| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

# CENTRES OF RESEARCH EXCELLENCE
## Full Proposal

## 1. RESEARCH TITLE
New Zealand Centre for Earth Deformation, Resources and Geophysical Exploration

## 2. PARTNERS

| Institution | Role |
|---|---|
| Victoria University of Wellington | Host Organisation |
| University of Otago | Tertiary Partner |
| University of Auckland | Tertiary Partner |
| University of Canterbury | Tertiary Partner |
| GNS Science | Non-Tertiary Partner |
| NIWA | Non-Tertiary Partner |

## 3. DIRECTOR


| | |
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| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

## 4. RESEARCH AREA

**Fields of Research Classification**

| Codes | | Keywords |
|---|---|---|
| 040402 | Geodynamics | Earthquakes, seismogenesis, slow slip, tremor, fault lines, subduction, tectonics, material science, rock mechanics, fluid pressure, basin analysis, geological resources, energy, geothermal, oil and gas, seismic exploration, extended economic zone, GPS |
| 040407 | Seismology and Seismic Exploration | |
| 040301 | Basin Analysis | |
| 040305 | Marine Geoscience | |
| 040313 | Tectonics | |

## 5. SOCIO-ECONOMIC OBJECTIVES

**Socio-Economic Objective Classification**

| Codes | | Keywords |
|---|---|---|
| 850103 | Oil and Gas Exploration | Resilience to earthquakes, education of public, graduate study, culture of wealth creation, building a geological framework for economic advancement, economic growth, economic diversification, mineral deposition, increased overseas student enrolements |
| 850102 | Geothermal Exploration | |
| 961010 | Natural Hazards in Urban and Industrial Environments | |
| 961008 | Natural Hazards in Mountain and High Country Environments | |
| 961099 | Natural Hazards not elsewhere classified | |

## 6A. INTENT

The New Zealand Centre for Earth Deformation, Resources and Geophysical Exploration (EDGE) will conduct innovative research on, geological structures and processes, both in onshore New Zealand and offshore Zealandia, which will advance natural hazard assessment and underpin resource exploration. The CoRE will involve international collaborations, training of our next generation of earth scientists and provide a scientific base for economic development.

6b. OUTCOMES:

Safety, Wealth, and International Investment

The risk from earthquakes and the potential to generate wealth from natural resources are the two most strategically important earth-science issues facing New Zealand.

From a scientific point of view, these issues are both underpinned by processes of earth deformation, faulting, compaction of sediments and fluid flow in the crust. Here we use the term ‘earth deformation’ to mean changes of the earth that occur due to forces that accumulate in the crust on time scales that can vary from seconds (earthquakes) to years (slow slip). Earthquakes, either “regular” or “slow”, are causally related to fluid migration and physical changes in the crust and mantle. Over long timescales the flow of geothermal fluids and tectonic processes result in petroleum and mineral deposits. The main differences between the occurrence of earthquakes and the creation of natural resources relate to time scale: seconds to weeks to years for earthquakes, as compared to thousands to millions of years for resources.

The high level goals of our CoRE can thus be divided into interlocked themes (see figure 10 of section 7 b.): Building Kiwi Array; Earthquakes, fluid flow, tremor and slow slip; Margins of Zealandia. Our three science themes eventually lead to three clear, and linked, outcomes for New Zealand: safety, wealth, and international investment. The safety outcome will come from a better assessment of the science behind earthquakes in a New Zealand setting; the wealth outcome from developing then implementing a comprehensive science plan for the research on the geological formation and trapping of resources; and the international investment flows from our special setting of straddling one of the classic plate-tectonic boundaries of the world. The pathway from themes to outcomes is what we describe in the science plan (section 7b) of the proposal.

We will deliver scientific and applied outputs in collaboration with downstream users. These will include improved knowledge of energy release and hazards from regular and slow earthquakes, and the development of predictive tools for resource location and extraction.

***Impacts***

- *A safer nation through better understanding of the processes deforming the earth and creating natural resources on a range of time and space scales.*
- *A wealthier nation through a stream of international investment into New Zealand earth science and new knowledge of the range and scale of our geological resource base, and improved planning for the safe and sustainable utilisation of natural resources.*
- *Enhanced earth science capability and technology transfer in government and industry through working with stakeholders and training of postgraduate students and post-doctoral fellows.*
- *A better culture of innovation and wealth creation amongst New Zealand earth science researchers.*
- *Improved knowledge of earthquake hazards and of active fault structures that threaten our urban areas.*
- *A public well-informed about earth science.*

***Activities***

- *We will build a moving array of instruments (Kiwi Array) across pre-selected swaths of New Zealand and Zealandia that will collect observations pertaining to the geophysical-geochemical-geological structure of our land.*
- *We will use Kiwi Array to research the occurrence, mechanisms and causes of earthquakes, slow slip and seismic tremor throughout New Zealand.*
- *We will use Kiwi Array in conjunction with leveraged international and industry science to undertake collaborative research on the margins of Zealandia.*

***Outputs***

- *Data-bases observations of geological structure of Zealandia from the sedimentary basins down to the upper mantle.*
- *Public lectures, outreach activities to engage schools and the wider community, and partnerships with teachers and local Iwi.*
- *Meetings with end-users such as the Ministry of Business and Innovation, the Petroleum Association of NZ and the Geothermal and geotechnical industries.*
- *Communication of research through symposia, workshops and journal articles*

Our team has a high level of academic excellence, as evidenced by 11 active Marsden grants within a team of 18 PIs. Past research for members of the CoRE has led to significant outcomes for New Zealand: major international geophysical explorations to map the thickness of the New Zealand's crust, which provides the basic background for understanding geothermal development, mineral emplacement and oil formation; leadership of the team that discovered the $4bill oil and gas fields of Tui and Kupe; discovery of new minerals of potential economic importance in off shore volcanic vents; a method under development to predict volcanic eruptions on Mt Ruapehu; original discoveries on the link between reservoir filling (Lake Pukaki in the 1980s) and induced seismicity; recent studies of the link between geothermal development and earthquakes; and geophysical discoveries that link slow earth deformation as seen in GPS measurements with zones of major earthquakes. Within the CoRE we also have a strong record of communication. One member (M. Quigley) won the Prime Minister's award in 2012 for science communication for dealing with the media after the Christchurch earthquakes, another (S. Lamb) the 2014 American Geophysical Union award for science communication based on a full-length film on climate change.

A strength of New Zealand earth science has been its ability to attract matched international science funding to New Zealand (tables 1, 2, sec 9c). However, in the transition to the science challenges a major gap in funding for New Zealand earth science has developed. While the science challenges are focused on applied outcomes, the principal recourse for teams pursuing a more fundamental science path, which may lead to applied outcomes, is the Marsden fund. Yet the scale of what we propose here, in terms of logistics and investment, is too large to be achieved through individual and short-term (3 years) Marsden grants, and therefore support for a CoRE is vital. A CoRE will provide the surety that international partners seek and thus leveraged, matched, funding to New Zealand earth science will increase. Continued leverage is vital as it gives us access to the best talent in the world and new technologies as they are developed that will help us unlock new knowledge on our resources and earth deformation. Our CoRE will provide a solid, independent platform to ensure that New Zealand can participate in, lead and disseminate knowledge from large (multi-million dollar) international experiments for maximum benefit to New Zealand.

## 7A. RESEARCH PROGRAMME SUMMARY

### Abstract

For New Zealand to prosper, it must diversify economically, provide resource security and reliability of energy supplies, and be resilient to earthquakes and other geological hazards. We therefore identify earth deformation and geological resources as research targets that will make important contributions to the economic growth and social stability of New Zealand, and should be the basis for a CORE in Earth Sciences.

Knowledge of the subsurface underpins nearly all understanding of earthquakes, resource accumulation and other geological processes. Yet, much of New Zealand's subsurface is unexplored, in particular in the recently gazetted Exclusive Economic Zone and Extended Continental Shelf (EEZ/ECS). About 96% of New Zealand territory lies offshore, and New Zealand now controls more continental crust per head of population than any other country on Earth. To explore and understand both our onshore areas and the EEZ, is an enormous and challenging task. We contend the most effective way to do this is to develop a new type of geophysical observatory - we use the word geophysical in the sense of encapsulating a broad range of earth science activities. This is a task that only a large consortium of leading earth scientists can do. Previous examples of other countries undertaking a similar process include the BIRPS programme in offshore UK, Lithoprobe in onshore Canada and the continent-wide Earthscope array in the USA. These projects have been successful in providing fundamental information on the geological framework of the countries involved, and making important contributions to our knowledge of earth structure and dynamics in general.

