
President

[1] https://thespinoff.co.nz/science/26-06-2017/ziggy-stardust-and-the-scientists-from-new-zealand/

[2] https://scienceandtechnologyaustralia.org.au/event/science-meets-parliament-2017/

3 *New Zealand Science Review* 2015, vol. 72(1), p. 2. President's Column http://scientists.org.nz/files/journal/2015-72/NZSR_72_1.pdf

4 Education Act 1989: 162, 4(a)(v). http://www.legislation.govt.nz/act/public/1989/0080/latest/whole.html

5 *Nature* (September 2017) vol. 549(7671): p. 143–144, doi:10.1038/549143a

A window into thousands of earthquakes:
Results from the Deep Fault Drilling Project (DFDP)

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In 1941, two geologists, Harold Wellman and Richard Willett, traversed the length of Westland, mapping what would become one of the most influential continental faults in the world, New Zealand's Alpine Fault (Wellman & Willet 1942). The Alpine Fault strikes down the western edge of the Southern Alps, a youthful mountain range on New Zealand's South Island (Fig 1). Here, collision between the Australian and Pacific Plates forms peaks over 3000 m in elevation which trap rain-laden clouds, resulting in 5–15 m of precipitation a year in central and south Westland. Driven by gravity, the rain and snow migrate into fractures and voids along the Alpine Fault, becoming heated and saturated with reactive ions along the way. Within the fault zone, these fluids play a fundamental role in the processes that drive earthquake nucleation and rupture propagation. Measurements made, and rocks recovered, from boreholes drilled during phases one and two of the Deep Fault Drilling Project (DFDP) have enabled scientists to document and quantify these processes for the first time.

Background

The Alpine Fault is an 850 km-long plate boundary fault that represents the largest known onshore seismic hazard in New

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Carolyn Boulton is a Royal Society of New Zealand Rutherford Postdoctoral Fellow at Victoria University of Wellington. Carolyn was awarded a PhD from the University of Canterbury in 2014, and she spent three years at the University of Liverpool as a Postdoctoral Research Associate. She participated on-site during DFDP-1 and DFDP-2 drilling. Her academic research focuses on experimental rock deformation, physical controls on earthquake cycle processes, and geochemical and microstructural indicators of deformation and fluid flow. She has either authored or co-authored fourteen publications on the Alpine Fault.

Lucie Janku-Capova did her MSc in Applied Geophysics at Charles University in Prague, Czech Republic. She is currently completing her PhD at Victoria University of Wellington. Her PhD thesis research has involved participating on-site during DFDP-2 drilling, post-drilling temperature monitoring, and laboratory measurements. Lucie's research uses temperature measurements from the DFDP-2B borehole to identify groundwater flow through fractures and the thermal properties of deformed rocks; together, these datasets are being used to help quantify the overall heat budget in the central Southern Alps.

Jack Williams has a PhD from the University of Otago, during which he investigated fracture damage induced by Alpine Fault earthquakes. As a part of his PhD research, Jack participated on-site during DFDP-2 drilling and in detailed analysis of DFDP-1 cores and downhole images. In addition to Alpine Fault research, he has worked on factors that may allow deformation to localise in the mid-crust (depths 10–20 km), and he contributed to recording the unusually complex surface ruptures that were generated by the 2016 Kaikoura Earthquake.

Jamie Coussens has an MSc in Earth Sciences from Oxford University and recently submitted his PhD thesis at the National Oceanography Centre at the University of Southampton. Jamie's PhD research used models of fluid and heat flow in the Southern Alps to understand how hot fluids modulate the Alpine Fault's seismic cycle. He participated on-site during DFDP-2 drilling and is well known for his dedication to obtaining borehole measurements through rain and gale-force winds.

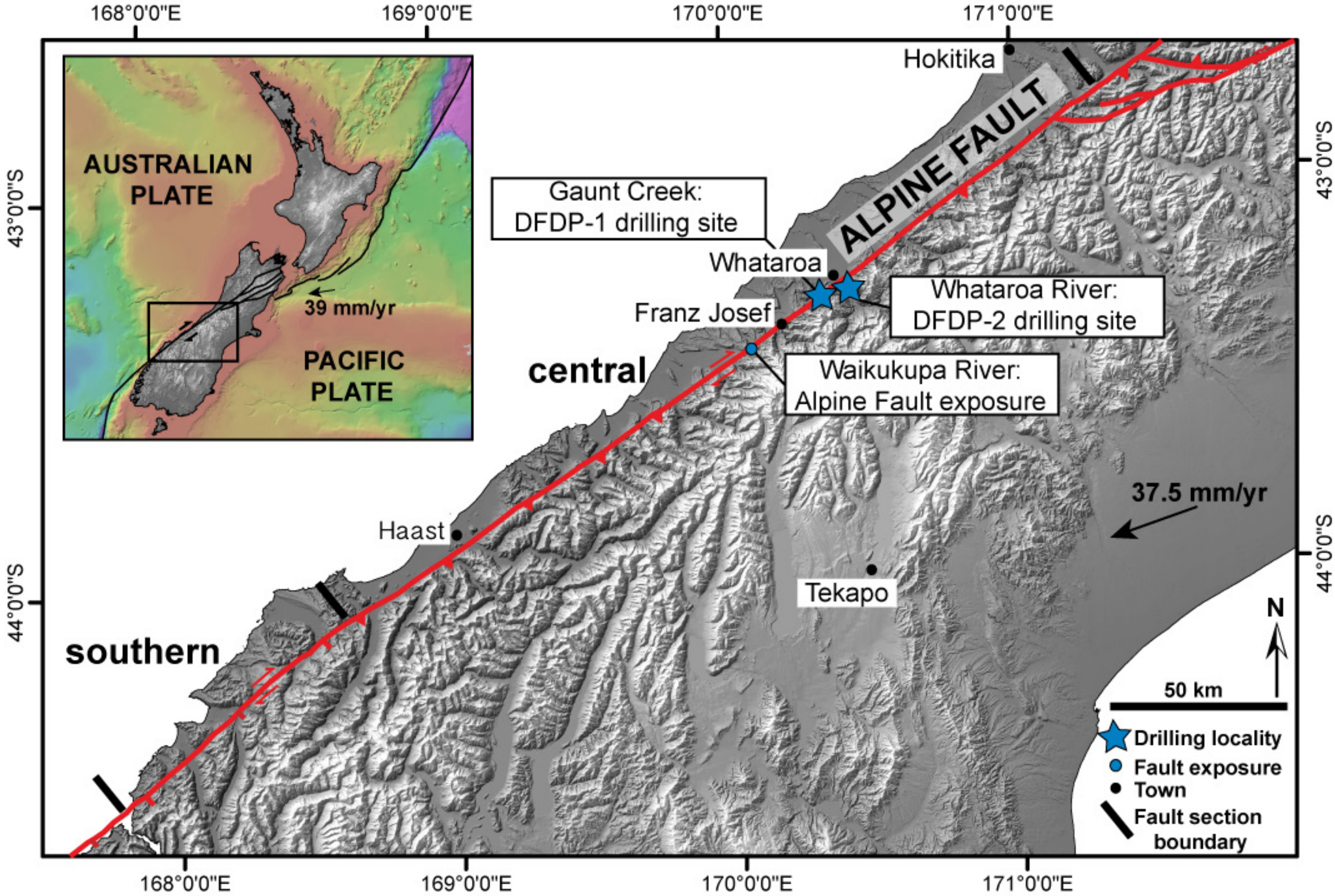

Figure 1. The tectonic setting of New Zealand's South Island, which sits astride the Australian and Pacific Plates (inset). The larger greyscale map is a digital elevation model (DEM) that depicts the trace of the Alpine Fault along with the location of the Deep Fault Drilling Project boreholes at Gaunt Creek and the Whataroa River (blue stars). On the DEM, the boundary between the southern and central Alpine Fault is shown by bold black lines (after Boulton *et al*. 2017a).

Zealand (Fig 1). Years before the advent of plate tectonic theory, Harold Wellman recognised that the Alpine Fault displaces once-contiguous basement rocks in Nelson and Otago by 480 km (Wellman 1953). Today, through the work of Wellman, Evison, Norris, and many others, we know that displacement along the fault occurs during large earthquakes ($M_w \approx 7$–8) that repeat cyclically every 200–400 years as a result of relative motion between the Australian and Pacific Plates (Evison 1971; Norris & Cooper 2007; Berryman *et al.* 2012; Cochran *et al.* 2017). Since the last Alpine Fault earthquake occurred in 1717 CE, current estimates suggest that there is around a 30% probability of an Alpine Fault earthquake in the next 50 years (Cochran *et al.* 2017).

The earthquake cycle is a theoretical framework used by earth scientists to describe the repeating processes of tectonic stress accumulation between earthquakes and stress release during earthquakes (Fig 2). On time-scales of decades to centuries between earthquakes (the 'interseismic period'), the crust surrounding a fault accumulates elastic strain and the driving stresses acting on the fault increase. When the driving stresses exceed the frictional strength of the fault, the stored elastic strain energy is released on time-scales of milliseconds to minutes in the form of an earthquake (the 'coseismic period'). Earthquakes force the fault to slip, fracture rocks around the fault, and generate seismic waves (e.g. Reid 1910; Scholz 2002). After an earthquake (during the 'postseismic period'), any remaining energy is gradually released during smaller earthquakes ('aftershocks'), whose magnitudes decrease with time (e.g. Scholz 2002).

The green fractured rocks exposed in large landslides and warm springs emanating upslope from these crush zones have long hinted at the crucial role fractures and fluids play in the processes that govern the Alpine Fault's earthquake cycle (e.g. Barnes *et al.* 1978; Koons *et al.* 1998; Norris & Cooper 2007).

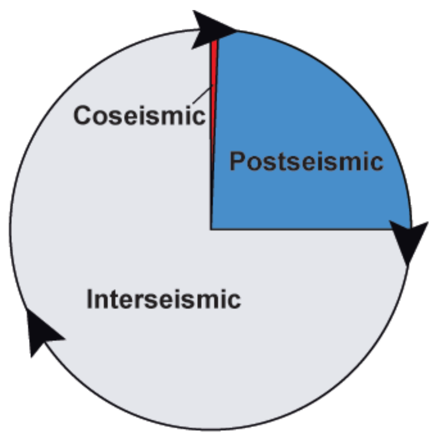

Figure 2. Schematic figure of the earthquake cycle, wherein the process of interseismic strain accumulation and tectonic stress build-up is repeatedly followed by earthquake nucleation and coseismic slip. Coseismic slip often promotes large-scale fluid migration and stress re-adjustments, which can trigger aftershocks in the postseismic period; this phase of the Alpine Fault's earthquake cycle is still poorly understood.

Ongoing uplift has exhumed deformed rocks from around 35 km depth, giving earth scientists the opportunity to study the origins of Alpine Fault earthquakes (e.g. Little *et al.* 2005). However, until recently, poor exposure in the forested terrane had kept researchers from gathering the measurements and continuous rock record necessary to quantify physical processes at work in the 'earthquake factory' beneath the Southern Alps. The first two phases of the Deep Fault Drilling Project (DFDP), in 2011 and 2014, drilled, sampled, and monitored the Alpine Fault to better understand earthquake cycle processes.

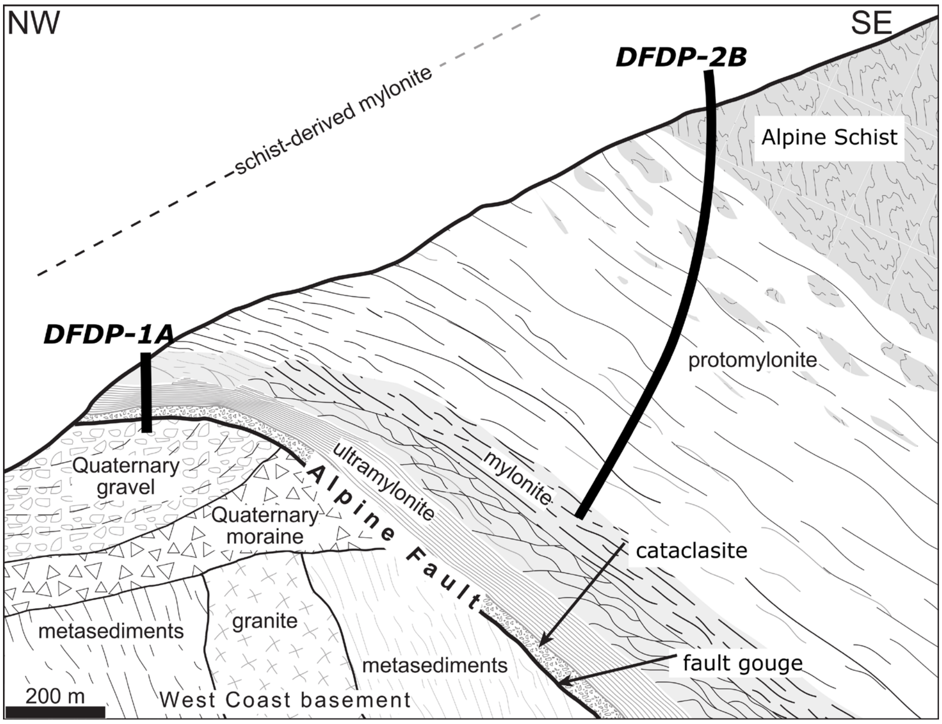

Figure 3. A simplified cross-section of the central Alpine Fault, which accommodates both strike-slip and thrust (top-to-the-northwest) movement. Thrusting brings Pacific Plate rocks deformed at high temperatures and pressures (such as schists, protomylonites, mylonites, and ultramylonites) to the surface more rapidly than they cool. In the brittle part of the fault, the exhuming schists and mylonites are broken up and altered by fluids, forming cataclasites, breccias, and gouges. Sometimes, so much heat is generated during an earthquake that the rocks melt and form pseudotachylytes. Thick, bold lines schematically show the sequences of rocks sampled in DFDP-1 and DFDP-2 (after Norris & Cooper 2007).

Deep Fault Drilling Project Phases 1 and 2

Phase 1 of the Deep Fault Drilling Project occurred in January and February 2011 when two boreholes were drilled at Gaunt Creek, about 20 km northeast of Franz Josef Glacier (Cooper & Norris 1994) (Fig 1). The two vertical boreholes were drilled to depths of 100.6 m (DFDP-1A) and 151.4 m (DFDP-1B) and yielded the first continuous set of rock cores and geophysical measurements from the Pacific Plate to the Australian Plate through the Alpine Fault (Fig 3). In addition, *in situ* measurements of fluid flow in and around the fault were made, and an observatory was installed to provide long-term monitoring of temperatures, fluid pressures and chemistry, and seismic activity near the fault (Sutherland *et al.* 2012; Townend *et al.* 2013; Toy *et al.* 2015).