At the heart of the CoRE will be the building and running of a mobile observatory called Kiwi Array, comprising a closely-spaced network of state-of-the-art instruments. Over time it will move across New Zealand and into the offshore regions, making seismological, geodetic, electrical, gravity and magnetic measurements, and geological, geotechnical and geochemical observations. This array will image New Zealand's subsurface in unprecedented detail, which is crucial to achieving the two key goals of the CoRE: new knowledge on earthquake processes and the natural resources within the New Zealand continent.

Allied to Kiwi Array will be laboratory measurements that will constrain microphysical and microchemical properties of key materials (fault zones, ore bodies, reservoirs) that can be combined with the large-scale geophysical data sets to generate testable quantitative physical-chemical models. Within the CoRE we propose to also support research on the economic factors surrounding both earthquake hazard and resource exploration in a New Zealand setting.

The existence of both the CoRE and Kiwi Array will attract international science funding to New Zealand. This, together with other international co-funding for geophysical projects is likely to outweigh CoRE investment, and we have existing proposals and track record on previous leveraged funding to support this claim.

Other key outcomes from the CoRE include: (1) tertiary training of new generation of NZ geoscientists, particularly in marine and energy sectors (2) wealth creation culture instilled in graduates moving into industry and research; (3) linkages between the university sector and minerals, petroleum, and geothermal industries; (4) and earthquake research to underpin downstream work by the National Hazards Platform.

### Science Plan

Understanding earth processes in the three overlapping projects will require a collaboration across several key sub-disciplines of the earth sciences, and across the institutions signed up to this proposal. These projects are:

(1) A mobile Geoscience observatory: Kiwi-Array

We will build a moving array of geophysical instruments that will operate across pre-determined swaths of onshore New Zealand. The back-bone of the array will be a 50 seismometer array that can operate in a variety of geometries and provide accurate information about the composition and structure of the crust that builds on the permanent GeoNet network. Kiwi Array will move across onshore New Zealand in a manner similar to that of Earthscope in the US. In addition to seismological observations, electrical, geomagnetic, geodetic and geological measurements will be made within the array. Kiwi Array would be seen as national facility that members of the CoRE can use and its location will be proposal driven. Kiwi Array will have an offshore component of Ocean bottom seismometers (OBS) added to it when it encounters the coast line. We don't anticipate purchasing OBSs, rather we will tap into instrument pools being developed in Australia and an existing pool of OBSs in Japan.

Outcome: In 6 years we will have built Kiwi Array, conducted at least two deployments, and have deposited the data in a national archive. We will have made structural interpretations from the surface to a depth of 50 km for both regions.

(2) Earthquakes, fluid flow, tremor and slip

We will fund geological and geophysical studies to understand how fracturing and fluid flow interact to on short and long timescales to accommodate tectonic motions and produce earthquakes. In particular we will fund projects that use Kiwi Array for seismology studies, but we will also support related geological studies that bear on earthquake hazard. A new feature of this research is that we will incorporate continuous and temporary networks of GPS instruments so that we can broaden our approach to combine seismology with coeval straining of the earth. In parallel, we will fund work with the geothermal, petroleum and hydro-electric industries to better understand how and why human activities associated with resource extraction such as hydraulic fracturing and reservoir filling result in some of the same seismic phenomena. We plan to develop expertise to a level where the CoRE will be regarded as the key New Zealand institution for advice on earthquakes linked to human activities.

Outcome: in 6 years we will have produced detailed maps of earthquake locations and earthquake mechanisms along two swaths across onshore NZ. We will have attained a much-improved understanding of seismogenesis in New Zealand related to both tectonic and man-made earthquakes.

(3) Margins of Zealandia

A prime focus of the CoRE is the off shore continental crust that lies within the EEZ. This is a broad and ambitious target that only a CoRE can really tackle in a coordinated manner. The greater NZ EEZ potentially holds large petroleum resources, and may also host a range of mineral deposits. Sparse observational data and limited scientific understanding are, however, barriers to policy makers and explorers determining the economic risk in frontier regions. We will use leveraged marine geophysical surveys, scientific drilling, remote-control and manned submersibles, and petroleum industry data to interpret the tectonic structure of our vast offshore region (96% of New Zealand's area). We will also fund focussed marine surveys on specific problems of resolving crustal structure that are not done by industry exploration. Research on our offshore sedimentary basins will be a focus as data and interpretation of them is a key selling point for industry investment in New Zealand's resource estate.

Outcome: After 6 years we will provide community models of the crustal structure and geological history of offshore sedimentary basins.

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7B. RESEARCH PROGRAMME DESCRIPTION

# CoRE PROPOSAL 2014

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# 1. NEW ZEALAND CENTRE FOR EARTH DEFORMATION, RESOURCES AND GEOPHYSICAL EXPLORATION (EDGE)

## 1.1 Introduction

New Zealand is largely a submarine continent with 95% of its sovereign territory below sea level (Figure *1*). *Zealandia* is the term we will use for this extended New Zealand continent. The boundary between the Australian and Pacific plates passes through the middle of Zealandia. Over the past 25 million years, tectonic forces exerted along the boundary between these two plates have deformed and uplifted a narrow corridor of the Zealandia landmass that we know as the islands of New Zealand.

Much of New Zealand undergoes active Earth deformation as a consequence of its position at the boundary between moving tectonic plates. Earth *deformation* (differential rock motion) exerts a primary control upon the location and nature of destructive earthquakes and upon the geological development of natural resources, including mineral and hydrocarbon deposits and geothermal energy. Hence the pairing of earth deformation and resources is a natural one from a scientific point of view, and we see these two topics as being the most strategically important earth science research for New Zealand in the future.

New Zealand has an outstanding record in international earth science research. For example, about 10 years ago earth sciences was the area of greatest science investment by the (USA) National Science Foundation (NSF) in New Zealand[1]. Thus our CoRE will be building research capability into an area of existing excellence.

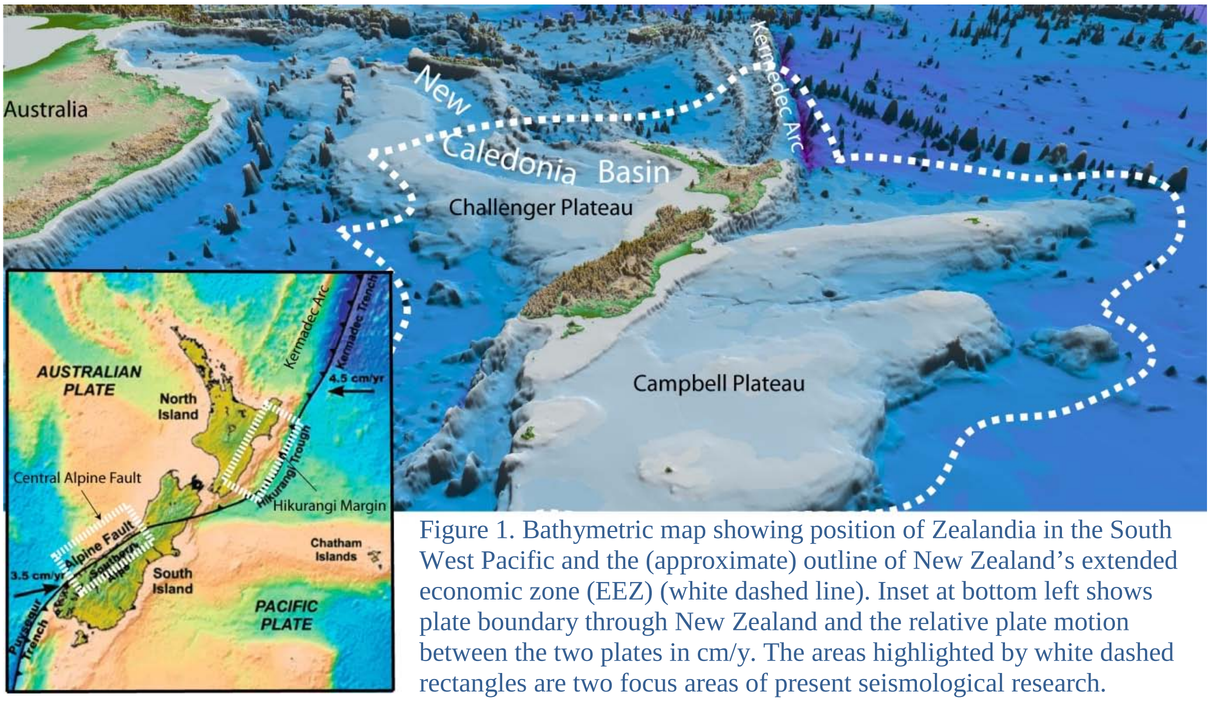


Figure 1. Bathymetric map showing position of Zealandia in the South West Pacific and the (approximate) outline of New Zealand's extended economic zone (EEZ) (white dashed line). Inset at bottom left shows plate boundary through New Zealand and the relative plate motion between the two plates in cm/y. The areas highlighted by white dashed rectangles are two focus areas of present seismological research.

***The goal of the CoRE in Earth Deformation, Resources and Geophysical Exploration is to conduct innovative research on Earth deformation that will underpin the development of more effective approaches to natural hazard assessment and resource exploration.***

[1] Speech in NZ parliament buildings by then NSF Director, Rita Colwell (2002).

## 1.2 Earth Deformation Science and our CoRE

Earthquakes are the biggest short-term threat to the well-being of New Zealanders. Their impact far exceeds that of all other natural disasters (Figure *2*). The few seconds of an earthquake can cause tens of billions of dollars of structural damage, as well as substantial loss of life or injury. Coupled with this is the potential for tsunami destruction of coastal regions. The adverse effects of earthquakes are felt by New Zealand at many different levels for years to decades after the event.

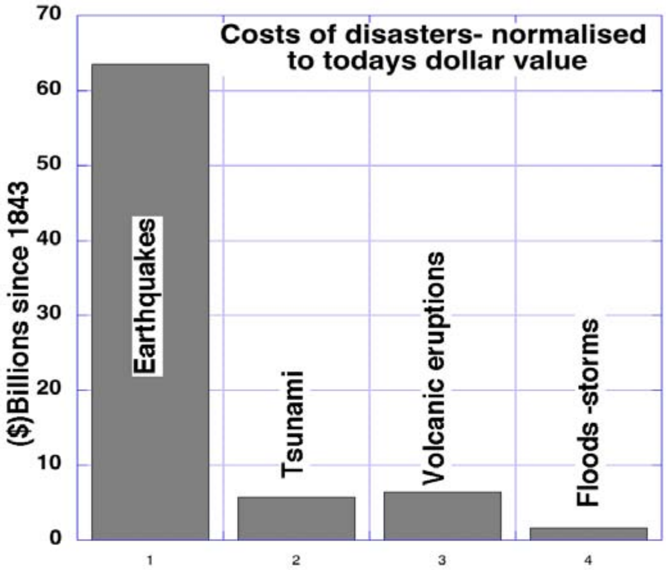


Figure 2. Estimated cost of New Zealand disasters since 1843, normalised to today's NZ$. Based on data presented at NHRP meeting 13 September 2013.

But because of our short historical record of past earthquakes our understanding of their causes and our ability to assess seismic hazards is far from satisfactory. Existing seismic hazard assessment approaches – those of the Natural Hazards Research Platform (NHRP) – are observation-based and statistical. They rely on the study of the pattern of past and present earthquake activity together with the geological identification and study of faults that are likely to rupture in an earthquake (Stirling et al., 2010). Hazard assessment also tends to focus on fast moving faults near large urban centres. But as the Canterbury earthquakes showed, remote, hidden, or slow-moving faults can also be a source of major damage. Our CoRE will improve our basic understanding of causative earthquake physics and deformational processes. It will work with NHRP in order to harness this new scientific knowledge to improve our evaluation of seismic hazards.

Rocks fail when the forces acting on them (usually expressed as a stress or force per unit area) exceed their strength. Between earthquakes, the steady motion of the tectonic plates results in a increase in stress until failure occurs (the seismic cycle). A strong rock can break suddenly – in the same way that glass or pottery snaps if it is subjected to a large force – generating an earthquake. Weak or incohesive rocks, on the other hand, may "crumble" so that deformation occurs continuously (*Figure 3*). In these cases, the breaking process is essentially "silent" or "slow" and no earthquake is felt.

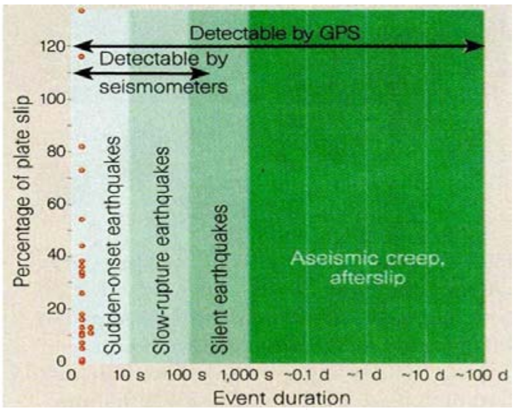


Figure 3 The time-spectrum of behaviour linked to sudden-onset earthquakes (seconds), creep and afterslip (days, years). Orange dots show estimates of the percent of plate boundary slip expressed in regular "sudden-onset" earthquakes for a variety of active margins. Most are 50% or less. After DeMets (1997).

Recording of "silent" or "slow" creep has only been possible in the past decade due to improvements in seismological data coupled to measurements of relative ground motions through GPS (Global Positioning System)-based geodesy (Schwartz & Rokosky, 2007). We have now started to unravel a rich spectrum of earthquake-related phenomena in zones of tectonic activity. Earthquakes are at one end of this spectrum and continuous creep at the other (*Figure 3*). Between these extremes are accelerated, localised creep and slow-slip events. Both seismometers and GPS instruments are required to unravel the full spectrum of earth deformation.

With new tools, our CoRE is in a position to advance our knowledge of seismic processes. It is likely that the full spectrum of earthquake-related behaviour is characteristic of most zones of tectonic deformation (DeMets, 1997; Ide et al., 2007). This is certainly true of New Zealand's two most important zones: the Hikurangi margin, and the central Alpine Fault zone (*Figure 1*). But understanding the spatial and temporal distribution of deformation and the controls on whether it occurs by slow and silent creep or by earthquakes is crucial. This is one of the key foci of our CoRE. This basic science will underpin our attempts to develop better tools for the assessment of earthquake hazards.

## 1.3 The Science of Geological Resources and our CoRE

Our CoRE will not only advance our understanding of natural hazards, it will provide an improved scientific foundation for the exploration and exploitation of mineral deposits, hydrocarbons, and geothermal resources. At present 63% of energy use in New Zealand is based on hydrocarbons and oil is our 4$^{th}$ largest export commodity in 2013 (MBIE sector report, 2013). Thus we identify the fundamental science behind oil, gas, minerals and geothermal power as being another key focus of our CoRE.

### 1.3.1 Hydrocarbons

Even though the basic science of petroleum formation is understood, predicting where an economic accumulation of petroleum can be found is far from straightforward. This is where our CoRE will make a significant contribution by defining the tectonic setting and origin of our resource-rich sedimentary basins.

Understanding plate tectonics is crucial to understanding mineral deposits and their economic potential. Analyses that are currently used to predict the maturity of oil and gas accumulations depend on tectonic models of basin subsidence and uplift, sedimentary filling, heating, deformation, and fluid migration (Allen & Allen, 2005). Our CoRE will extend research on the processes at active and ancient tectonic plate boundaries in both on and offshore regions. For example, it is important to know if any particular basin evolved as a rift (extensional) or foreland (compressional) basin. Very different thermal histories, and thus hydrocarbon maturation rates, are implied by these contrasting basin types. It's this type of 'geological detective work' that is not necessarily undertaken by exploration companies, but is well suited to the CoRE. Members of the CoRE have a track record in doing this (King & Thrasher, 1992; Stern & Holt, 1994; Sutherland et al., 2010; Bassett et al., 2010).

Gas hydrate, an ice-like form of natural gas and water, is considered a promising unconventional hydrocarbon resource (Boswell, 2009). New Zealand has had a programme of government-funded research in this area (Pecher et al, 2010) (section 2.8), and it is an area that our CoRE will support. At present the hydrocarbon industry in New Zealand is not pursing gas hydrates in a commercial sense, but production tests both onshore and offshore elsewhere in the world now show that it is technically possible to produce commercial gas from hydrates (http://www.ibtimes.co.uk/gas-hydrate-china-start-commercial-production-flammable-ice-1465892).