During Phase 2 of the Deep Fault Drilling Project, initial (DFDP-2A, 212.6 m depth) and primary (DFDP-2B, 893.2 m depth) boreholes were drilled in late August to December 2014. Situated on the banks of the Whataroa River, about 5 km southeast of Whataroa township, DFDP-2 boreholes intersected sediments and fault rocks entirely within the Pacific Plate (*Front cover*; Figs 1, 3). Achieving the original goal of drilling through the Alpine Fault, into the Australian Plate, proved impossible due to technical problems (Sutherland *et al.* 2015). Nevertheless, outstanding geophysical measurements were obtained in DFDP-2B using downhole sensors and geochemical and hydrological indicators of fluid flow within the borehole. Data collected from DFDP-2B complemented results from DFDP-1 and highlighted the intriguing interplay between fluids and fractures in rocks just above the plate-boundary contact (Sutherland *et al.* 2017).

Alpine Fault rocks are exhumed from mid-crustal depths more rapidly than they can cool (e.g. Koons 1987; Little *et al.* 2005; Beyssac *et al.* 2016). As a result, fluids migrating through the uplifted fault rocks are heated and forced to the surface by the combined effects of topography and fault zone structure (e.g. Koons *et al.* 1998; Menzies *et al.* 2014, 2016; Sutherland *et al.* 2017). Along their flow paths, the variably heated fluids play a critical role in: (1) controlling the type and abundance of minerals present, (2) governing the strength of the fault when it slips during an earthquake, and (3) re-strengthening the fault after a slip event. Fluids play such diverse roles because of their ability to both dissolve and precipitate minerals *and* become pressurised when confined within layers of rock. Recent insights into these earthquake cycle processes are described further below.

Borehole measurements

Measurements made within DFDP boreholes provide fundamental information on the fluid flow and temperature regimes around and within the Alpine Fault (Fig. 4). In contrast to laboratory measurements, which are typically made on small (cm-sized) rock samples, borehole measurements reflect system-scale processes, meaning that the integrated effects of topography, fracture sets, and different rock types can be quantified. Downhole measurements of permeability* in DFDP-1B returned a fascinating result: within the borehole – and in the laboratory – plate-boundary contact materials have the same low permeability (Boulton *et al.* 2012; Sutherland *et al.* 2012; Carpenter *et al.* 2014). At Gaunt Creek, permeability decreases up to 6 orders of magnitude within a few tens of metres of the plate boundary, reaching extremely low values at the contact with the Australian Plate. These low values indicate that most open spaces within Alpine Fault rocks immediately above the plate boundary, from the cm-scale to the km-scale, have been sealed, inhibiting fluid movement. Furthermore, fluid movement

*Permeability is a measure of the ease with which a fluid (or gas) moves through a medium: the lower the permeability, the more slowly this migration occurs.

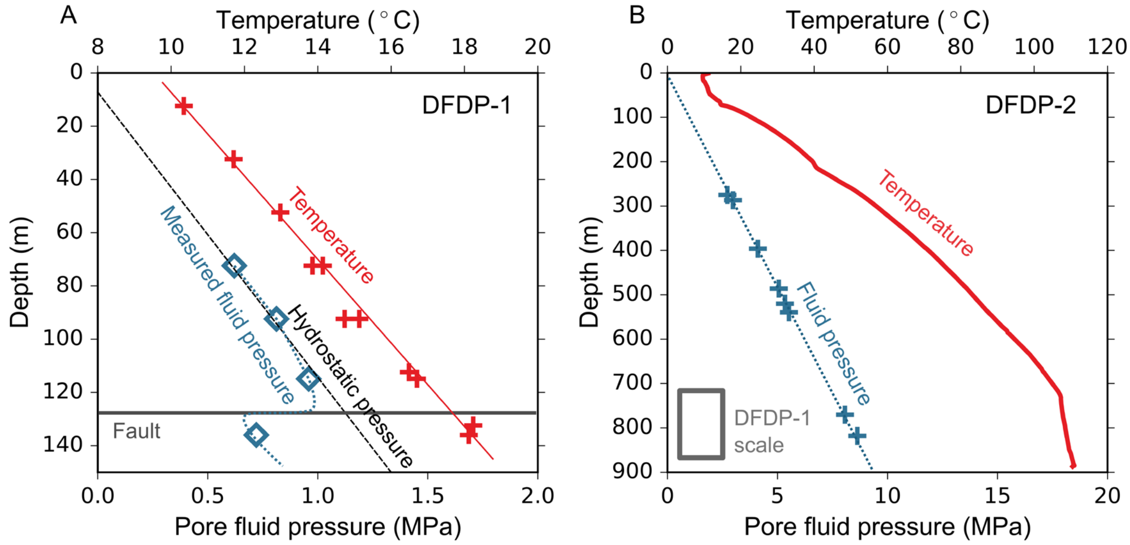

Figure 4. Temperature and pressure measurements from DFDP-1B and DFDP-2B boreholes. (a) DFDP-1B is a shallow borehole drilled through the damage zone of the fault at Gaunt Creek, a minor tributary to the Waitangi-taona River. In the DFDP-1B borehole, fault rock permeability is very low, and very little fluid movement is allowed. Therefore, temperature rises linearly with depth, as does the fluid pressure. Fluid pressure decreases within 20 m of the fault in rocks which have been almost completely sealed by clay and calcite precipitation, and pressure drops dramatically in the Australian Plate rocks below the fault. The line labelled 'hydrostatic pressure' is for reference. Hydrostatic fluid pressure is the pressure created by the weight of the volume of water at a given depth: a hydrostatically pressured fluid is in equilibrium. (b) In DFDP-2B, fault-related fractures are not sealed. Groundwater flows in great volumes and becomes overpressured as it is concentrated under the major Whataroa River valley (i.e. its pressure is greater than hydrostatic). The fluid pressure increases with depth more steeply than in DFDP-1B, and if the borehole was not cased and cemented, the pressurised fluid would have created a column of water 60 m high (similar to a geyser). The upward flow of water is also causing the concave shape of the temperature profile because the water is bringing heat with it. The bottom part of the borehole, where the temperature gradient suddenly drops from > 100°C/km to < 50°C/km, is probably associated with a 'reservoir' where water flows so vigorously that it gets mixed, effectively having almost the same temperature over a hundred metres (after Sutherland *et al.* 2012, 2017).

is particularly sluggish within the layer of clay-rich plate-boundary rocks called *gouges*, within which the slip occurs during earthquakes (Figs 3, 4, 5).

The DFDP-2B borehole penetrated rocks 1000 m to 100 m from the impermeable plate-boundary gouges (Fig 3). At these distances, fluids move rapidly through fault-related fractures that have not been sealed. Normally, thick layers of river sediments keep these pressurised fluids underground, but most keen locals know where they can dig a natural hotpool along a braided river. In DFDP-2B, keeping the fluids from overflowing at the wellhead was a significant drilling-related challenge. The high specific heat capacity of water makes it a very efficient medium for heat transport in the geological environment. Temperatures of fluids surrounding the fault, though, depend on their flow rate through the rocks and the amount of heat that is available to be transferred from the rocks themselves.

Scientists have often tried to calculate the temperature of the rocks surrounding the Alpine Fault. However, past attempts to model the geothermal gradient* differed markedly because of uncertainties related mainly to the influence of topography and fault zone permeability structure (e.g. Koons 1987; Allis & Shi 1995; Upton *et al.* 1995; Batt & Braun 1999). Accurate measurements of the geothermal gradient adjacent to the Alpine Fault were made for the first time in the DFDP-1B borehole, yielding a gradient of 62.6±2.1°C/km (Sutherland *et al.* 2012). In the DFDP-2B borehole, temperature increases even more markedly between the surface and 700 m vertical depth (730 m drilled depth) by a gradient of 100–200°C/km. Below 700 m, the geothermal gradient decreases to 30–50°C/km. The extremely high gradient measured in DFDP-2B (125°C/km on average) is higher than 99% of all other deep boreholes in continental crust (Sutherland *et al.* 2017).

Revised models that combine these temperature measurements and our new understanding that the Alpine Fault forms an impermeable barrier to fluid flow show that: (1) hot upwelling fluids are concentrated into major river valleys (like the Whataroa River) on the West Coast, and (2) the average temperature of the fluids varies with depth along the length of the fault, in response to the changing style and rate of fault movement (Sutherland *et al.* 2017). Temperature is a major control on the way rocks accommodate deformation and the type of minerals that can form within a fault zone.

Rocks recovered

Mineralogy

Between Haast and Hokitika, the Alpine Fault accommodates over 70% of the total relative motion between the Australian and Pacific Plates (27±5 mm/yr horizontally and 6–9 mm/yr vertically) (Norris & Cooper 2001, 2007; Beavan *et al.* 2010). This figure suggests that, compared to all the other faults in the Southern Alps, the Alpine Fault is relatively weak and mechanically efficient at accommodating tectonic motion. There are multiple reasons for the fault's relative weakness, including its longevity, geometric simplicity, and the high temperature of the rocks within it at depth (e.g. Koons 1987; Norris & Toy 2014). Earthquakes, however, only originate in the cooler portions of

*The geothermal gradient is a measure of how much temperature increases with depth below the surface of the earth, and stable continents generally have a geothermal gradient of 20 to 40 °C/km.

the fault at temperatures less than 350 to 450 °C. Here, the dominant fault-forming minerals quartz and feldspar cannot deform aseismically (*without earthquakes*) by ductile creep mechanisms (like worked metal in a forge) (Sibson 1977; Scholz 2002). Instead, deformation occurs frictionally. Frictional behaviour is usually characterised by a locked interseismic period, followed by a rapidly sliding coseismic period.

A special group of hydrous, platy minerals termed phyllosilicates (loosely called clays here) rarely become locked and instead relieve tectonic stress by sliding steadily due to the easily broken bonds between the platy mineral surfaces (e.g. Moore & Lockner 2004). When sufficient clay enrichment occurs, faults are weak, creep continuously, and accumulate less stored elastic strain energy. Thus, weak faults pose a lower seismic risk. In rock mechanics, 'weak' and 'strong' are adjectives used to denote how easily rocks break or slide when pressure is applied. A famous example of a weak, clay-rich creeping fault is the San Andreas Fault near Parkfield in California, USA (Hickman & Zoback 2004; Lockner *et al.* 2011).

Unlike the San Andreas Fault, the weakness of the Alpine Fault cannot be easily explained by an abundance of low-strength clay. Rocks recovered from the core of the Alpine Fault in DFDP-1 yielded an intriguing result: most rocks near the plate boundary are not markedly enriched in clay minerals relative to more distal portions of the fault zone (e.g. Boulton *et al*. 2017a). In fact, the frictionally weak clay montmorillonite only occurs within a narrow, <10 cm-wide, layer immediately adjacent to the Australian Plate (Fig. 5) (Boulton *et al*. 2012, 2014, 2017a; Schleicher *et al.* 2015). Montmorillonite is thermodynamically stable at temperatures less than 150°C, and it requires small reactive particles and fluids with the right chemistry to form. By the time it reaches the surface, the frictional part of the Alpine Fault has experienced between five and ten thousand earthquakes. However, because most of these earthquakes happen where the fault is hotter than 150°C, and the rocks are exhumed so quickly, the weak mineral montmorillonite does not have enough time to form. Instead, montmorillonite only exists in the near surface (upper ~2–4 km) and scarcely influences the interseismic behaviour of the fault zone, which has been completely locked during recorded history (e.g. Sutherland *et al.* 2007).

Earthquake-simulation experiments

In the past twenty years, scientists working in experimental rock deformation have developed extraordinary machines capable of simulating frictional sliding during earthquakes (e.g. Di Toro *et al.* 2011; Ma *et al.* 2014). Earthquake-simulation experiments were conducted on a complete suite of faulting-related rocks recovered from DFDP-1 boreholes (Boulton *et al.* 2017b). These experiments tested how Alpine Fault rocks would behave during an earthquake. During each experiment, powdered rocks were forced to slide at 1 m/s, typical of coseismic slip rates. Instruments recorded the rock's resistance to shear during the sliding, which can be converted into a friction coefficient*. Results showed that all Alpine Fault rocks tested, both wet and dry, have exceedingly low friction coefficients during earthquakes (Fig. 6). Low-permeability, water-saturated gouges containing montmorillonite exhibited the weakest behaviours because pressurised fluids within them are unable to escape during sliding. Planes containing these clay-rich gouges offer little resistance to slip during an earthquake, helping to explain the long history of large-displacement, surface-rupturing earthquakes observed on the Alpine Fault (e.g. Sutherland *et al.* 2007; Berryman *et al.* 2012; Cochran *et al.* 2017). The earthquake-simulation experiments also demonstrated another reason for the Alpine

*The coefficient of friction is a measure of the strength of a rock. Most rocks have a coefficient of friction in the range of 0.60 to 0.85.

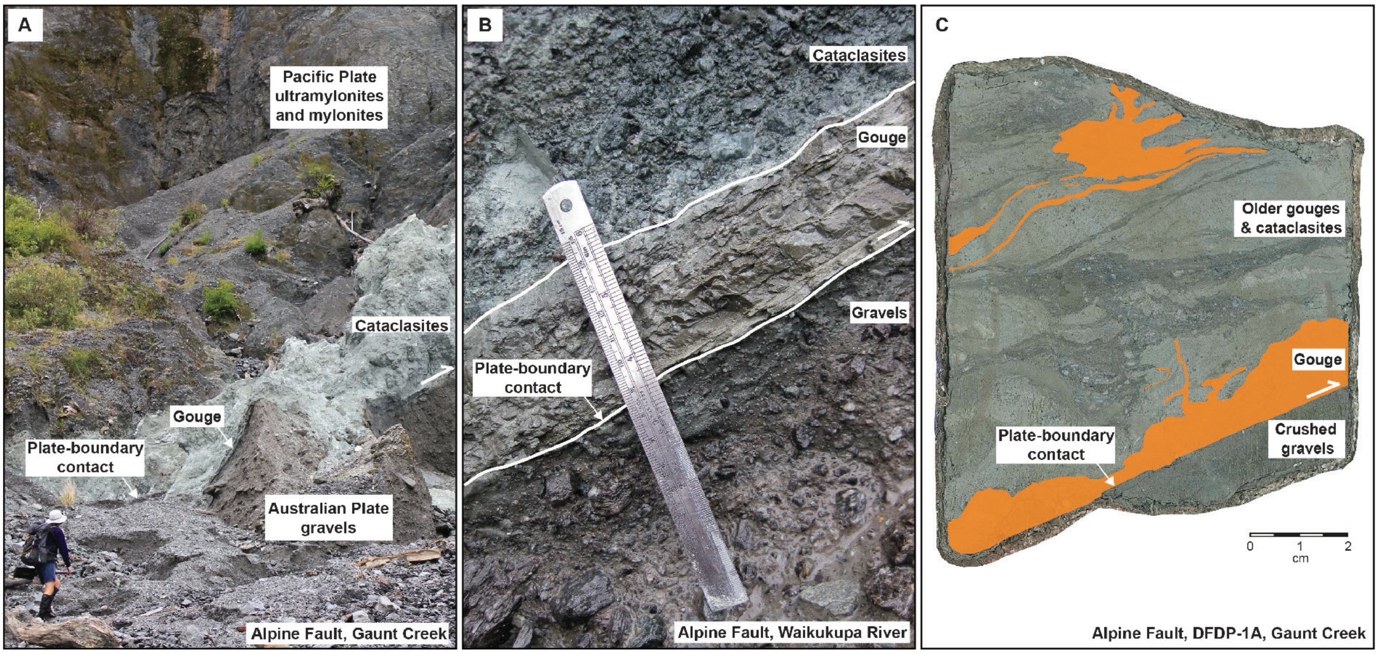

Figure 5. Images of Alpine Fault plate-boundary gouges. (a) The contact between exhumed Pacific-Plate mylonites, cataclasites, and gouges and Australian Plate gravels exposed in a scarp at Gaunt Creek (figure for scale). (b) The same contact exposed in a scarp at the Waikukupa River. The brown-coloured gouges at the plate-boundary contain the weak mineral montmorillonite (ruler for scale). (c) In DFDP-1A drill core, multiple generations of gouges containing montmorillonite are seen (shaded in orange). Older generations are deformed in the rocks above the plate-boundary contact. The most recent generation occurs as a thin layer along the boundary. The orientation of all images is southeast–northwest (L–R) (figures a and b after Boulton *et al.* 2012).