### 1.3.2 Mineral Deposits and Geothermal Energy

Like hydrocarbons, mineral deposits are a great source of potential wealth, though our ability to find viable deposits is limited. Mineralisation is the process whereby naturally occurring minerals or elements are concentrated in the Earth. Almost all the important elements for our industrial society occur naturally in rocks at levels that are measured in parts per 1000 to parts per million (or even less) –1g of element for every kilogram to tonne of rock. The greatest concentrations occur in rocks that were once molten, derived from deep below the Earth's crust, in the mantle. Here there is a rich store of elements that were incorporated into the Earth at the time of its formation.

A crucial feature of the Earth that leads to mineralisation is the ubiquitous presence of water in cracks and pore spaces in all rocks extending to depths of several tens of kilometers. At the high temperatures and pressures that exist in the Earth, many elements are soluble in the water. The water in the Earth is continuously flowing through the rocks, driven by both its buoyancy and the cycle of earthquakes and earth deformation that not only create channels and pathways in fractured rock, but also act as a pump (Sibson et al. 1988). Fracturing and faulting during the seismic cycle are likely to play an important role in this water flow. When water reaches levels at lower temperature and pressure, the elements become less soluble and precipitate out as mineral veins. Sometimes these veins are fabulously rich and contain pure metals such as gold or silver.

Our current understanding of processes of mineralisation suggests that rich mineral deposits are most likely to occur where there is, or has been, both volcanic activity and earth deformation. Both of these are fundamental features of the New Zealand plate boundary. We know that many important mineral deposits are abundant along boundaries where two tectonic plates collide or where one is subducting beneath the other (Griffin et al., 2013). However, our ability to search for minerals is under-developed. The key to building a long term strategy for locating mineral deposits in commercial quantities is an improved understanding of the underlying processes in the plate boundary that lead to mineralisation, and an appreciation of the tectonic setting where this mineralisation will occur. Our CoRE will bring together key researchers in physical processes of fluid flow, fracture, and fluid chemistry to help constrain future exploration of New Zealand's mineral resources.

### 1.3.3 Offshore EEZ

The geology of New Zealand has been mapped and researched for 154 years since the initial work of the Austrian geologist Hochstetter (Fleming, 1959). The resulting geological database is now one of most complete and well-documented in the world, particularly so for the on-land part of New Zealand, and provides considerable leverage for international investment into resource and energy developments. Offshore New Zealand, however, is under-researched.

Our CoRE will help explore the submarine geology of New Zealand's recently-established Extended Economic Zone (EEZ). This vast region (5.7 mill $km^2$ or 1.1 % of the surface area of the earth) represents about 95% of our sovereign territory and means we control more of the earth's crust per head of population than any other country with a population >1 million (Figure *4*). Most of our EEZ is underlain by continental rather than oceanic crust. The histogram plot of figure 4 is hugely significant for New Zealand in the sense that most of the resources that are needed to sustain modern life come from continental crust. Every New Zealander should be aware of this plot, and the opportunities and responsibilities it implies.

The EEZ almost certainly harbours substantial petroleum and mineral deposits such as gold, silver, copper, manganese, cobalt, phosphate, iron-sand, methane-gas hydrates, and trace metals required by new technologies (e.g. touch screens). Exploring an offshore territory that is some 18-times larger than onshore New Zealand is an enormous and ambitious goal. It will require a plan that could span 50 years. This proposal sets out the first 5 years of that plan.

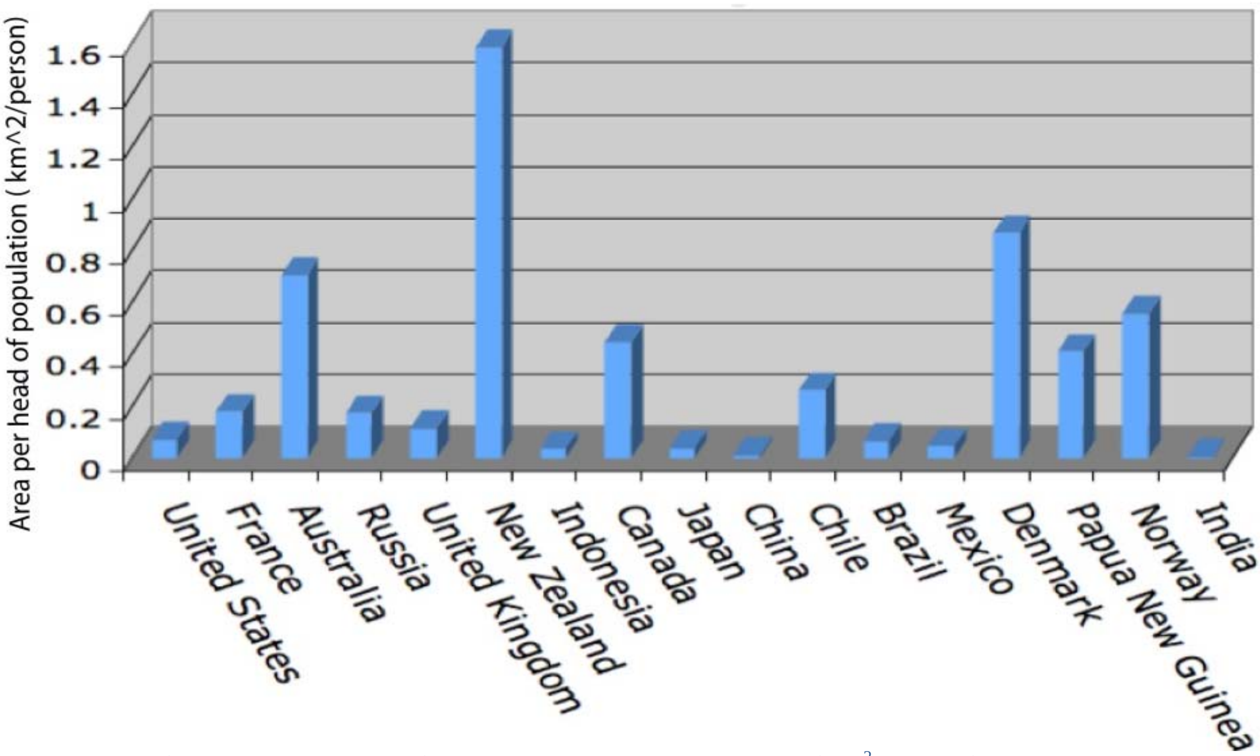


Figure 4. Plot of crustal area per head of population (vertical axis has units of $km^2$/person) for countries with populations >1 million. The area = land area + EEZ. Data from Google.

Our CoRE will coordinate the academic research effort with government and industry. It will train the next generation of scientists for these sectors. Focussed fundamental research on the extent and origin of sedimentary basins is needed within our EEZ to firstly ascertian what is there then, secondly, help prioritisation of targets and approaches in the exploration of the EEZ.

## 1.4 Economics of Geological Resources and our CoRE

New Zealand's mineral, hydrocarbon and geothermal resources, which are major contributors to the future wealth of New Zealanders, are all largely controlled by earth deformation at and adjacent to the present and past plate boundary of New Zealand and Zealandia (Figure *1*).

The importance for geological exploration of our EEZ, as proposed for our CoRE, becomes apparent when one considers the economics of our present resource industries. Natural resources already form an important part of New Zealand's economy, representing 2.5% of GDP and 6.2% of exports (New Zealand Sectors Report 2013, Petroleum and Minerals, Ministry of Business Innovation & Employment).

The petroleum and minerals sector has a significant impact on the wider economy in employment and business activity in downstream industries, and in the procurement of a wide variety of goods and services. Fuel for transport is almost entirely derived from hydrocarbons, and as yet there are limited alternatives. Demand for hydrocarbons is growing (*Figure 5*) despite an increase in geothermal and wind energy in the past decade. In 2012, 63% of New Zealand's energy came from hydrocarbons versus 37% from renewables, and this gap is widening (*Figure 5*).