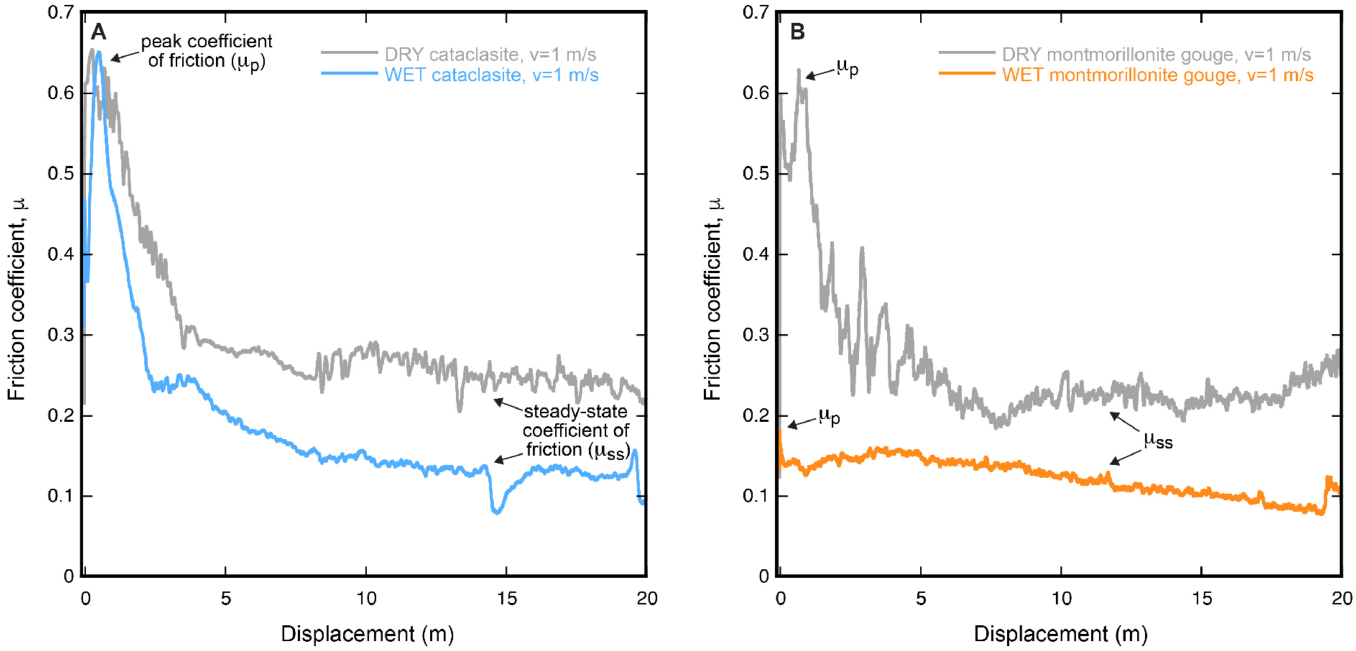

Figure 6. Earthquake-simulation experiment results show the extraordinarily weak frictional behaviour of Alpine Fault rocks at coseismic slip rates. (a) Typical data obtained during dry and wet simulation experiments on Alpine Fault cataclasites, where the coefficient of friction is plotted against displacement, or slip. The coefficient of friction is the ratio of shear stress, the resistance to sliding, to normal stress, the pressure applied to the rock. Note the high peak, but low steady-state friction coefficients. (b) Typical data obtained during dry and wet simulation experiments on Alpine Fault montmorillonite gouges. Note the extremely low peak and steady-state friction coefficients of the wet gouge (orange line) (see Boulton *et al.* 2017b for a complete description of experimental methods).

Fault's relative weakness: frictional heat generated during a large earthquake activates numerous mechanisms that collectively and concurrently reduce the strength of the fault (Boulton *et al.* 2017b).

Images of interseismic strengthening

When an earthquake occurs, rocks surrounding the fault break. Imagine trying to squeeze a fractured rock: it crumbles. For the brittle rocks surrounding a fault to re-accumulate elastic strain energy, and re-start the earthquake cycle, the fractures must heal. Rocks recovered during DFDP-1 drilling record thousands of earthquakes. X-ray images of entire rock cores, along with optical and electron images of smaller polished rock samples, show that circulating fluids above the Alpine Fault heal the damage done during earthquakes (Figs 7, 8) (Williams *et al.* 2016, 2017; Boulton *et al.* 2017a).

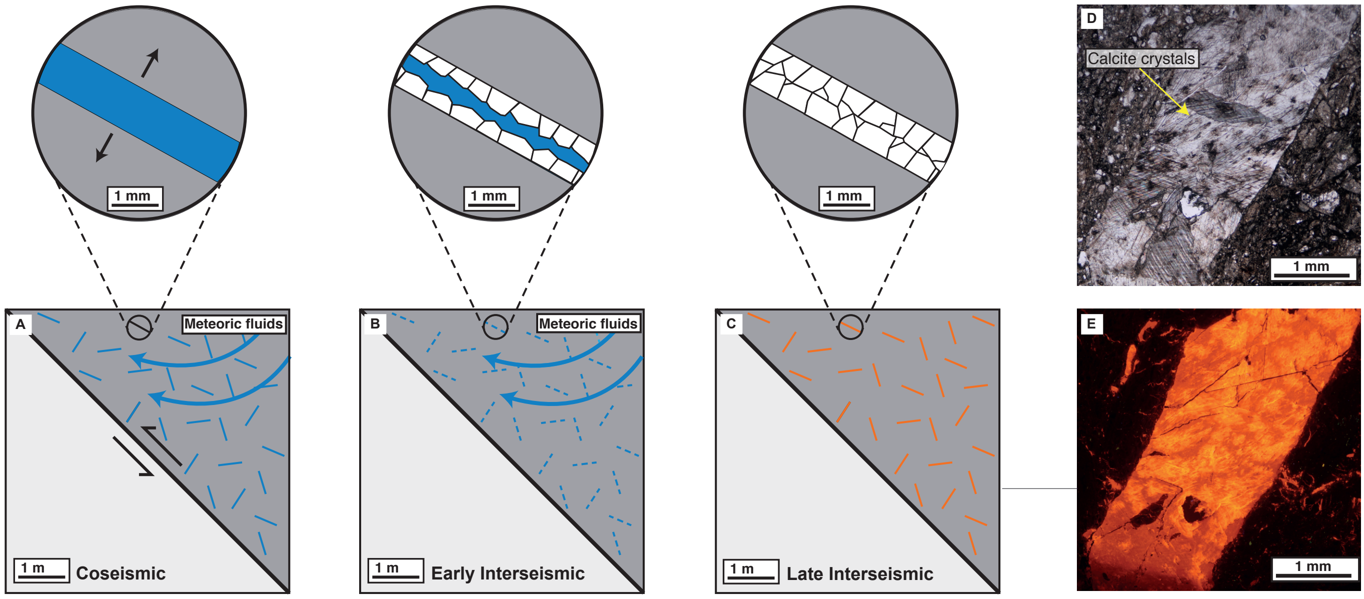

Figure 7. The important role calcite plays in sealing fractures and reducing permeability near the plate-boundary fault. (a) During an earthquake, rocks adjacent to the Alpine Fault are fractured, creating pathways for fluids saturated with calcium and carbonate ions. (b) Fluids (blue arrows) that originated as rain and snow on the Southern Alps migrate through the fractures, precipitating calcite crystals along fracture margins. The fluids are effectively trapped in the Pacific Plate by the impermeable clay-rich gouges. (c) The calcite crystals grow until they meet other crystals, sealing the fracture and reducing the permeability of the rock. (d) A plane-polarised light microscope image of a calcite vein in cataclasite recovered during DFDP-1. (e) The same vein imaged in cathodoluminescence, showing the orange and yellow excitation colours of calcite (after Boulton *et al.* 2017b and Williams *et al.* 2017).

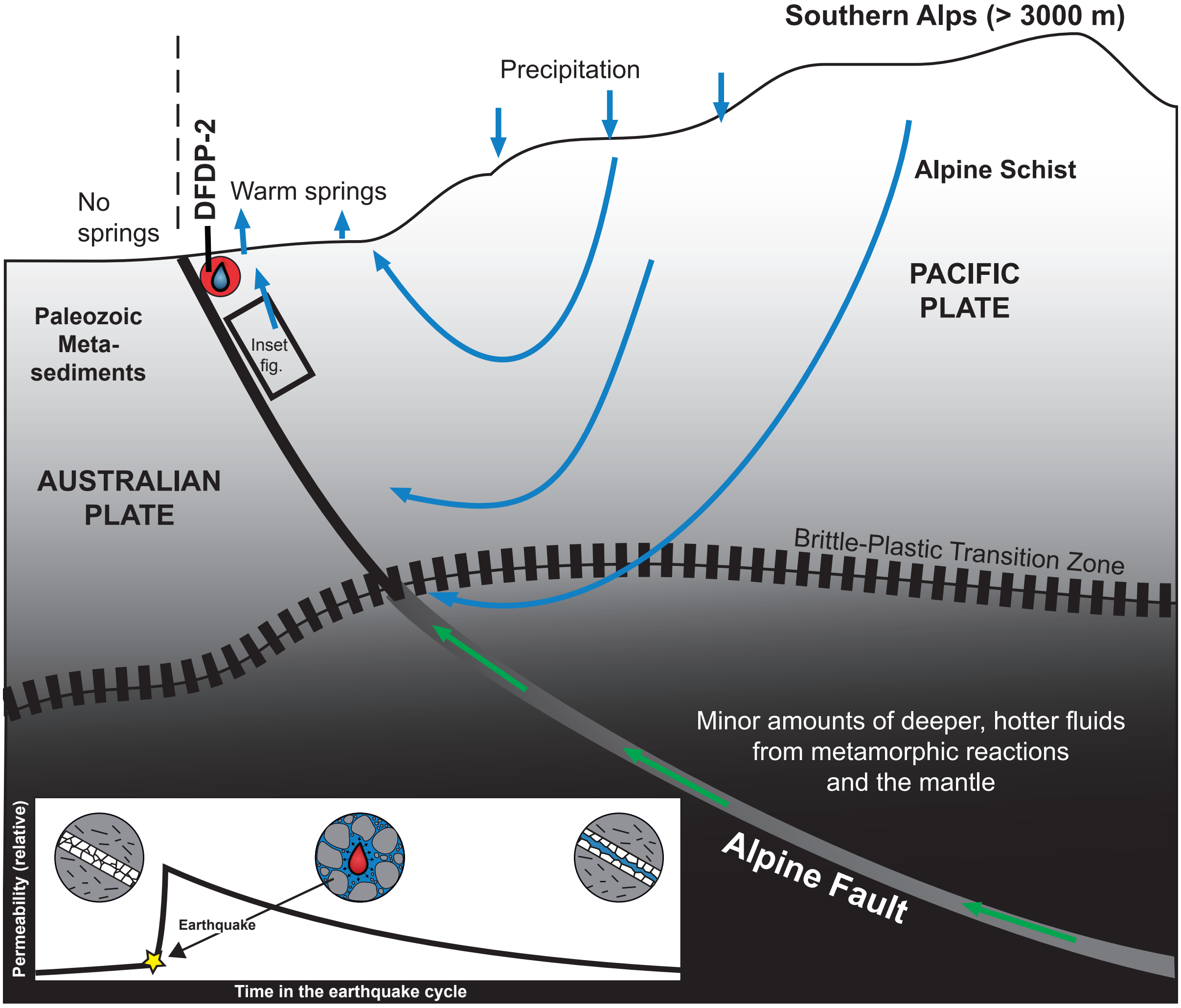

Figure 8. Plate boundary cross-section based on field observations and data collected during the Deep Fault Drilling Project (modified from Menzies *et al.* 2016 and Boulton *et al.* 2017a). The Alpine Fault forms an impermeable barrier throughout the earthquake cycle (bold diagonal line). While there are several fluid sources within the Alpine Fault Zone, meteoric water is volumetrically dominant within the brittle crust. (*Inset*) A plot of relative fault-zone permeability against time in the earthquake cycle, showing the increase in permeability expected during and immediately after an earthquake. Icons illustrate the progressive infilling of fractures with calcite precipitated from hot fluids during the interseismic period. The sealing of open fractures decreases permeability, potentially creating pockets of highly pressured pore fluids which can trigger another earthquake and/or become further pressurised during frictional sliding.

Earthquake-generated fractures are a haven for hot fluids. After an earthquake, these open fractures create permeable pathways through the crushed rocks above the plate-boundary fault (e.g. Sibson 1992). In the upper ~ 6–8 km of the fault, migrating fluids are saturated with reactive calcium and carbonate ions, the principal components of the mineral calcite (e.g. Menzies *et al.* 2014, 2016). In Alpine Fault rocks located closest to the plate-boundary, calcite invariably fills fractures, appearing white in whole-rock samples and optical microscope images, and stunning oranges, reds and yellows in cathodoluminescence (CL) images (Fig 7). At deeper levels, fractures are sealed mainly with a combination of calcite, quartz, and other minerals (Upton *et al*. 1995; Toy *et al*. 2010; Menzies *et al.* 2014).