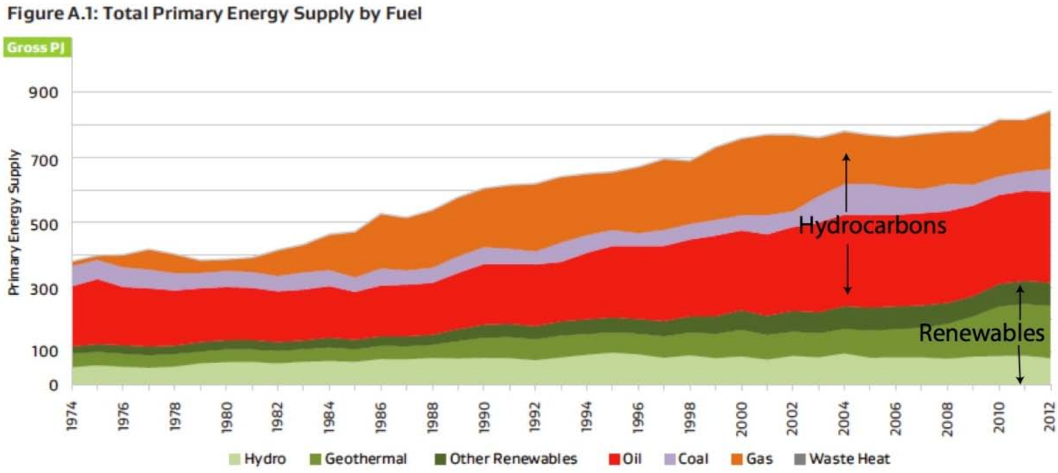


Figure 5. New Zealand energy use by type 1974-2012. Red-purple-orange represent hydrocarbons, green colours represent renewable sources (hydro, geothermal, other).From MBIE publication, 2013.

Sustained growth for more than 10 years in the petroleum and minerals sector has seen employment doubled and exports tripled (in 2012 exports were worth $2.8 billion). The sector results in high-value employment and has one of the highest median salaries ($105k pa). In the past six years, a total of $8.2 billion has been invested in New Zealand petroleum exploration and development and $213 million in minerals exploration. In the same period, the Government was paid a total of $1.9 billion in levies and royalties – $380 million in 2012 alone.

Although there is considerable and justified debate about New Zealand's future energy plan, what is clear is that the debate needs to be informed from knowledge of what our assets actually are. Thus the main thrust of the resource research we propose within the CoRE centres on learning about what we own, its distribution, its potential and its long-term sustainability.

## 2. Previous Work in New Zealand Related to CoRE Activities

### 2.1 Seismology

*From New Zealand's short historical record of earthquakes, we can roughly expect a magnitude 8, 7 and 6 earthquake every 100, 10 and 1 years respectively (Hatherton, 1978). It has long been recognised that earthquakes are spread throughout the country (*

Figure 6) with the exception of the extreme northwest (Northland) and the southeast (east Otago).

But knowledge of past earthquakes in New Zealand is lacking compared to countries like Japan who have written *records* going back more than 1000 years. This lack of knowledge impedes our ability to assess and predict earthquake hazard. The Canterbury earthquakes of 2010-11 sadly underscore this point. On the Geonet web site 17 of our largest historical earthquakes are listed. These range in magnitude from the 2011 Mag 6.3 Christchurch event to the 1855, magnitude 8.3 event on the west Wairarapa fault (http://info.geonet.org.nz/display/quake/Historical+Earthquakes). Of these 17 events only three occurred on known and mapped active faults. Moreover, half of the listed earthquakes did not form a surface rupture. This underscores the need to develop new methods of assessing earthquake hazard that build on the traditional method of mapping of active fault traces. Within the CoRE we propose to improve this situation by gaining new geological knowledge of past earthquakes by applying novel geophysical methods to search for recently active fault lines ( Louie, 2001; Ghisetti et al., 2014) in the subsurface and using advanced applications of geodetic data (Beavan & Haines, 2002; Wallace et al., 2004; Wallace and Eberhart-Phillips, 2013; Lamb & Smith, 2013) to assess the build of up stress on faults and crustal deformation zones within New Zealand.

*In New Zealand, we have both deep (>40 km) and shallow earthquakes. Deep earthquakes (*

Figure *6*) delineate subduction zones beneath New Zealand: the Pacific Plate subducting beneath the Australian at the eastern North Island and the Australian Plate beneath the Pacific in Fiordland at the southern margin of New Zealand (***Figure 1***). In the middle of the South Island we have a poorly understood form of plate boundary, called a continental transform, where two continental plates slip past one another but also move together and "shorten". This diversity of plate boundaries over a short distance in New Zealand is unusual and is one of the big attractions for international scientists to come and work here.

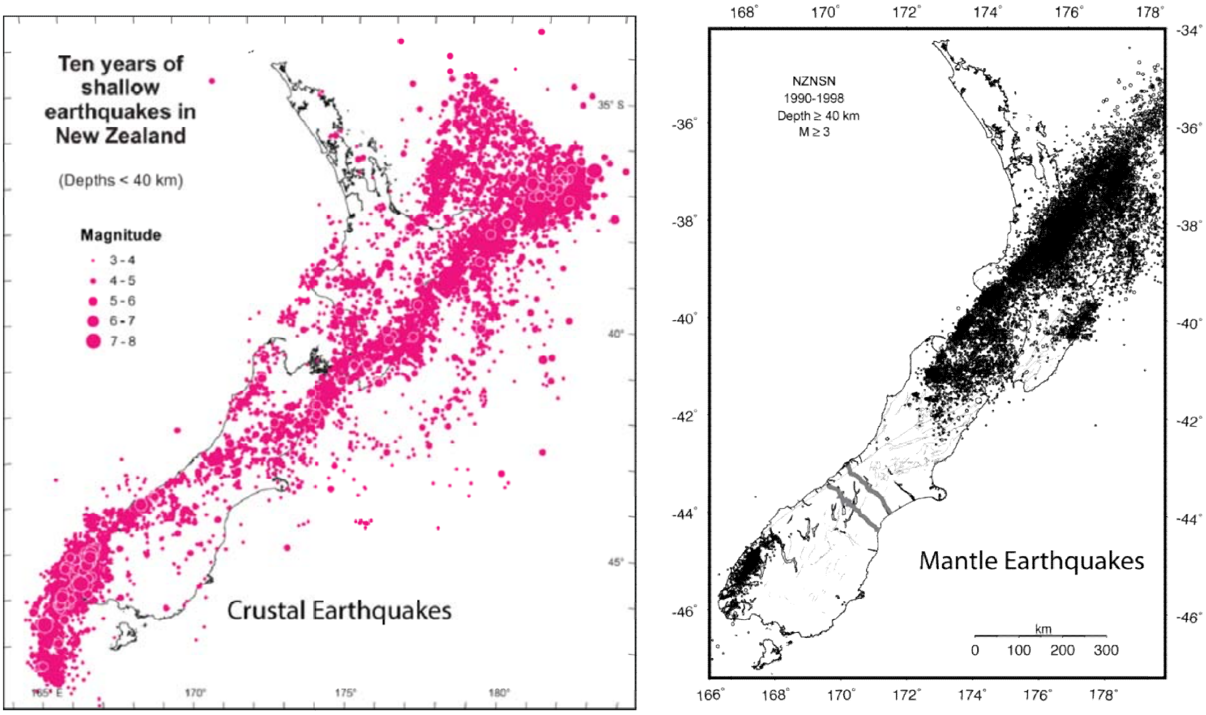


Figure 6. Crustal earthquakes (<40 km depth) (left) and mantle earthquakes (right) associated with subduction for a 10 year period shown in right panel. Data and maps from the GeoNet website. Lines across mid South Island are the SIGHT seismic lines discussed shortly.

Most of our earthquakes are ascribed in a general way to plate boundary processes. This may include the mechanical "frictional collision" aspects of subduction, but also includes effects due to mineralogical changes as the subducted plate deepens beneath the continental margin.

Seismic monitoring in New Zealand is carried out by GeoNet (http://www.geonet.org.nz) (Figure *7*). Its role is to gather data, including continuous GPS, but analysis is left to science groups. This rich data set is well organised, open access, and is easily accessible via online facilities. In addition to the GeoNet network, there are a series of portable and temporary arrays currently running that were deployed in 2013 by Victoria University of Wellington (VUW), GNS Science and colleagues from the USA, as shown in Figure *7*. These micro-earthquake networks carry out detailed studies in specific areas over time spans of typically 1-2 years.

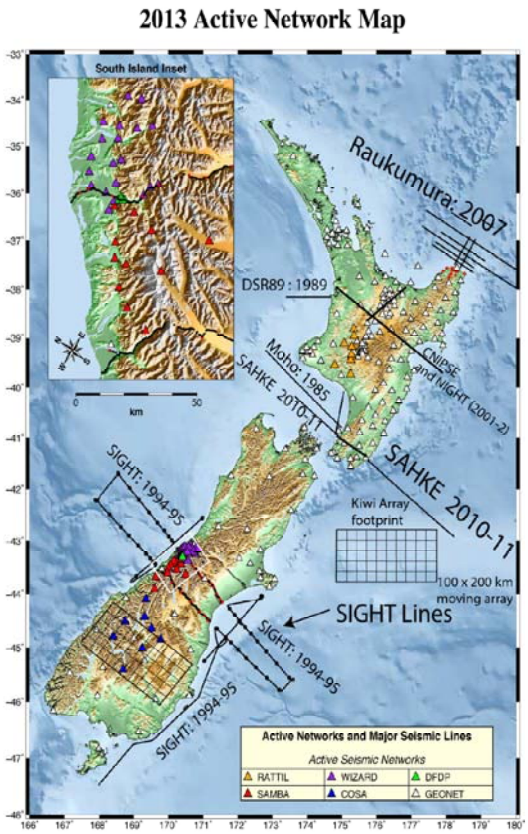


Figure 7. Seismic arrays active in 2013 and Kiwi Array. GeoNet in white triangles, short-term microearthquake arrays in colour. Black lines offshore are ship tracks for seismic profiles associate with onshore-offshore projects referred to in the text to investigate crust and mantle structure. The inset shows the arrays in the Southern Alps – SAMBA (VUW) and WIZARD ( USA). Grid shows our proposed footprint of a 20 km–spaced Kiwi Array, and this for print superposed on central Otago where the first deployment is proposed . A japanese array is presently installed in northern South Island but is not shown here.

Recent discoveries and developments in New Zealand seismology include new high-precision means (Zhang & Thurber, 2006) of locating earthquakes with the double difference tomography method (Reyners &Bannister, 2007; Reyners et al., 2006), the use of earthquakes to map attenuation structure in the crust and mantle (Eberhart-Phillips et al., 2008), and the study of the stress along the plate boundary in New Zealand (Townend et al., 2012). In the past few years, major earthquakes in Canterbury have been researched (Fry & Gerstenberger, 2011; Kaiser et al., 2012; Quigley et al., 2012) and there is on-going work on these sequences. Several studies using micro-earthquake arrays of portable instruments have made significant discoveries (Reyners, 1980; Salmon et al., 2011; Seward et al., 2009) including the discovery of tremor deep on the Alpine fault of central South Island (Boese et al., 2013; Wech et al., 2012).

One of the most significant breakthroughs in global seismology in the past 20 years has been the verification of seismic tremor, low-frequency earthquakes and slow slip (Obara, 2002; Schwartz & Rokosky, 2007) All three phenomena are related (Figure *8*), but how and why is still not clear (Peng & Gomberg, 2010). What slow slip and tremor show is that accumulated strain on faults is not necessarily released quickly (in a few seconds), but can be released in episodes that may last minutes, hours, days or even years. It can also be shown that displacements linked to slow earthquakes that go on for months or years can be equivalent to that of a magnitude 7 earthquake (Figure *8*). Indeed it is calculated that perhaps 50% of relative plate motion in boundary zones is released by such slow slip mechanisms (DeMets, 1997). But possibly the most important aspect of slow slip events is that they may be implicated in the transfer and build of stress elsewhere in a fault zone, and therefore be a forerunner of larger earthquakes (Shelly et al, 2006; Miyazaki et al., 2011).

Slow slip, tremor and low frequency earthquakes have all been recently discovered in New Zealand (Douglas et al., 2005; Wallace and Beavan, 2006; Wech et al., 2012; Wallace & Eberhart-Philips, 2013; Chamberlain et al. 2014) and will be a focus for researchers within the CoRE. Recent discoveries of precursory slow-slip, prior to the magnitude 9 Tohoku earthquake (Miyazaki et al., 2011), underscores the importance of these phenomena as a possible harbinger of larger earthquakes.

## 2.2 Geodesy

Geodesy is the study of the shape of the Earth and the change in shape as a result of earth deformation. A continuous GPS network for New Zealand is currently maintained by GeoNet (Figure *7*) (Beavan et al., 2011; Beavan et al., 2004; Beavan & Litchfield, 2012).

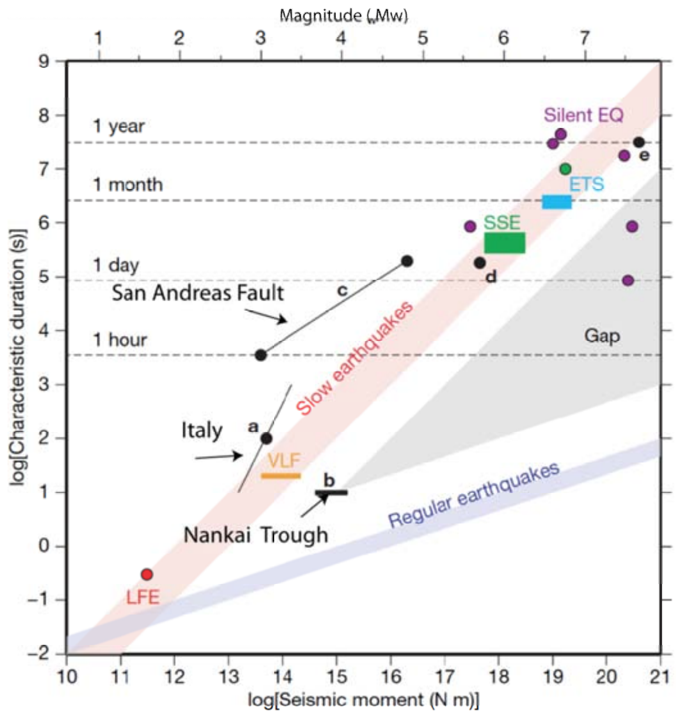


Figure 8. Scaling relationship between duration time and earthquake magnitude across the spectrum between regular earthquakes and slow slip events. After Ide et al, 2007.

This network was initially installed for survey purposes, with a wide spacing of ~100 km. Subsequently, with the study of 'slow slip' earthquakes along the eastern part of the North Island, the spacing of parts of the network has been reduced to ~20 km. GPS data are crucial to understanding the full spectrum of earthquake related processes, because they are a direct measure of the strain caused by loading within New Zealand, as well as constraining motions before, during, and after actual rupture events.

New methods of assessing geodetic data are becoming available (Kaneko et al., 2010), including those by members of the CoRE (Lamb & Smith, 2013; Wallace et al., 2004). Research within the CoRE will further advance these methods and work on the link between slow slip and seismic tremor.

## 2.3 Geophysical Exploration

Over the past 20 years, more than 3000 km of non-industry, crustal-scale, seismic reflection/refraction lines (including onshore/offshore experiments) have been acquired in New Zealand (Figure *7*). These profiles are unlike industry lines in that the specific purpose is imaging the crust at depths relevant to earthquake processes (5-40 km). These crustal structure seismic profiles have ensured that onshore New Zealand is well imaged to mantle depths in some places, though gaps exist particularly in the offshore region. The role of the CoRE will be to substantially increase the number of seismic lines shot in New Zealand's EEZ for crustal structure purposes.

Major crustal structure initiatives such as the MOHO (Stern & Davey, 1990), SIGHT (Okaya et al., 2007), Raukumara (Bassett et al., 2010) and SAHKE (Henrys et al., 2013) projects (Figure *7*) involved leveraged funding of industry funds, and international groups from the USA, Germany and Japan. Advances made from these crustal-structure projects have improved our understanding of tectonics, earthquake processes and resource bearing basins (Godfrey et al., 2001; Scherwath et al., 2003; van Avendonk et al., 2004), and provided crustal structure evidence for the oil and gas rich Taranaki Basin to be a foreland basin (Holt & Stern, 1994).

The SIGHT, Raukumura and SAHKE projects (Figure *7*) brought ocean bottom seismology (OBS) to New Zealand. Since then a major offshore OBS study (MOANA) was conducted by the USA (University of Colorado and Woods Hole Oceanographic Institute) on each side of the South Island (Wech et al., 2013; Yang et al., 2012) as a follow up to the SIGHT project of a decade earlier. This project represents fresh technology transfer to New Zealand as it was based on the new development of broadband, ocean-bottom seismometers. Ocean bottom seismology is a vital skill for us to develop given the area of real estate we own that lies beneath the sea (*Figure 9*). Within the CoRE we intend to develop our own expertise in this technology, then conduct OBS studies using instruments borrowed from the Australian consortium ANSIR ( http://ansir.org.au ), which we will join, and partner organisations in Japan and the USA.