The net effect of fluid migration and associated calcite (± quartz) precipitation is a gradual decrease in permeability during the interseismic part of the earthquake cycle (Figs 7, 8). At the same time, rock competency increases, promoting interseismic strain build-up. Numerical models of these processes show that as permeability decreases, fluids trapped within the fault zone can become highly pressured, a way of decreasing fault strength and triggering earthquakes (e.g. Gratier *et al.* 2003; see also Sibson 1992). This triggering, or *nucleation*, of a large-magnitude earthquake with a rupture area that spans much of the Alpine Fault marks the start of a new earthquake cycle (Fig. 2; inset, Fig. 8).

Key results

The Deep Fault Drilling Project (DFDP) has provided researchers with unparalleled opportunities to understand the mechanisms that generate earthquakes on the Alpine Fault. Results show that fluids play a fundamental role in explaining the weakness during earthquakes. When fault slip occurs during an earthquake, trapped fluids become pressurised, allowing slip to occur easily. Between earthquakes, fluids circulate through fractures located above the impermeable plate-boundary fault gouge. These circulating fluids carry tremendous amounts of heat, as well as the building blocks of fracture-sealing minerals. Following an earthquake, the gradual precipitation of calcite into open fractures strengthens the fault and primes it for a future seismic event.

Geophysical observations made in the DFDP-1 and DFDP-2 boreholes, along with geological observations made in the laboratory, provide vital information for models of seismic radiation and strong ground motion. Furthermore, the drilling project has enabled over 40 international undergraduate, postgraduate, and early career researchers to collaborate on borehole measurements as well as rocks exposed in the West Coast's rivers and valleys, recovered from the DFDP boreholes, and sent to laboratories worldwide. Just as Harold Wellman's career was inspired by surface observations of the Alpine Fault's astonishing and then-inexplicable movement, our new underground observations are motivating researchers to discover the physics that underpin these dramatic displacements and the as-yet unpredictable earthquakes that accompany them.

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Article

If only I had time: Teachers' perceptions of teaching high-ability science students

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With many countries relying on science and technology for their economic prosperity, science educators are tasked with nurturing curiosity and encouraging high-ability science students to become creative and innovative scientists of the future. This exploratory case study employed semi-structured interviews to investigate how four award-winning science teachers identified and addressed the learning needs of their high-ability science students. The research was underpinned by a constructivist theory of learning.

Findings suggest that these teachers were not aware of mandated policies for Gifted and Talented students. They used English and mathematics standardised tests for identifying high-ability science students, supplemented with their own approaches to identification. Although literature identifies the importance of student-led science inquiry, we found no evidence of the teachers engaging their students in authentic scientific inquiry to enable them to investigate their own questions. These findings are discussed in the light of extant literature.

Keywords: high-ability science students; gifted and talented in science; identification of high-ability science students

Introduction

The late Sir Paul Callaghan, eminent scientist, passionate orator, and proud New Zealander, promoted his vision for his country *where talent wants to live.* Sir Paul's dream was for New Zealand to concentrate on cutting-edge science and technological innovation by attracting our most able students into the field. It would be fair to say that many developed countries are focussing on science and technology for their future. Policy and practice demonstrates that much is being done to achieve this in New Zealand (Timms & Pirls 2015) by aiming to attract outstanding students to sciences. However, it is unclear how this will be achieved in a climate where students are not choosing to study sciences at secondary school (Education Counts 2015; Kearney 2016).

This research focussed on the teaching of high-ability science students by a purposive sample of science teachers. The four New Zealand teachers were each recipients of a university Excellence in Teaching award. They were invited to give their perspective on how they identify, plan and then meet the needs of their most able science students. With New Zealand schools required by the Ministry of Education to report on how they address the needs of high-ability (or, more globally labelled 'gifted and talented') students, it was important for us to determine how this requirement translates to classroom practice and how teachers are supported to meet the needs of these students. Findings are discussed with regard to educational policy requirements for gifted and talented students and existing literature.

In New Zealand, the National Administration Guidelines (NAGs) 'set out statements of desirable principles of conduct or administration for specified personnel or bodies' that sit beneath the legislation governing the country's education system as it affects schools (Ministry of Education 2017, n.p.). In relation to students who may be gifted and talented, NAG 1 (iii)c requires 'school boards, through their principal and staff, to use good quality assessment information to identify students who have special needs (including gifted and talented), and to develop and implement teaching and learning strategies to meet the needs of these students' (Education Review Office; ERO, 2008, p. 1). While this NAG does not prescribe how staff ought to create and use 'good quality' assessment information, or how they should plan to meet these students' needs, there is a plethora of recommendations both nationally and internationally that describe what effective practice could look like (see, for example, Colangelo *et al.* 2010; Taber 2016; Van Tassel-Baska *et al.* 2008).

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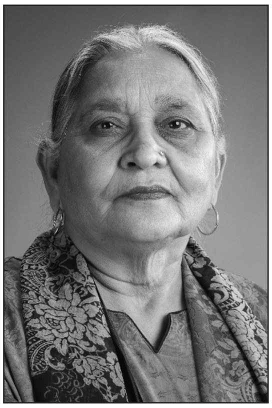

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Given that it is mandated that all schools must assess, identify and make provision for their gifted students, it is reasonable to expect these practices to apply to all schools nationwide. However, ERO (2008) reported that only 42% of those schools reviewed met the needs of high-ability students (i.e. through enrichment[1] or acceleration[2] or a combination of both). Features of the schools that the ERO considered were demonstrating 'good practice' included school leadership, being knowledgeable about effective practice for gifted and talented students, and the schools having responsive and appropriate programmes and well-developed procedures for defining and identifying these students. Interestingly, while the report describes seven cases of effective practice, not all schools included science in their gifted classes. Those that did, cited acceleration provision for the students to enable them to meet criteria for these science programmes. For example, one intermediate school accessed secondary school science for their high-ability students and one secondary school accessed university level science. ERO identified that there were many schools still to make progress in these areas.

A search for international 'requirements' in relation to the education of gifted and talented students revealed wide variation in what is mandated and what is recommended. There is a national mandate in some countries but variation occurs between these nations. In New Zealand, for example, the aforementioned NAG requires schools to identify and report on gifted students. In the United States of America, policy on gifted and talented education is available at state and local levels (Brown & Garland 2015) and in Australia, policy is available at state level (see for example, Australian Capital Territory Government 2017; Government of South Australia 2016). There is variation in policy and practice across Europe, with reports of confusion and inconsistency in Turkey (Mammodov 2015), and collaboration and attempts at cohesion between European countries as they wrestle with issues pertaining to provision and policy for gifted students (Mönks & Pflüger 2005).

Overall, it appears that policy and practice vary between and within countries, but a unifying agenda highlights the importance of differentiated practice to meet the needs of each country's most able citizens.

Defining and identifying high-ability students

Borland (2009) suggests that identifying students for gifted programmes is potentially fraught with challenge as there is no agreement about 'what this construct, giftedness, is, how it reveals itself, or what it is composed of.' (p. 262). He suggests that identification of gifted students must include both predictive validity (does the assessment predict future criteria for inclusion in gifted programmes?) and construct validity (does the assessment measure giftedness?).

International provision for identifying and meeting the needs of high-achieving students is well reported in literature (see for example, Assouline & Lupkowski-Shoplik, 2012; Renzulli & Reis, 2004). New Zealand schools select their own definition and means of identification, with suggested models that include Renzulli's (1978) Three-Ringed Conception of Giftedness and Gagné's (2008, 2009) Differentiated Model of Giftedness and Talent (DMGT). Whereas Renzulli's model focuses on gifted behaviours (above average ability, task commitment, and creativity), Gagné distinguishes between gifts and talents, recognising the developmental process in learning and acknowledging the role of environmental factors in students' education.

Renzulli *et al.* (2009) recognised behavioural characteristics often cited in research that identify students gifted in science. These include curiosity, enthusiasm and interest, and clear articulation of data interpretation. An observational scale comprising these and other characteristics is used to rate students and to measure their interest and engagement with problem solving and understanding of science concepts. Similarly, Taber & Riga (2007) advocate using a range of characteristics to identify high-ability science students, while Kornmann *et al.* (2015) recommend teacher nomination based on their knowledge of the students. Other methods of identifying gifted students include the use of: dynamic assessment (Sternberg & Grigorenko 2002), portfolios (Johnsen & Ryser 1997), and multifaceted tools to ensure identification reflects the diversity of today's classrooms (Borland & Wright 2001). Standardised testing is recommended for inclusion in advanced placement and other elite gifted programmes (Brody 2015).

Regardless of the means of identifying students who are gifted in science, what is arguably more important is ensuring high-ability learners receive an appropriately planned curriculum that enables them to experience 'opportunities for creativity, flexibility, and critical thinking in science … [including] advanced and differentiated services in science.' (Renzulli *et al.* 2009, p. 101).

Provision for high-ability science students

Science education research has identified the importance of gifted science students having a strong understanding of the Nature of Science (NoS) (Gilbert & Newberry 2007; Taber 2016). Gilbert & Newberry (2007, p. 18) state that 'anybody who is in any way gifted in science must be on their way to a grasp of the philosophy of the Nature of Science'. They emphasise the need for these science students to receive high levels of content knowledge. Taber (2016, p. 94) suggests that teaching NoS provides an opportunity to 'engage and challenge those learners who are judged to be gifted in science'.

The role of depth, complexity and authentic enquiry in science education for gifted students is evident in research (Kaplan *et al.* 2016). Van Tassel-Baska *et al.* (2008) and Kaplan *et al.* (2016) not only identified the importance of authentic enquiry, but also cited the need for science teachers of the gifted to consider how lessons are paced, ensuring optimal conditions for teaching and learning while including planning for ability grouping. They reiterated the importance of providing gifted students with a foundation that enables them to become producers of knowledge, gaining internalised scientific skills (observation, experimentation, and measurement) while developing a way of thinking that empowers them to consider the world through the mind of a scientist. Van Tassel-Baska *et al.* (2008, p. 584) identified five key components of science programmes that support gifted students to develop these skills: opportunities to experiment in a laboratory; content-based curriculum pitched

[1] Enrichment 'refers to the provision of learning opportunities that give depth and breadth to the curriculum in line with students' interests, abilities, qualities, and needs' (Ministry of Education 2012, p. 59).

[2] A seminal definition of acceleration describes it as 'progress through an educational program at rates faster or at ages younger than conventional' (Pressey 1949, p. 2).

at a high-level; opportunities to engage with 'real' scientists; focus on inquiry processes; and, science topics that focus on 'technological applications of science in the context of human decision making and social policy'. Unsurprisingly, science-enriched programmes for the gifted impact positively on students' attitudes towards science, with gains in both motivation and confidence in science (Oliver & Venville 2011; Stake & Mares 2005).

Key elements of science programmes for high-ability students are: opportunities to experiment in a laboratory, content-based curriculum pitched at a high level, opportunities to engage with 'real' scientists, a focus on inquiry processes and authentic topics (Han 2017; Kaplan *et al.* 2016; Van Tassel-Baska *et al.* 2008), and the important role of NoS (Gilbert & Newberry 2007; Taber 2016). We consider these in conjunction with national policy and recommended practice alongside the data gathered from the teacher participants in this study.

Life-long learning in science

Nationally and internationally, where students can opt out of studying science they are choosing to do so. A report from the United Kingdom cites parents' and teachers' lack of knowledge about potential careers in science as a reason for students choosing not to continue studying science subjects through secondary school (Kearney 2016). Kearney suggests that encouraging high grades discourages students from studying science as high grades are perceived to be easier to attain in other subjects. A recent Programme for International Student Assessment (PISA) report found that in New Zealand 'There are larger proportions of students with low performance in science … than there were before 2012' (Education Counts 2015). Paradoxically, the report identified that – when compared to other 15-year olds in OECD countries – New Zealand science students were less confident in their own science ability, but had greater levels of enjoyment in learning science, coupled with a higher awareness of the NoS and the utility of science study for later life (Education Counts 2015). While retaining students' interest in science is an issue, so too is the need to ensure that our most able science students continue to study science while receiving a curriculum that is commensurate with their capabilities.

An important component in generating life-long learning in science is the ability to engage students in topics of interest to them (OECD 2008). Engagement encourages students' enjoyment in learning, creates curiosity, and stimulates interest (Mulqueeny *et al.* 2015; Slavit *et al.* 2016). Engagement is important in preventing high-ability students from becoming bored and underachieving (Landis & Reschly 2013; Rubenstein *et al.* 2012).

Methodology

This small-scale exploratory case study was aimed at investigating the perceptions and beliefs of teachers of high-ability science students. Our intention was to gain a deeper understanding of how a group of highly able teachers identified and addressed the needs of their high-ability students. Case studies provide 'thick rich description of the phenomenon under study' (Stake 1995, p. 42) and use an inductive mode of reasoning through which 'generalisations, concepts, or hypotheses emerge from an examination of the data grounded in the context itself' (Merriam 1998, p. 13). We decided that a case study with in-depth interviews with participating teachers was the best approach. The research was informed by the constructivist theory of learning which is underpinned by the idea that knowledge is personally constructed by the learner making connection between new ideas and their prior knowledge. Additionally, a teacher's knowledge and understanding of the needs of high-ability students and providing rich learning experiences for capability-appropriate knowledge construction is essential.

The paper focuses on teachers' views relating to the identification, provision and perceived effectiveness of programmes for high-ability science students in their classes. The research questions were:

1. How do novice teachers in their first three years of teaching identify and make provision for those students of high-ability in science?
2. What evidence do these teachers gather to identify the effectiveness or otherwise of these provisions?
3. What barriers might these teachers identify in meeting the needs of their high-ability science students?

Participants

Participants in this study were four teachers who had each gained an Excellence in Teaching Award, which is their university's acknowledgement of a small group of student teachers who excelled in both the academic and practicum components of their year-long studies in initial teacher education. These student teachers either completed a Graduate Diploma in Teaching or a Master of Teaching and Learning qualification ($n=250$ to 350). The awards are restricted to ten students ($n=10$) each year. There were additional student teachers who had gained an Excellence

Table 1. Participant information.

	Years in teaching	Teaching subjects	Current teaching	School type	Relevant background information
Sam	First year	Maths and physics	Maths from Years 10 to 13 (Age 14 to 17 years)	Large (1800 students), state, coeducational	Has worked in government departments. Very capable and has come to teaching in his 50s. Master of Teaching and Learning.
Jane	Third year	Science and chemistry	Year 9, 10, 11 Science, Year 12, 13 Chemistry	Medium (1000 students), state, coeducational	She has a real passion to work with special needs students, very creative, owns a business with her husband and makes science themed jewellery. Graduate Diploma in Teaching (Secondary)
Beth	Third year	Science and physics	Science in Years 7, 8, Physics to Years 12, 13	Small (600 students), private boys	Beth has a PhD in Physics and is a trained clinical psychologist. Graduate Diploma in Teaching (Secondary)
James	First year	Science and physics	Science to Years 9 & 11, Physics to Years 12, 13	Medium (800 students), state, coeducational	James has a degree in Biology and Chemistry Has come into teaching straight after gaining his degree.Graduate Diploma in Teaching (Secondary).

award, but those who were purposefully selected had a background in science, taught science, were willing to participate in the research, and were teaching in local schools accessible to the researchers. All names reported here are pseudonyms and the information provided ensures their anonymity.