## 2.4 Fault Studies and Material Science

Mapping of active faults is an important part of hazard assessment in New Zealand, especially where the seismic images of faults can be calibrated to a drill hole and then used to measure the rates of movement for a particular fault (Lamarche et al., 2006; Lamarche et al., 2005). Seismic imaging of active faults with likely earthquake potential (Barnes et al., 2002) is especially important. But as pointed out above there has historically been more damage from hidden faults. The CoRE will address this question by encouraging methods to explore for hidden faults that do not break the surface. For example, high-resolution studies of fault structures have been made in the South Island with standard seismic reflection methods (Dorna et al., 2010; Ghisetti et al., 2014), and shallow seismic reflection images of areas in regions of rapidly deposited sands have shown active faults not far beneath the surface (Ewig, 2009). New methods of shear-wave dispersion have proved to be useful for unearthing active faults that are buried by a few ~ 20 m of sand or gravel (Louie, 2001)

The Deep Fault Drilling Project (Sutherland et al., 2012) is a large international project that aims to understand ambient conditions and materials of large continental faults. The next phase of the drilling of a 1.3 km hole is underway now (October, 2014). One of the important skill developments the CoRE will support is laboratory work that treats rock samples from the drill hole as engineering materials to understand better the way they deform, what controls the way they deform and the way energy is consumed in a wide range of poorly-understood physical and chemical processes that occur in and around faults. These processes (e.g. fracture of particles, flow of fluid through pore spaces, frictional sliding, solid-state creep, dissolution and precipitation of minerals) are interconnected and together control earthquake nucleation, rupture and arrest.

## 2.5 Mineralisation

Mining of minerals in New Zealand is focused principally on gold from the large epithermal Martha Hill deposit of Waihi in the North Island, and the Macraes and Reefton deposits in the South Island. These deposits constitute a billion dollar industry, with further gold coming from sedimentary deposits in Otago and Southland. Active exploration for gold deposits is high priority in the industry, and close links are maintained between industry and professional researchers to advance new concepts of gold concentration mechanisms and the background geological context for these deposits (Rowland & Simmons, 2012; Wilkinson, 2013).

New on the scene are the volcanic massive sulfide (VMS) deposits from offshore New Zealand associated with submarine volcanoes along the Kermadec volcanic arc, and phosphate deposits of the Chatham Rise (de Ronde et al., 2011). The former have the potential to realise billions of dollars of metals in mostly copper, gold and zinc, and the latter a strategic resource for the burgeoning dairy industry in New Zealand and its ever-increasing appetite for super-phosphate fertilizer. Some of the VMS mineralisation is host to rare earth elements (REEs), an increasingly important group of elements in the growing electronics industry. In this regard it is important to think about what will be the next REE that proves vital to some part of industry ? The example of Lithium (used in batteries) having turned the economies of small countries like Bolivia (Romero, 2009) is particularly relevant to New Zealand.

One of the aims of the CoRE is to provide an explanation and working model for mineralization throughout New Zealand, within a plate tectonic context. By having members of the CoRE who are familiar with mineralization from all areas in New Zealand, and in Australia, we will have the capacity to see the bigger picture, which will help develop predictive models for mineralization in new regions.

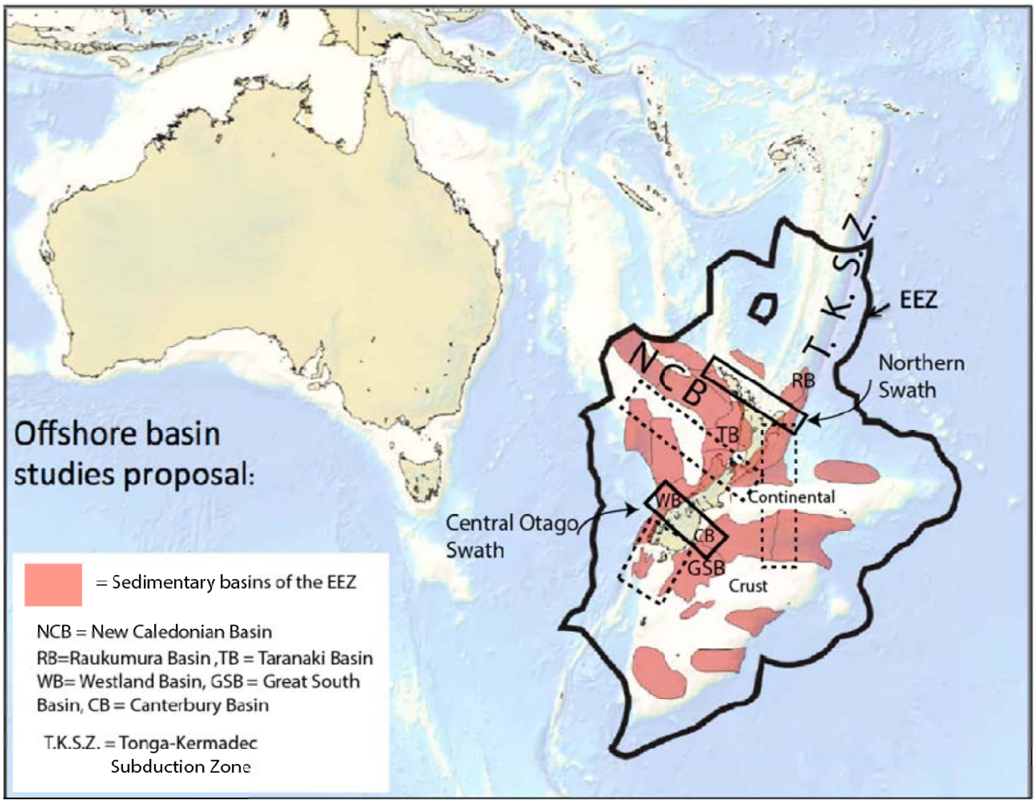


Figure 9. Map of our EEZ shown in relation to Australia. Solid rectangles represent targets for the Kiwi Array (section 3) 2015-20, dashed rectangles represent possible targets for 2020-30.

## 2.6 Offshore Basins, Crustal Structure and Resources

Pioneering work on exploration of New Zealand's sedimentary basins started with the quest for oil and gas in the 1960s and 70s (Pilaar & Wakefield, 1978). Government-sponsored research in our offshore regions went hand in hand with the exploration companies and also utilised "ships of opportunity" that were passing through New Zealand (Davey, 1977).

With the onset of modern multi-channel seismic methods from the mid 1980s better data became available for exploration needs, and both industry and academic research on our offshore regions benefited. Since the mid-1970s all exploration data had to be made open file, or publically available, and until the early 1990s these were archived with what was then the Geological Survey. Now digital methods are required for archiving and this is handled by New Zealand Petroleum and Minerals (NZPM), which is a branch of the Ministry of Business and Innovation (MBIE). This large and excellent quality data set is available for public use and parts of the science community have been using it to carry out new research on offshore basins that would not otherwise be done by the oil industry e.g., (Bache et al., 2013; Baur et al., 2013; King and Thrasher, 1992; Sircombe and Kamp, 1998). Members of the CoRE will further exploit this database for scientific research.

One of the three themes (section 3) of the CoRE is to collect new data on the margins of Zealandia, particularly the offshore basins (*Figure* 9). This is possibly the most ambitious theme of the CoRE because of the cost, remoteness and the sense of the unknown. Nevertheless, we feel all these obstacles are surmountable and this theme is one of the most compelling reasons for the CoRE.

A recent change in government policy means that exploration licences are now issued for 15 years, rather than the previous 5 years. This means the open-file release of industry seismic data, which can be used for scientific research, will be slowed. This change in policy just enhances the reasons for a CoRE as we propose.