Semi-structured interviews of approximately one hour for each teacher took place in the teachers' schools at a time convenient to them. The information sheets and consent forms were sent to the participating teachers beforehand. Table 1 provides descriptive information about the teacher participants in this study.

Each teacher interview was conducted, audio-recorded, and transcribed by the same researcher. Questions were prepared following a review of existing literature, then trialled with a non-participating teacher after which minor changes were made for clarity. The analysis was conducted through reading and re-reading the transcripts and coding statements with similar ideas. A non-participant researcher was asked to code the same interview transcripts and these codes were discussed and agreed upon. The themes that emerged are presented in the results below where we have used a balance of quotations to provide teachers' voices.

Results

The findings presented describe the participant teachers' understanding of ways to identify and provide for high-ability science students, their perceptions of the effectiveness of these provisions, and any perceived barriers to meeting the students' needs.

Awareness of policy for gifted and talented

None of the participating teachers knew about their school's policy for addressing the learning needs of gifted and talented students. Jane said that she had not been given access to such a policy document. She added 'I mean there probably will be a policy somewhere … we have streamed-classes … that would be as far as the policy goes, as far as most teaching staff are aware anyway.' Beth was unsure: 'Yes, I think it is somewhere, I have considered hunting it down. I did the Gifted and Talented course [during her university study] and just follow what I learnt there.' James said that he had not seen such a policy document, while Sam reported that his school had not told him they had a policy but he intended to ask his PRT[3] supervisor about this.

Identification of high-ability students

Participating teachers in this study had not sighted school policy pertaining to identification of gifted and talented students. When asked how they identified these students, all participants said that their schools conducted Progressive Achievement Tests[4] (PATs) for English and mathematics. These tests assess students' mathematics, listening comprehension, punctuation and grammar, reading comprehension, and reading vocabulary. Most secondary schools use these when students enter year 9 (aged 13 years), their first year of secondary schooling. All four teachers had access to the results of these tests and two (Sam and James) said that their school streamed year 9 classes based on these test results.

All four teachers said that they used PATs as a guide; however, Jane did not think they were particularly useful for her students – she had a class of students who all had learning difficulties due to dyslexia, dyscalculia, or dyspraxia. They typically scored lower than other students due to their challenges with reading. Jane said:

> *I think behaviour issues have got in the way of their learning quite a bit and have resulted in lower outcomes and so while they are a challenging class, we also have some high-ability individuals in the class and in general, apart from maybe two or three students, they are probably higher ability than what their PATs show*

Each teacher used additional indicators and, although talking with the students was one way of gauging their ability, all teachers had slightly different ways of identifying their high-ability students. For example, Sam agreed that he considered their test marks along with his own way of deciding. He talked about a girl in his year 9 class:

> *I've kept track of all their results of all their assessments … I had to go on that … there were some students one I put in even though she hasn't done that well because I KNOW [emphasis is original] she's really bright, but it was mainly based on their assessment results and a couple I threw in just because I thought they were pretty talented but they just hadn't really pushed themselves.*

Beth's decisions were based on PATs but she gave priority to 'students who are curious and creative, thoughtful learners, ask questions often…' Importantly, her school encouraged participation in science beyond the classroom, exemplified in the following statement. Beth elaborated that these students have:

> *Consistently high marks in tests, often accelerated in one or more subjects. They are keen to learn, often involved in out-of-class science activities such as Olympics, science fairs, enjoy going to science related talks at Royal Society..*

James identified his high-ability students not based on PAT marks but on how quickly they answer questions and understand conceptual ideas. He found it easier to support the more able learners because, he said, he understands their learning needs. James said he used the following criteria:

- High engagement level and enormous curiosity
- Consistent high grades across all topics
- Fast learners
- Questions that show high level of thinking: visible effort in trying to fit the new knowledge into existing world views or to change the world view to accommodate the new facts.
- Application of newly learnt facts and theory in novel situations.

James added that, 'One of the students I have selected from my year 9 class has a better conceptual understanding of the NoS ideas than my seniors.'

Two of the schools streamed their year groups in years 9 and 10 and put their high-scoring students in an accelerated learning class. As none of the participating teachers were teaching an accelerated learning class, it was unclear whether such classes were given the opportunity to be accelerated to the next level up.

[3] PRT supervisors are in charge of 'Provisionally Registered Teachers' for their first two years of teaching.

[4] PATs are a series of standardised tests developed specifically for use in New Zealand (for further details see http://www.nzcer.org.nz/tests/pats).

Teachers planning lessons to address the learning needs of high-ability students

Sam said that this was his first year in teaching and although he would like to plan lessons to extend his students, he was struggling to find the time to do so. However, he tried to differentiate his teaching so that the more able students had some challenge. For example:

> *….the start-up questions, sometimes they're easy, sometimes they lead into something else. Sometimes they're excellence*[5] *questions because I feel that we didn't do well enough in the previous lesson and need to revise it. I would like to do more.*

Jane added that she makes sure that her high-ability students have an opportunity to learn and excel and gain scholarships in year 13. James was concerned that it is probably his less able students who miss out:

> *I probably pitch my lessons towards the top end and often the less able students do not get the best deal. I am trying my best to differentiate my lessons. Sometimes unconsciously, and too much. As a perfectionist and high achiever myself, I often unconsciously pitch the content to the level that I think I would be happy with, which is higher than the mainstream standard. I bring in anecdotes that demonstrate that theory is interesting and thought-provoking. This often satisfies the top students but confuses the majority. But on the other hand, as a beginner teacher, I am not very good at differentiation. Most of the times I do not have heaps of extension material for the gifted and talented due to time constraints in planning.*

Beth said she was much happier this year; she felt she had time to plan for these students and they responded well. She added, 'Until last year most planning I did was to give them more challenging work sometimes. This year I have definitely managed to plan for them and it is so good to see them blossom.'

Pedagogical approaches to address the needs of high-ability students

Although all teachers were aware of the need to extend their high-ability students in their classes, they gave different examples of their practice; to illustrate:

> *I guess the talented ones, the ones that I know can do things, like they usually jump straight to the more difficult ones and I like spending time with them, getting them to work out how to solve it and maybe just give them a hint…. At other times, when I'm going over something on the board, I will just take it a little bit further and I'll be linking it to other things and other topics that they otherwise wouldn't know. Linking it to next year's maths umm, and saying, I'll just show this, you don't have to know this but I'll just show you it anyway… that works to raise their curiosity. (Sam)*

Jane said she encouraged her students to come up with the kind of interesting questions that would take them beyond the obvious; she thought that helps to develop their thinking: 'I need to ask those questions and have those discussions,' not just to extend them but to keep them curious and interested in 'wanting to learn more.' Having been a scientist, Beth talked about challenging her students through structuring her lessons around a problem and allowing them to work with others:

> *I tend to introduce lessons as problems that need attention, or set up a challenge for the students to work their way through. These students like to work with others of similar ability and interests. So, I have let them choose their own groups to work in and have not had any problems.*

All four teachers gave examples of how they tried to teach the high-ability students in their mainstream classes. For example, James said:

> *When doing experiments, if the more able students finish early, I give them more challenging tasks. For example. after observing and describing the onion epidermis cells, I would ask them why you can hardly see any cells if you put a whole piece of onion under the microscope, or, give them leaf samples and ask them why the onion cells were not green while the leaf cells were. Or ask students to problem solve or design certain things via a circuit, for example, to test knowledge.*

Although all the teachers tried to say they were not doing much for their high-ability students, they each demonstrated an awareness of the learning needs of these students and of providing opportunities to challenge and extend them.

Assessment for qualifications, a main driver for student learning

Sam started his conversation by saying, 'I like assessing them (laughs) but I've only run about four or five other little assessments because I've just been too busy'. Sam appeared to get a lot of pleasure when his students could understand an idea:

> *I like spending time with students, knowing them, being able to read their reactions … from their responses to questions and when you see that 'ah-ha' look in their eye when they get it 'ah', or when you come around and explain it and they suddenly say, 'ohh, I see now' ….and get on with it.*

Jane demonstrated her response in terms of how she was trying to get her students to learn so that they succeeded and did not just rote learn the answers to gain a particular grade, emphasising, 'this is the kind of thinking you will need, rather than, this is the kind of answer you need to write':

> *I find it is really important for them to model excellent thinking, whether it's in discussion or starter questions and things and to make sure that I'm going through starter questions or whatever it is we're doing, I'm talking really specifically around, this is how you respond at a merit level. This is the kind of thinking that you need to be showing for excellence.*

Beth negotiated the learning and assessment issues and was clear about the importance of both:

> *Our school likes to have very good results but I like the students to learn and then I help them to prepare for assessment;*

[5] The terms Achieved, Merit, and Excellence in our context align with levels of achievement and, although coined for assessment, they are being used extensively to describe the assessment grades students achieve and have become a way of talking about teaching and learning. Briefly, an Achieved grade indicates that a student can describe things, a Merit grade means they can explain, and gaining an Excellence means they can discuss their responses in a more thoughtful manner. Generally,

- Achieved (A) for a satisfactory performance
- Merit (M) for very good performance
- Excellence (E) for outstanding performance
- Not achieved (N) if students do not meet the criteria of the standard. (http://www.nzqa.govt.nz/qualifications-standards/qualifications/ncea/understanding-ncea/how-ncea-works/standards/)

it works especially for more able kinds who really DO want to UNDERSTAND [emphasis original].

James found that his school prioritised learning, which he perceived to be 'great.' He liked the focus on learning but believed that he had some very able students in his class whose needs he tried to address, and he would like to do even more for them. However, most students he taught *struggled* with science and his energy went into supporting them so that they gained at least an Achieved grade. He was spending time with his high-ability students during lunch times and after school to focus on their needs. He enjoyed doing this but it meant he had little time for himself. James laughed and said, 'I guess this is the life of a first-year teacher!' The following year he thought he would have more time. He was satisfied with having some success with raising the achievement level of both the majority of the students in the class and the few who needed extending.

Jane's school was:

Very, very into 'Excellence' grades [laughs] and we're still trying, they [school] still push us to get the kids to Excellence which does mean that you end up rote teaching Excellence skills a bit as opposed to [teaching] thinking in a lot of situations. You have to fight really, really hard to try and encourage the thinking and not just make it content cramming.

Reflecting on her current classes she said, 'They've actually learnt to think a bit more.' Ever concerned about her highly able special needs students, Jane convinced her principal to allow some of her students to sit the chemistry external examination at a higher level, affording them the opportunity for moving into senior chemistry so they were not held back by the class.

Evidence of student learning

When asked how they knew their high-ability students were learning, all teachers said that assessment information and examples of student scores across a range of topics were indicators that students were learning. Sam used:

A whole range of evidence, not just test, their answers, how they explain something to the others, when they come back and ask for clarification. Jim (student) is a very deep thinker. He goes to the philosophy club…. I like talking conceptually; we talk about physics and the universe and stuff like that. What is puzzling is that he failed the last calculus assessment. Yet he seemed to get it in class, understand it in class. One reason can be that he is dyslexic. He has a problem and gets an extra 10 minutes for tests for this reason.

James said he collected his evidence from:

…students' ability to answer the 'tricky' questions; explain complex concepts and phenomena with accuracy and clarity both in class and in assessments; asking thought-provoking questions; and their ability to apply new concepts to novel situations; participating in science related activities after school; self-research on topic of interest; and having the drive to come and want to learn MORE after school.

Beth favoured formative assessment, sometimes running competitive quizzes, using 'Kahoot!' (an online quiz) and tasks for students to do individually and in groups, and she talks with the students while they are working, dropping a question and coming back to them to see where they are at. Jane uses tests, quizzes, formative assessment, and importantly, teaches her dyslexic students how to manage their learning issues and strategies to cope with them.

From the interview data, we analysed how aware the participating teachers were of the policies focussing on the nature of science, aspects of science pedagogical approaches, and programmes within their schools that provided opportunities for acceleration and enrichment of students (*see* Table 2). The sparseness in this table reflects teachers' views.

Table 2. Awareness of teachers on policy, curriculum, and science engagement to support high-ability students.

Teacher	Sam	Jane	James	Beth
National Admin. Guidelines				
Nature of Science			✔	
Laboratory				
Authentic inquiry				
Inquiry			✔	✔
Acceleration	✔			✔
Enrichment				✔

Perceived barriers and teacher concerns

The most common response to identifying perceived barriers to meeting the needs of high-ability science students was 'Time, that's it. I think I could but I just need more time.' James was frustrated with *content heavy* schemes that often "focussed on facts regurgitation, rather than using enquiry learning and practical investigations to develop content understanding and thinking skills.' Beth agreed that their teaching schemes were also content-intensive. There was very heavy emphasis on assessment which James considered and Jane believed transformed the internal motivation from curiosity and mastery to the external motivation of getting good grades. In Sam's and James' view the combination of assessment focus and drive for grades was having a detrimental effect:

I have a top biology student in Y12 who told me that she hated the gas exchange topic because it was "useless." She said, why would you need to know how the spiracles of insects work in any real-life situation? I found this really concerning because adaptation is the key concept of biology and it helps to explain a lot of other concepts and helps to build the big picture. A top inquisitive student who has lost the appreciation for the wonders of the natural world while taking on a utilitarian approach to learning is probably the saddest thing I can think of. (James)

James quoted Pablo Picasso and said 'Every child is an artist. The problem is how to remain an artist once we grow up.' With a sigh, James added, 'my challenge is to keep those who are able and curious wanting to be interested in science.' Beth was also concerned about time but for both herself and the students. She said, 'Just time, my finding time and these students in my school have more out-of-school commitments (debating, sport, dancing, you name it!).'

Sam (who also teaches mathematics) was concerned about students who were exceptionally able: 'really good and I try to help them out':

There are some international students in year 11 and 12, standout great mathematicians, Asians, who I couldn't help because they have been here only a short time and they struggle with English. They are high-ability students too, I *guess I help them a bit, but not sure that we are addressing their learning needs.*

Jane was concerned about her special needs class. She had asked for them all to be in one science class. Every child in the class had learning needs:

So, there's a lot of autism and dyslexia, dyscalculia, dyspraxia. A lot of anxiety, a lot of eating disorders as well in that class but the students are NOT [emphasis is original] low-ability. About a third of the class could be performing at the top end and after getting past their learning issues most are beginning to believe that they can achieve. It has taken half a year for them to learn strategies to manage their learning difficulty but now they are experiencing success. I like that, and I am loving it!

Sam is sometimes puzzled that a student gains an Excellence in one topic, and gains Merit or even just an Achieved in another:

It's like I'm used to someone who's really good just getting excellence in everything, for example Tim just loves maths but there are others who are very capable, they can do it but they don't seem to have a passion for it. I do not have the top maths class but would love to have the opportunity to teach a class of highly able mathematicians who LOVED maths. In the school where I trained I did teach a year 10 high-ability class, it was just wonderful. They just picked things up. They understood things. You could enjoy the beauty of maths with them because they understood and could see it.

School approaches to addressing learning needs

Two schools had some form of streaming and students in the year 10 accelerated learning class could do mathematics with the year 11 class. It appears it is too difficult to try multi-level teaching across all subjects in a large school. There was no provision for acceleration in two out of the four schools where these teachers were then teaching. Jane's school had a homework club which students could attend for extension or catch-up, or whatever they needed. In James's school, acceleration was an option for year 10 and 11 students in mathematics. James had also developed an electronic learning guide for each lesson. His more able students could work their way through the easy questions very quickly and then start tackling the more difficult ones which required them to research more information or to combine different concepts. This was an enrichment programme he was developing that had captured the interest of his senior biology students.

Beth's school offered all students the opportunity to become involved in science competitions and although she encouraged her more able students to participate, only a few did.

James and Jane did not know of any enrichment programmes in their schools but wanted to set up Creativity in Science and Technology for their students. This programme is organised by the Royal Society of New Zealand and offers three levels of projects – Bronze, Silver, and Gold – that students can work on with support from practising scientists.

Discussion

Our findings reveal that all four participating teachers were aware of the learning needs of their high-ability students. None of the teachers was satisfied with the time they had available to focus on planning and working with their high-ability students. From the results, we have identified emergent themes which we have discussed in light of the extant literature.

Although New Zealand has guidelines for meeting the needs of gifted and talented students, our participants had not seen the policy documentation in their schools. While their comments suggest that they were trying to address the needs of their high-ability students, an awareness of the policy might well have encouraged the teachers to consider additional means to support the students and to seek guidance from other teachers. It is noteworthy that content in their initial teacher education courses touched upon students with special needs, including those with high ability, but did not cover it in depth. Beth had taken an additional course in Gifted and Talented education and she said that what she had learnt there she applied in her teaching practice.

The teachers had worked out their own way of identifying the more able students. Each mentioned using the PATs, which all juniors participate in at the start of the year. PATs are used to identify high-ability science students but they are not *science tests*; they are English and mathematics tests. Using these tests for streaming may disadvantage the more able science student who may be weak in English or advantage those who are strong in mathematics. Further, these tests to stream classes do not necessarily identify high-ability *science* students. This was commented on by Sam who acknowledged that just because his student was exceptionally able in one aspect of mathematics, it did not follow that he would be just as good in another aspect. Teacher comments suggested that they thought this selection process was a *blunt tool*, but the best they had access to. Teachers' use of PATs also indicates that the PATs are valued as *standardised* tests with high reliability, an aspect that is constantly reinforced when they are asked to cite evidence. Borland (2009) highlights the need to use tests that are valid for selection of high-ability students and our findings suggest that such tests are not current practice in these teachers' schools.

In accordance with Renzulli *et al.* (2009), the participating teachers used some of the behaviours demonstrated by gifted science students such as creative thinking, enthusiasm for learning science, curiosity, interest in science, and competence in investigative skills. Taber & Riga (2007) advocate the use of a range of characteristics for identifying high-ability students in science. However, the participants used their teacher knowledge of such behaviours and were not using instruments available to measure them in any way. They relied on their own criteria, which could be considered teacher nomination as recommended by Kornmann *et al.* (2015).

The teachers said they used pedagogical approaches that challenged students to think, to be curious, and to ask questions. One could argue that these approaches are useful for all learners, and indeed they are. It appears that the teachers believed the pedagogical approaches they used were important to extend the high-ability science student and all tried to incorporate these in their teaching. Beth's approach was to present the learning as a problem, and in her opinion this challenged the more able learner, a view that is supported by Taber & Riga (2007) who consider problem-solving to be one of the behaviours of high-ability students in science. That said, most participants had good intentions to provide for these students but all acknowledged they did not have the time to thoughtfully plan for teaching high-ability students. James mentioned incorporating tasks that would enable high-ability learners to develop a nuanced understanding of the NoS recommended by the curriculum and by scholars for high-ability students (see, for example, Gilbert

& Newberry 2007; Taber 2016). Sam talked about his student Jim going to the philosophy club, which Sam also went along to, but there was little evidence of other students learning anything about the philosophy of science.

Another interesting finding was that each participating teacher had their own interests and that is what they focused on. Jane was exceptionally good at identifying the requirements of students who had special learning needs and was supporting this group of students. James, who had recently completed his teacher education course, was keen to help students to develop an understanding about the NoS. Beth, who had an interest in gifted students, provided challenges for her students, and framed her lessons around problems that needed to be addressed.

Having the opportunity to engage in authentic scientific inquiry is promoted as an important aspect in the development of scientific thinking, creativity and reasoning (Osborne 2014, 2017). We did not find any evidence of the teachers engaging their students in authentic scientific inquiry to enable them to come up with their own questions to investigate. Scientific inquiry – and practical work in general – has been regarded as a commonly used pedagogical approach in science (Hodson 2014; Millar 2004). Only one teacher mentioned using inquiry, and open-ended investigations (recommended by Han 2017; Kaplan *et al.* 2016) that would challenge these students and perhaps motivate them was not general practice. These teachers may well have provided opportunities for all students to engage in practical work but this was not reported as a specific approach for the high-ability students.

Sam and Beth stated that their schools offered an accelerated learning class but they did not teach such a class and had limited knowledge of how students were accelerated. Beth, who had a personal interest in science outside the classroom, talked about some of her more able students attending science-related talks at the Royal Society of New Zealand and said her school offered enrichment opportunities for the high-ability students.

An interesting aspect raised by Jane related to preparing students for assessment. There is no doubt that assessment of learning matters, and perhaps matters more for the high-ability students. Jane felt she was constantly trying to maintain a balance between encouraging thinking and learning and *training her students to perform in assessment*. The current environment in our country appears to prioritise credits and grades in assessment over deeper learning (Moeed 2015).

Teachers' beliefs have a role to play in how the curriculum is implemented in the classroom. These teachers were aware of the need to both identify high-ability students, and provide the best opportunities they could to extend and enrich learning in science while meeting the learning and assessment needs of their high-ability students. They faced the challenge of not having enough time to do as much as they would have liked in terms of planning to teach in ways that would be ideal for the high-ability students.

Conclusions and implication for policy and practice

In this exploratory study we set out to investigate the ways in which participating teachers identify and make provision for high-ability science students, the evidence they use to evaluate the success of the approaches they take, and the possible barriers they face in being able to provide for these students. The discussion shows that, in the absence of familiarity with the mandated policy and owing to limitations of selection processes, the participants used their own beliefs about the needs of high-ability students to make provision for this group of students. They all used tests and assessment to gauge the success of these students. Not having a clear picture of the policies, and a lack of time to do more were the major barriers they identified.

This is an under-researched area that needs a more comprehensive research project to find out if these teachers' experiences are limited to relatively inexperienced teachers or whether they are more common in secondary school science teaching and learning of high-ability students. A concern that was highlighted was whether and how staff are informed about the policy requirements to meet the needs of high-ability students. In New Zealand, recent international tests like PISA have highlighted the poor performance of the lower-achieving students which has been a current focus of the Ministry of Education and schools. We wonder if this focus on low-performing students is impacting on the needs of the high-ability students, an aspect that needs further investigation.

As these teachers have demonstrated, their enthusiasm for science teaching goes some way to overcoming possible barriers in meeting the needs of their high-ability science students. However, given that New Zealand – and other nations – aspire to develop cutting-edge science and technological innovation, it seems critical that focus is given to ensuring teachers have the knowledge, the tools, and the support to ensure high-ability science students remain in the sciences and potentially become the leaders and innovators of the future.

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THE CONVERSATION

The following article is republished from The Conversation, dated 23 June 2017.
The article has not been edited, and we have attributed the author and his institute, and given the internet citations.

The lark descending: Are non-native birds undervalued in New Zealand?*

Stephen D Wratten
Professor of Ecology, Lincoln University, New Zealand

New Zealand has an audacious plan to protect its native birds. The country has pledged to rid itself of introduced mammalian predators by 2050 and, this year, will spend $20 million on the 'Battle for the Birds'[1], one of the largest predator control programmes in the country's history, across more than 800,000 hectares of land.

Of the 168 bird species that are native to New Zealand, four in five are in trouble, according to a report[2] published last month by the Parliamentary Commissioner for the Environment. New Zealand's native birds deserve all the help they can get, but this should not detract from the fact that new data[3] show that several introduced bird species are also disappearing.

European settlers arrive with avian cargo

The early settlers brought 130 bird species to New Zealand[4], and 41 of them established. Given that in lowland areas in the Canterbury province, for example, less than 1% of the original biodiversity remains, perhaps we should place greater value on non-native biodiversity, *faute de mieux*.

Not everybody agrees with the value of non-native birds. In 1883, Te Whiti was the leader of a peaceful resistance movement at Parihaka, protesting about the sometimes violent confiscation of land by European settlers. He cared about endemic fauna and wrote: 'it was not good work bringing those birds out here; they eat all the potatoes and the oats; they are not good birds to bring out … were there not plenty of good birds in New Zealand that eat no man's food?'

A key recent development, however, which appears to be raising New Zealanders' awareness of the value of introduced birds is the New Zealand Garden Bird Survey[5], organised by Eric Spurr of Landcare Research. This is an example of well-managed citizen science, garnering the help of New Zealanders to make systematic observations. After a decade of data gathering, the results show that at least six non-native species – starling, song thrush, blackbird, goldfinch, chaffinch, and dunnock – have declined since the survey started.

Silent gardens

The counts are only of birds in gardens, and the reasons for the declines have not been determined, but the picture is beginning to mirror the dramatic declines in bird populations in Europe over the last 40 years. Even the common starling is declining[6] in Britain, at the rate of 150 birds for every hour since the 1980s. The skylark, too, has suffered dramatic changes in its numbers in Western Europe. A major decline of 75% between 1972 and 1996 put it in the Red List[7].

In Europe, these birds have played an enormous part in art, poetry and literature for hundreds of years. One is reminded of the poem *The Lark Ascending* by Meredith, and Vaughan Williams' music on the same theme. In art, birds such as the goldfinch have featured in work by Fabritius and Tiepolo, and throughout the Renaissance period this bird's blood-red face and its habit of feeding on thorny thistles led to its association with Christ on the cross. Even the Beatles sang a song called Blackbird, in 1968.

In New Zealand, introduced bird species do not seem to generate the same level of affection as endemic ones such as the tui. In Canterbury, flocks of rooks, which are a key part of the English countryside, were common, but they have been poisoned and shot almost to extinction[8].

Nature's health benefits

International research is clearly showing the restorative benefits[9] of 'a dose of nature', such as a walk in the countryside. Recently, Lin Roberts and colleagues at Lincoln University wrote a major report[10] for the New Zealand Department of Conservation which analysed and quantified the contribution of native ecosystems to New Zealanders' mental health. However, we can't afford to ignore the contribution that our non-native flora and fauna make to our sense of place and well-being.

It is quite possible that the contribution which introduced bird species make to New Zealand is also delivering other ecosystem functions and services. They eat weed seeds and pest insects, pollinate native shrubs and trees, and distribute the seeds of native and endemic plants, just as our endemic birds used to do before their numbers were drastically reduced by New Zealand's introduced predator fauna.

In Britain, urbanisation, fragmentation of the countryside and intensification of agriculture are being associated with these huge losses. In New Zealand, there have been dramatic changes in the farming landscape[11] over the last decade or so. Are these changes likely to impact on the surveys of garden birds? It would be foolish to speculate too boldly on whether farming intensification has impacts on garden bird numbers as there is no serious monitoring of farmland birds.

However, any declines that are there could be yet another warning of this country's biodiversity loss. Male skylarks used to sing in the sky above my house when we were surrounded by low-intensity farming, but now I see and hear virtually none. We are beginning to lose our under-valued introduced bird species and this should be a cause for concern.

**The Conversation*, 23 June 2017. https://theconversation.com/the-lark-descending-are-non-native-birds-undervalued-in-new-zealand-79509

[1] http://www.doc.govt.nz/our-work/battle-for-our-birds/
[2] http://www.pce.parliament.nz/publications/taonga-of-an-island-nation-saving-new-zealands-birds
[3] http://www.landcareresearch.co.nz/__data/assets/pdf_file/0017/143360/nzgbs-2016-report.pdf
[4] https://teara.govt.nz/en/introduced-land-birds/page-1
[5] http://www.landcareresearch.co.nz/science/plants-animals-fungi/animals/birds/garden-bird-surveys
[6] http://onlinelibrary.wiley.com/doi/10.1111/j.1474-919X.2007.00684.x/full
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[9] http://www.pnas.org/content/112/28/8567.abstract
[10] http://www.doc.govt.nz/Documents/science-and-technical/sap258entire.pdf
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Correspondence

NZAS comments on recent water quality publicity*

Dear NZAS member,

We have been made aware by several members of concern and discussion in the scientific community regarding a recent interview on *The Country*, in which Doug Edmeades (soil scientist), and Jacqueline Rowarth (agricultural economist, EPA Chief Scientist) expressed their views about Mike Joy (freshwater ecologist) and his statements concerning water quality [1]. This was a follow up to a column by Edmeades, entitled 'Is Mike Joy a biased scientist?' [2].

The NZAS Council has considered this matter at length and would like to comment as follows:

Professional scientists can and do disagree about the completeness and quality of data, conclusions that can be drawn from that data, as well as the implications that might arise from these conclusions. This is how science works. For the most part, this happens behind the scenes, but it sometimes occurs in public. It is normal practise, for instance, for journalists to seek critical comment from other scientists when newsworthy results are first published.

Calling into question the integrity and professionalism of scientific colleagues, however, is not normal. Ideally, science is a contest of ideas, not reputations, even if it doesn't always live up to this ideal. A public accusation (or accusation by implication) of a lack of professionalism or integrity, of one scientist by another, is unusual and can be serious. Many of the world's scientific bodies have codes of professional conduct that allow for formal means of complaint to deal with such matters.

The Royal Society Te Aparangi's Code of Professional Standards and Ethics reflects the seriousness of this. For example, its code states that members of the society must endeavour to obtain and present facts and interpretations in an objective and open manner; strive to enhance the reputation of their profession; avoid falsely, vexatiously or maliciously attempting to impugn the reputations of colleagues or otherwise compromising or denigrating them in order to achieve commercial, professional or personal advantages; and accept that researchers working on different approaches to a problem may reach different but supportable conclusions within the context of their own research.

We would encourage all our members to reflect on both the letter and the spirit of the Royal Society's code, and the way in which public dialogue of this nature presents scientists and our work to the public.

Sincerely,

Craig Stevens

President of the NZ Association of Scientists

[1] http://www.nzherald.co.nz/the-country/news/article.cfm?c_id=16&objectid=11841935
[2] http://www.stuff.co.nz/business/farming/opinion/91398389/doug-edmeades-is-mike-joy-a-biased-scientist

*This message was emailed to members 6 May 2017. It was not released as a media statement. [Editor]

Is Mike Joy Biased: A response from Dr D C Edmeades to the New Zealand Association of Scientists

The President of the New Zealand Association of Scientists, Dr Craig Stevens, has kindly offered me the right of reply, to explain my recent public statements in which I have suggested that Dr Mike Joy (ecologist Massey University) is biased.

Some background is essential.

I write a fortnightly column for one of the farming magazines, 'NZ Farmer'. I have been doing so for over two years. This activity is *pro bono* and it offers a wonderful opportunity to 'do my bit' to bridge the gap between science and the public – in my case agricultural science and the farmer. I am aware that the New Zealand Association of Scientists, the New Zealand Royal Society and the Prime Minister's Chief Science Advisor are all very enthusiastic about enhancing this interaction.

When selecting topics for the column I am cognizant of the need to stay within the boundary of my expertise – soil fertility, pasture nutrition, fertilisers and general agriculture. But because I work one-on-one with farmers I am often challenged to consider issues outside of my immediate expertise, which impact upon farming. One such issue is the effects of farming on water quality.

I found myself drawn into the public debate on water quality when Dr Jacqueline Rowarth (then Professor in Agribusiness at Waikato University) was personally vilified in the farming press for comments she made about the water quality of the Waikato River based on an OECD report. I obtained a copy of the OECD data- base, which confirmed that what she had said was correct. As recorded in my fortnightly column in September 2016:

> *Professor Jacqueline Rowarth of Waikato University, citing data from the OECD, made the comment that the nitrate levels in the Waikato are considerably lower than many other rivers in the world, adding that this applies also to phosphorous and e-coli.*
>
> *Dr Alison Dewes, a Waikato based vet and self-described agro-ecologist, said Rowarth was, ".... almost twisting the science," and "when people are saying stuff like that they do need to be called on it." Professor Russell Death from Massey University said Rowarth's assertions were wrong.*
>
> *I was curious, what does the OECD data say? A good summary comes from the Morgan Foundation; "The OECD data is interesting in that it shows the three New Zealand rivers covered (Waikato, Waitaki and Clutha) have very low levels of nitrate and relatively low levels of total phosphorous, compared to major rivers in other developed countries. Indeed the Waitaki and Clutha rivers have the lowest and second lowest nitrate levels of any of the 98 rivers reported on. The Waikato has the fourth lowest level of nitrates."*
>
> *Given that Rowarth faithfully reflected the OECD data, why the outcry? Who needs to be called on what? Why the nastiness?*

At about the same time (September 2017) the Havelock North water quality issue emerged and Jamie McKay, the host of a popular national radio show, interviewed Professor Rowarth and Dr Mike Joy (Massey University) about this issue. I wrote a further column in September reporting on the interview:

> *The host of "The Country Show", Jamie MacKay, promoted it as "The Great Water Quality Debate". He introduced the two protagonists using political nomenclature: Professor Jacqueline Rowarth, (Waikato University) in the blue corner and Dr Mike Joy (Massey University) in the red corner. It was and still is (soundcloud/nzherald/the-country-jamie-mackay/water-debate) riveting listening.*
>
> *The discussion started with the Havelock North drinking water fiasco. The initial question was: Is dairying to blame? Rowarth was considered and measured. The matter is still under investigation but here are some possibilities, other than dairying, as to the possible cause. Joy responded somewhat defensively with a clarification – he said that intensive farming was the cause, not dairying. Rather a moot point I would have thought, a trick used most frequently by politicians.*
>
> *He then painted a picture; feed-pads, mob-stocked, big slushy pools of urine and faeces, easy obvious pathway for that material, not just one or two sheep but hundreds and hundred and thousands of cows, so I think on the balance of probability that would have to be right up there. (The implication was that the cows are the obvious source of the contamination in the Havelock North aquifer)*
>
> *In contrast to Rowarth's rational approach, Joy was being emotional. Rather than the blue and red branding offered by MacKay I think the correct categories are science versus alarmism.*
>
> *There were other examples of this contrast. Joy's suggestion that there have been "many outbreaks in intensively farmed areas" was reduced by Rowarth to two instances of water-borne outbreaks of campylobacter, one in Havelock North in 1998 and the other in Darfield in 2011.*

Prior to Christmas 2016 'Plan Change One' – the plan to restore the water quality of the Waikato River – was notified (made public). It created considerable concern among farmers. I attended various farmer meetings and came to the view that farmers needed help in terms of understanding the science behind the Plan. They simply did not have the technical language and knowledge to come to terms with the Plan.

The relevant CRIs – NIWA and AgResearch – were involved in the development of the Plan and the Regional Council was promoting it; it was clear to me that they were unlikely to empathize with the farmers plight and so decided that I needed to get myself up to speed to assist them. During the holidays (2016/17) I read the relevant reports and with the help of several local water-quality scientist came to my own understanding of the subject.

My earlier knowledge was reinforced; there are four major contaminants in water: nitrogen, phosphorus, pathogens and sediments and catchments differ in terms of which of these contaminants is most limiting water quality. Also it became clear that there are many sources of these contaminants: background and urban sources together with the various categories of land use; dairying, drystock, cropping and intensive market gardening (see www.pmcsa.org.nz/wp-content/uploads/PMSCA-Freshwater-report. pdf)

In the New Year (2017) I wrote, what turned into a series of columns, on this subject trying to explain the science in layman terms. Based on the feedback, they were well received. In particular people commented on the clarity and balance I brought to the issue

In March 2017 I was in mid Canterbury visiting farmer clients and the 'plight' of the Selwyn River was discussed – it was 'dry'. I was reassured that this happens from time to time depending on the amount of the rainfall in the foothills. It was explained to me that it is an ephemeral stream (*see* https://www.ecan.govt.nz/get-involved/news-and-events/2017/selwyn-river-flow-explained/). I was subsequently amazed to see an item on TV showing Dr Joy in the Selwyn River essentially conveying the story that intensive dairy and irrigation was the cause.

I recorded my thoughts in a column dated April 2017:

It might have made "good" TV but it was, from my perspective at least, bad science. I'm referring to those pictures of Dr Mike Joy, a fresh water ecologist from Massey University, standing in the dry bed of Selwyn River lamenting about the poor state of New Zealand's rivers.

These pictures and his words perpetuate what appears to be his considered opinion, that, when it comes to water quantity and quality, all roads lead to any combination of nitrogen, dairying and irrigation – intensification of dairying full stop.

From my reading and understanding of the science of water quality, noting that this is not my specialty, it seems to me that Dr Joy's opinions on this subject are biased. I know some water quality experts who agree with this assessment.

The Royal Society of New Zealand, the body that sets the tone and standards for the conduct of science in New Zealand, has a Code of Professional Standards and Ethics.

Section 2.1 deals with "Integrity and Professionalism". It states that a member must:

a. endeavour to obtain and present facts and interpretations in an objective and open manner; and

b. strive to be fair and unbiased in all aspects of their research and in their application of their knowledge in science, technology, or the humanities;

I am not for a moment suggesting that Dr Joy lacks integrity or professionalism. I am raising the more awkward and difficult question: Given his scientific credentials, do the views he has expressed over a number of years in respect to water quality meet the standard set out by the Royal Society of New Zealand?

As I understand these matters there are 4 contaminants; nitrogen (N), phosphorus (P), pathogens and sediments and that all catchments are different in terms of which of these contaminants is the 'rate limiting step' in terms of water quality. Dr Joys speaks only of one, nitrogen.

As I understand these matters there are sources of these contaminants, other than dairying: natural background sources, urban wastewater, cropping and dry stock operations.

As I understand these matters the likely reason for the low water flow in the Selwyn River at present has nothing to do with irrigation. It is due to the drought conditions over the last 3 years in the headwaters of this type of ephemeral stream.

Thus from this perspective Dr Joy's approach to the science of water quality appears biased: one pollutant, one source and one solution.

There are several relevant points about this column that need emphasis. First, the pre-press version was sent to the newspaper's (Fairfax) lawyers. They suggested minor changes, which were made. Also my working title for the column was 'Balance is Important.' The sub-editor inserted the published title: 'Is Mike Joy a biased scientist?' Another feature of the column was that I made it clear that this was not my primary area of expertise (as required under the Code 2.1 (11)), and that my comments were from my reading and understanding of the science.

Jamie McKay did a follow-up to his earlier 'Great Water Quality Debate' and interviewed Dr Rowarth and myself. During this interview he asked – is Dr Joy biased? I agreed with this assessment.

On the 6 May 2017 the President of NZAS, Dr Craig Stevens sent an email to all members. It began:

We have been made aware by several members of concern and discussion in the scientific community regarding a recent interview on The Country, in which Doug Edmeades (soil scientist), and Jacqueline Rowarth (agricultural economist, EPA Chief Scientist) expressed their views about Mike Joy (freshwater ecologist) and his statements concerning water quality [1]. This was a follow up to a column by Edmeades, entitled "Is Mike Joy a biased scientist? [2]. The NZAS Council has considered this matter at length and would like to comment as follows: The key comment from my perspective was:

Calling into question the integrity and professionalism of scientific colleagues, however, is not normal. Ideally, science is a contest of ideas, not reputations, even if it doesn't always live up to this ideal. A public accusation (or accusation by implication) of a lack of professionalism or integrity, of one scientist by another, is unusual and can be serious. Many of the world's scientific bodies have codes of professional conduct that allow for formal means of complaint to deal with such matters.

I was not initially concerned about this development – I thought it was an email to members reminding them of their obligations to the Royal Society's Code of Professional Standards and Ethics. I was sure that I was operating well within these requirements and in any case the email did not make any specific allegations of misconduct.

My mood changed when I received a call from a Radio NZ reporter asking for my response to what I assumed to be the email. I did not enquire as to how they had received the email from NZAS. I realised that this, otherwise benign email, had been sent to at least one media outlet.* I told the reporter that I could not comment because I did not know what the issues were – there were no specifics. I then rang Dr Craig Stevens to ask him what was going on. I was none the wiser. I put my thoughts into an email to him dated 9 May 2017. Over night I had listened to an interview between Radio NZ and Dr Joy.

I have just listened to the RadioNZ item re Dr Mike Joy. It seems to me that, despite my comments to you and to RadioNZ last evening, my worst fears have been realised.

The concern I expressed last evening was that your email to all NZAS Members did not make it clear what the issues were 'on the table'. It contained no specifics - indeed it required no response from either myself or Dr Rowarth.

It is now clear to me, that you and I assume your executive, (by way of your email to all members and your statements on RadioNZ) are suggesting that Dr Rowarth and myself acted contrary to the spirit of the Code of Professional Standards by dealing in 'personalities not facts' or expressed differently, 'playing the man not the ball'. Without putting this specific issue to either Dr Rowarth or myself you have conducted your own kangaroo court and found us guilty. This is of course contrary to the principles of natural justice.

I believe I have the right of reply:

Your email of 6 May states: :"Calling into question the integrity and professionalism of a scientific colleague, however is not normal." Normal or otherwise, I specifically did no such thing. Quoting from my column I said: "I am not for the moment suggesting that Dr Joy lacks integrity of professionalism". I then ask the question: ".... do his (Dr Joy's) views which he has expressed for a number of years in respect to water quality meet the standard set out by the Royal Society? My answer, based on the evidence I discussed was no. If further evidence is required I suggest that you compare and contrast the approach adopted by Sir Peter Gluckman in his recent report on water quality see www.pmcsa.org.nz/wp-content/uploads/PMSCA-Freshwater-report. pdf) *with that adopted by Dr Joy.*

Thus I was dealing with section 2.1 b of the Code: "strive to be fair and unbiased in all aspects of their research AND in their application of their knowledge etc. "

Dr Joy now suggests that he does discuss the other contaminants (i.e. other than nitrate) in his lectures. This is of course irrelevant because I was commented on his public statements. How could I or the public possibly know what he says in his lectures!

Dr Joy now suggests that I am biased. His evidence is that I work in the agricultural sector. This is true but it is not evidence of bias per se. By the way I am more than happy to have my motivation and potential biases discussed – science and scientists must be open to scrutiny.

It seems to me that the NZAS has got the wrong end of the stick on this issue.

*Water quality is a matter of great public concern at present and rightly so. Farmers in particular are having to make major changes to their farming operation, sometimes at considerable cost. They need to be accurately informed and science and scientists have a major role to play in informing the public on the facts and issues. This should be done as the Code requires in a fair and unbiased manner. It is my view that Dr Joy is not assisting in this regard. And it is not just a matter of bias:**

Dr Joy was factually incorrect in asserting that the source of the problem with water quality in Havelock North was intensive farming (www.dia.govt.nz/Government-Enquiry-Into-Havelock-North–Drinking Water)

Dr Joy was factually incorrect to assert that the Selwyn River was running dry because of irrigation and intensive dairying (various observers, pers comm).

The NZAS has an important role as a moderator in supporting the Code. I would have hoped that in this context it would have supported the efforts of those scientists who, despite the risks, attempt to honour that Code.

I look forward to your response.

Subsequently I rang Dr Stevens to ensure he had received my email and to ascertain whether there was to be any follow up. I was informed that he would be taking the matter to the NZAS Executive. I enquired whether my email to him of 9 May would be tabled. I was given no assurance either way but I assume that the invitation, giving rise to this article is a consequence.

Reflections

What can be learnt from this episode?

First and foremost when a body like the NZAS receives a complaint it needs to be made in writing and it must be specific. In turn the specific allegation (s) must be put to the person (s) concerned and they must be given time to respond. Once this response is received and considered the NZAS can then decide what action if any is necessary. This action must then be conveyed to the person (s) concerned noting that once again the person (s) must be given time to respond.

In this case *apparently* a complaint was made and the Association without referring it to the person (s) concerned, put out an email/press release *alleging* misconduct by two members, Drs Rowarth and Edmeades. This is not natural justice and could expose the NZAS to legal difficulties and or public embarrassment and ridicule.

Dr D C Edmeades

26 June 2017

*See Editor's footnote on page 46

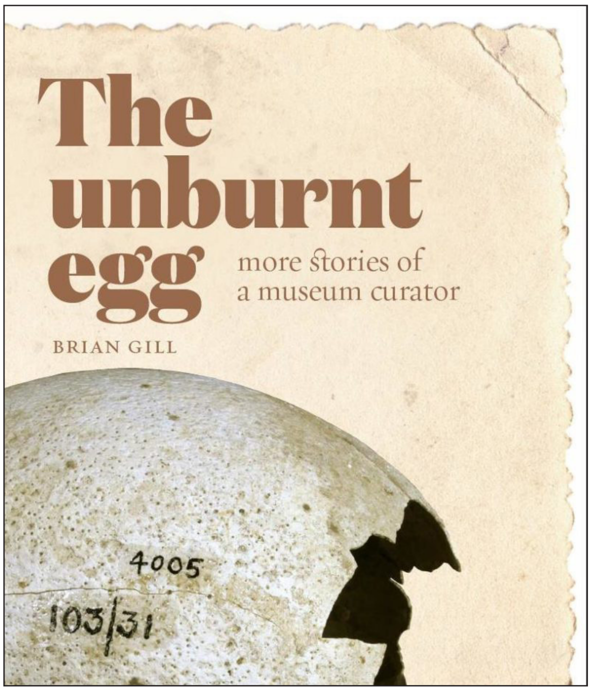
*Note that by the time of writing this column the official report on the Havelock North water issue was public (May 2017) and the cause was not dairy farming as asserted by Dr Joy. Similarly significant rainfall had occured in the headwaters of the Selwyn River catchment and the river was now flowing "normally".

Book Review

Brian Gill

The Unburnt Egg – More stories of a museum curator

Reviewed by Hamish Campbell*



If you ever had any doubts or concerns about the value of museum collections or the merits of maintaining natural history collections at a regional museum, then this is a book that explains all. It is a superbly crafted set of 14 fascinating stories that collectively illuminate the immensely important role of museums within the world of science.

Each story is an episode of scientific enquiry and endeavour set at the Auckland War Memorial Museum where Brian Gill was employed for much of his career in the Land Vertebrates Department. Through these stories, we the readers, gain an amazing insight into the procedures and skills of a museum curator of natural history. In Brian Gill's case, his world is very much that of an ornithologist (birds), oologist (one who studies eggs), mammologist (mammals) and herpetologist (reptiles and amphibians). His world embraces all land-dwelling vertebrate animals, but not just those of New Zealand; his reach extends well out into the exotic southwest Pacific. It is clear that Auckland Museum is serious about its 'regional' status not to mention its global significance.

There will be some surprises for most readers. For instance, I was delighted to learn that Walter Buller is not the biodiversity criminal that he is cracked up to be. Brian Gill argues, on the basis of sensible numerical evidence, the actual numbers of birds 'taken' by Buller (only 2,230 over a span of 50 years as deduced by Sandy Bartle and Alan Tennyson), that he was much less of a party to the extinction of certain bird species than has been suggested. And did you know that the huia was restricted to the North Island?! At least it was by the time Europeans arrived on the scene. I was also amazed to learn that about 1,000 bird species have been wiped out of the Pacific since the arrival of man, and in particular the spread of Polynesian peoples. One thousand! This is a very heavy burden to bear. As for the story of the 'Unburnt Egg', it is a sad story really, about Blanche Halcombe (a grand-daughter of William Swainson) who in later life became a recluse. But it is very instructive because there are many of us just like her, lost in our own natural worlds, with treasures so precious. What to do with them so as to avoid destruction? A subliminal message might be: act now and at the very least, get them formally registered and in time, lodged with your local museum.

If nothing else, I would urge all NZAS members and readers of *Science Review* to read the last chapter 'Further reflections'. It is a succinct verbal distillation of wisdom based on a life-time of experience as a scientist. We do not hear enough from such voices. In the light of my own background as a part-time earth science curator at the National Museum of New Zealand, Te Papa, I found Brian Gill's thoughts on the dangers of blending science with 'cultural relativism' slightly unnerving but refreshing and compelling. It is difficult for most of us to speak out and he does so well. It is as if he is expressing my own thinking, but transforming rather poorly-formed and uncomfortably non-PC thoughts into sharp clarity.

On the basis of numerous large-scale population surveys globally, museums are considered to be the most trusted entities within society. Brian Gill's writing exemplifies this trust. You cannot but be impressed by the scholarship he brings to bear

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*Hamish Campbell is a senior scientist at GNS Science and resident geologist at the Museum of New Zealand Te Papa Tongarewa.

on his subject matter, his choice of quest and his reasoning. His story-telling is sensitive and thoughtful and I love the way he describes and fuses his subjects (birds, eggs, mammals, lizards and snakes) with people, history, culture, time, place and philosophy. His stories are holistic and complete. He elegantly demonstrates the use and value of carefully curated collections of natural history specimens in museums.

I read this book from cover to cover over a series of flights between Wellington and Auckland, mopping up all that operational sitting-down-time in a distant seat near the back of the plane. So engrossing are the stories that time flew, irrespective of what the plane was doing, and I would surface as the last passenger off. If we all did this, the airline schedules would be seriously compromised! Nevertheless, I recommend this rich compendium wholeheartedly. It is perfect for all lovers of the natural world and a rare insight into what museum curators do and why they do it, and the quite extraordinary inherent relevance, value and power of museum collections in the contemporary world.

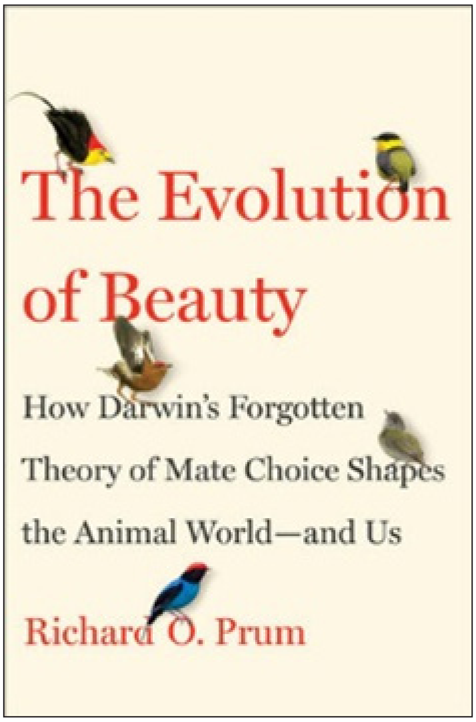
Book review

Richard O. Prum

The Evolution of Beauty: How Darwin's Forgotten Theory of Mate Choice Shapes the Animal World – and Us

Reviewed by Geoff Gregory*

Professor Richard Prum is an obsessive ornithologist, who, in forty years of field observations, is over one-third of the way towards achieving his boyhood ambition of watching every one of the ten thousand or more bird species in the world and researching their behaviour. He knows his subject intimately.



This book parades the facts that have led him to revisit Darwin's second great theory – the independent evolutionary mechanism of sexual selection. He calls this 'Darwin's really dangerous idea' – dangerous because it shows that Darwin's first great theory – natural selection – which is nowadays widely assumed to have all-embracing power, cannot fully explain some aspects of the evolution of species.

Although the notion of our ape-like ancestry generated all of the controversy and gained all of the publicity for Darwin's second great work, The Descent of Man, and Selection in Relation to Sex, the book also contained the revolutionary proposal that animals themselves could play a separate role in their own evolution through sexual and social choices. Referring to the complex colouring pattern of the male argus pheasant, Darwin stated that 'the most refined beauty may serve as a sexual charm and for no other purpose'; the beauty of the male argus had been gradually acquired 'through the preference of the females, during many generations, for the more highly ornamented males'.

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Length: 448 pages
RRP: Hardcover $30, Ebook $32.54
Published by Doubleday (paperback by Anchor Books)

*Geoff Gregory is a semi-retired science editor, formerly in the Department of Scientific and Industrial Research.

Professor Prum has a neat turn of phrase to express how this and other revolutionary ideas apply in his experience. Spice it up with what might be called penetrating observations on the genital structures of ducks, and the insights that these and the mating displays and social arrangements of other bird species give to human sexuality, violence, and artistic appreciation, and you have a stimulating read.

The theory of sexual selection has been subsumed into a utilitarian version of natural selection – that greater beauty is an 'honest indicator' of better genes – which is apparently the prevailing paradigm among evolutionary biologists, evolutionary anthropologists, and even evolutionary psychologists. Professor Prum has apparently had to self-censor his research papers in order to get them past the peer-review process into publication.

He argues that there is no reason to believe that a female great argus or any other species is able to discern the overall genetic quality of a male from his physical appearance or the physiological strengths shown by his display performance; rather it is the aesthetics of the show or the beauty of a colourful plumage that is the primary factor, and any associated attributes that could benefit the health or survival of her offspring are secondary.*

He backs this up with fascinating descriptions and diagrams and beautiful photographs of the gorgeous display feathers of various bird species, including notably some of the manakins, the small tropical bird species on which he is a world authority.

His studies of the evolution of feathers and the finding of colour-producing melanosomes on the fossils of some Cretaceous theropod dinosaurs show that the planar feather vane evolved as a 'canvas' on which to display beautiful colour patterns before flight became possible. It was beauty first, while the utility of the aerodynamic properties of the wings developed later.

Professor Prum describes how a balance between male sexual aggressiveness and female freedom of choice has been maintained by evolution of male morphology and sexual behaviour and co-evolution of female attributes. His examples come from the opposite extremes of sexual coercion and violence by male ducks contrasted with the home building by male bower birds and the supplicant displays by male manakins. Male ducks have evolved a weapon-like corkscrew penis to enforce penetration, while the females have co-evolved both taking off with a mate before sexual maturity enabling him to get in first at maturity and having a contorted vaginal structure to obstruct what is tantamount to subsequent gang rape by other males; she thereby has retained a large degree of control over her reproductive choice. This situation is described by Professor Prum as 'a sexual arms race'. In contrast, male manakins, like the vast majority of birds, do not have a penis, and inseminate the females by a consensual 'cloacal kiss', so they have to work to attract a female and have evolved their displays to this end, while the females have co-evolved an appreciation of beauty to aid their choice of a mate.

Sometimes aesthetic choice has resulted in evolution of maladaptive features. For example, the male club-winged manakin 'sings' to the female by the unique innovative production of violin-like tones from rubbing its wing feathers together, but this accomplishment has entailed the evolution of distorted wing tips and thickened wing bones, both impairing flight.

Turning to primates – as Darwin did – Professor Prum posits that the evolution of human social intelligence and cooperation came about through female choice. It required a transformation from male sexual aggression and the male behaviour of infanticide that is common among primates to paternal investment in collaborative child care and family support. Females choosing more socially and personally engaged mates would reward them with a more frequently repeated, long-lasting, and pleasurable sexual experience and benefit themselves and their offspring with improved survival and well-being. In this way, the co-evolution of parental care and sexual pleasure made possible the development of the human attributes of intelligence, social cooperation, language, and culture.

His 'aesthetic modelling theory' also encompasses an explanation of how same-sex behaviour might have evolved – in different ways for males and females – again, in order to provide females with greater sexual autonomy.

Professor Prum argues that the current social and sexual advantages men enjoy over women are culturally derived. The unfortunate development of patriarchal cultural systems is the new (in evolutionary terms) male component of the human sexual conflict arms race.

He affirms that, unlike men, women do not naturally seek dominance, but strive to retain their evolutionary freedom of choice, and social empowerment for women can be attained through sexual attraction and desire – the Lysistrata solution.

Read this thought-provoking, scientifically reasoned, view of how the stunningly diverse beauty and exuberance of nature came to be, and celebrate what Professor Prum calls 'a world of freedom and choice that is deeply thrilling'.

* It could be noted that the colour vision of birds is thought to be at least as discriminatory as that of humans. See, for example, Vorobyev, M.; Osorio, D.; Bennett, A.T.D.; Marshall, N.J.; Cuthill, I.C. 1998. Tetrachromacy, oil droplets and bird plumage colours. *Journal of Comparative Physiology A 183*: 621-633.

Scientists' stunning images

NIWA's annual photographic awards have produced some amazing shots this year, a few of which are shown here.

From the bottom of the ocean to the top of atmosphere, NIWA staff work in some of the world's most stunning landscapes.

These beautiful environments form the backdrop for the vast array of environmental science undertaken by our researchers, and are celebrated each year with NIWA's annual photographic competition for staff.

But, as described by Susan Pepperell, sometimes it's the stories behind the winning shots that also deserve telling.

Environmental monitoring technician Hamish Sutton tramped for three days, crossed three gorges and negotiated a long section of boulders to get his shot, which won the Our Places category of the competition.

The photo features Ivory Lake Hut on the West Coast, built for the Ministry of Works in 1970 to enable monitoring of the glaciers, and its walls are full of the names of past NIWA employees who have worked there.

Porters Pass. Credit: Shannan Crow

Freshwater fish ecologist Shannan Crow made several attempts and spent hours and hours waiting to get his photograph of Porters Pass which was a clear winner of the People's Choice voted by the public via social media.

Crow said he always wanted to the make the Milky Way the main subject but he also wanted the car lights in the foreground, which took a lot of waiting and timing it just right.

Meanwhile, Crispin Middleton lucked out with his winning shot for the Special Award. His squid triptych was taken while he was diving near the Poor Knights Marine Reserve.

'Despite the squid only being around 10–15mm long, my wife spotted it from the boat as we were driving along the coast of the Poor Knights. By the time we anchored I was sure it would have made a getaway but as soon as I backward rolled into the water, the little thing was right there in front of me posing for photographs. I wish more marine critters would behave like this.'

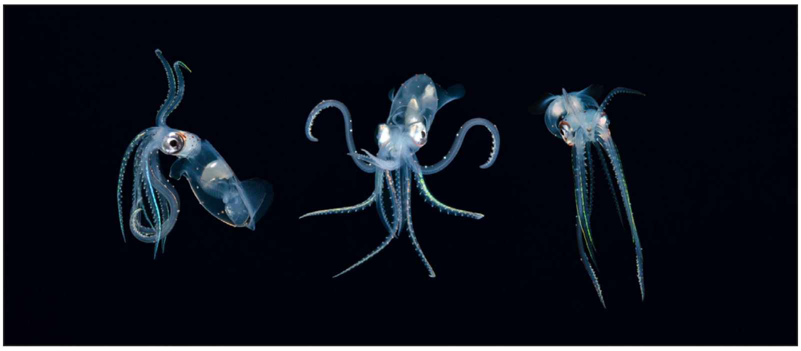
Brittlestar Anemone. Credit: Jennifer Beaumont

The judges – photography professionals Ross Giblin of Fairfax Media, Gerry le Roux from Science Lens – said the squid looked like ballet dancers on stage. 'The more you look at this photo the more details you see. We love the subtle, translucent detail against the very dark background.'

Jennifer Beaumont took her photo of a brittle star hiding in an anemone when snorkelling on a reef at the Sesoko Marine Station in Okianawa, Japan; she won the Our Work award.

> The link to all award-winning photographs is:
>
> http://www.niwa.co.nz/static/media/2017_9_photo_competition/

Jochen Bind's photograph of Fox River, taken during a road trip down the West Coast of the South Island, won the Freshwater award, and other winning images include a squid specimen taken by Rob Steward on board NIWA research vessel *Tangaroa* at the Kermadecs, a photograph by Lettie Roach of scientists on the sea ice in the Ross Sea, and a shot of Mt Taranaki at 2 am by Ayushi Kachhara.



Madonna squid. Credit: Crispin Middleton

Ivory Glacier. Credit: Hamish Sutton