### 2.7 Geothermal Studies

New Zealand research on high temperature (>250°C) geothermal systems has been at the international forefront for the last 50 years (Seward, 1974). Geothermal pioneers established state of the art geophysical techniques, particularly electrical methods, to delineate geothermal fields in the top 3 km of crust (Bibby et al., 1995; Hunt et al., 2009). More recently, magnetotelluric work has managed to resolve conductive structures to depths of 20 km giving insight into deep aspects of the geothermal source (Heise et al., 2007; Betrand et al., 2012). Seismic investigations in New Zealand geothermal areas have been done with active source and earthquakes to study caldera structures (Behr et al., 2010; Stratford and Stern, 2008), Vp/Vs ratios and anisotropy (Johnson and Savage, 2012; Sherburn et al., 2003; Unglert et al., 2011), and with Mighty River Power support, several recent seismic studies of geothermal areas have been published (Bannister et al., 2008; Clarke et al., 2009; Rawlinson et al., 2012). New geological field work and geochronology coupled with the exceptional database of downhole stratigraphy has led to an understanding of the tectonic and volcanic architecture of New Zealand's premier geothermal basin, the Taupo-Reporoa basin (Downs et al., in press GEOSPHERE). The Taupo Volcanic Zone's geothermal resource is an active epithermal Au-Ag mineralising environment (Brown, 1986; Simmons & Browne, 2000); joint geophysical, geological and geochemical studies of these systems shed light on comparable mineralised provinces elsewhere, e.g., Coromandel Volcanic Zone (Rowland & Simmons, 2012).

Work within the CoRE will be directed to the deep structure and mineralization associated with our active geothermal systems in a quest to learn more about its heat source and long term sustainability.

### 2.8 Gas Hydrates

New Zealand offers excellent settings to study gas hydrates, both as an energy resource and an ephemeral carbon-rich substance, in seafloor sediments that may be an important controller of climate and affect seafloor stability. The Hikurangi Margin was among the first regions worldwide where bottom-simulating reflections (BSRs) from the base of the gas hydrate stability were recognised as gas hydrate proxies (Katz, 1981). Ship-of-opportunity mapping during the French-New Zealand GeodyNZ survey revealed the vast extent of BSRs on the Hikurangi and Fiordland-Puysegur Margins (Townend, 1997). First resource estimates suggest the volume of gas in place in hydrate "sweet spots" is several times the original gas in place in New Zealand's largest conventional gas field, Maui (Henrys et al., 2009; Pecher and Henrys, 2003). These early studies have progressed significantly with the availability of modern 2-D seismic data focussing on resource estimates of individual reservoirs (Fohrmann and Pecher, 2012) and developing proxies for reservoir quality (Navalpakam et al., 2012). Recent studies into the link between hydrates and fluid expulsion (Crutchley et al., 2010; Pecher et al., 2010) as well as hydrocarbon seeps reveal that gas hydrate systems on active continental margins are highly dynamic with on-going gas hydrate formation and dissociation. Members of the CoRE have established skills in gas hydrate research.

## 3. Scope of Research Programme

The CoRE will spearhead a new programme of research to foster exploration of Zealandia and onshore New Zealand. We will bring together researchers with expertise in seismic exploration, mineral resources, and rock mechanics. At the heart of our initiative will be Kiwi Array as described in theme 1 below. Observations collected from this array will underpin research into the other two themes: 'earthquakes, fluid flow, tremor and slip' and 'margins of Zealandia'.

The CoRE will also coordinate, improve and enhance international leveraged projects to New Zealand. We have compiled (Table1,sec 9c) a list of 58 projects that would be aligned to the CoRE and are funded or submitted for activities through to 2017. These include drilling with the International Ocean Discovery Program (IODP), projects within GNS Science and NIWA, MBIE contestable projects and an EQC project. Internationally funded projects outnumber the local ones and the host countries are: USA, UK, Australia, Japan, Germany, and France. At present these projects occur on an ad hoc basis and the results are not necessarily conveyed in an efficient manner back to the New Zealand community. The CoRE will provide co-ordination and a link to maximise the return to New Zealand from these widely dispersed projects. From here on any reference to project #XX refers to those in Table 1, section 9c.

Our programme is divided into three themes:

- Kiwi Array, a moving array of geophysical and geological instruments that will underpin all our research
- Earthquakes, fluid flow, tremor and slip
- Margins of Zealandia.

## 3.1 Methods

Our principal method of exploration will be seismic exploration. This is the dominant method used by industry and academia to image and investigate the subsurface of the earth. The seismic method makes use of natural energy sources like earthquakes or ambient noise, or man-made sources such as dynamite shots. It provides first order definition of geometrical structure at depth and physical properties that then lead to interpretations of rock type, temperature and fluid pressure. Potential field methods, such as gravity, magnetic and electrical methods, will provide us with complementary data to the seismic methods. In particular, magnetotelluric (MT) methods can now penetrate to mantle depths in both marine and terrestrial settings (Naif et al., 2013). MT data provide excellent resolution of water rich zones at depth and allow one to interpret high fluid pressure and interconnected water at depth (Wannamaker et al., 2002).

Crucial to our interpretation of geophysical data will be geological and geochemical observations from sampling at the surface or in bore holes. We will use geological and geochemical sample data where available and undertake a comprehensive set of laboratory measurements on the material properties of rock samples recovered from drill holes and marine dredging.

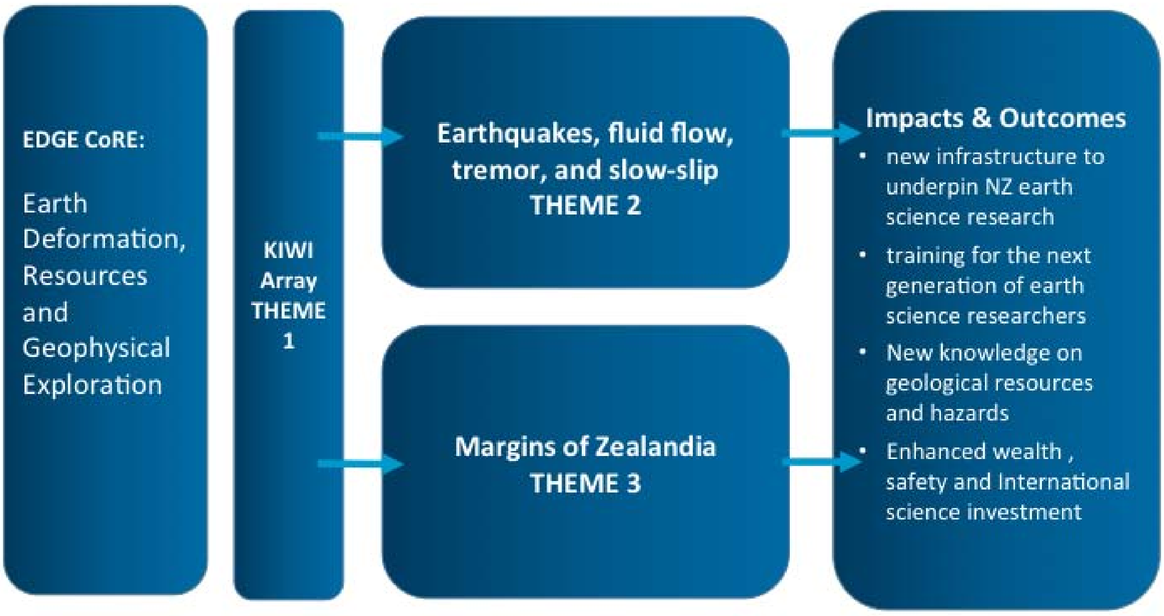


Figure 10. Relationship of Themes to Impacts and Outcomes

## 3.2 Theme 1: Building Kiwi Array

*Theme leader: Professor Martha Savage. Contributing PIs: Henrys, Bannister, Lamb, Lamarche, Townend, Betrand.*

Under this theme we will build national infrastructure in the form of a moving array of geophysical and geological instruments (Kiwi Array) that will operate across pre-determined swaths of onshore New Zealand. Kiwi Array will be focused on delivering knowledge of the crustal structure that is crucial to understanding earthquakes and volcanic eruptions, identifying future energy and mineral resources. The back-bone of the array will be a 66 seismometer array that can operated in a variety of geometries (Figure 7). This array will move across onshore New Zealand in a manner similar to that of USArray in the US (http://www.earthscope.org), Wombat array in Australia (http://rses.anu.edu.au/~nick/wombat/) or Polaris array in Canada (http://www.uwo.ca/research/excellence/docs/POLARIS.pdf). In addition to seismological observations, magnetotelluric (MT), geomagnetic, absolute gravity, GPS, geochemical and geological measurements will be made within the array. Kiwi Array will be a national facility that members of the CoRE can use, and its location and science orientation will be driven by peer-assessed proposals. International participation in the Array will be encouraged. Data collected with Kiwi Array will be open-access, archived in existing facilities such as GeoNet or IRIS. The science addressed by Kiwi Array will include all the topics central to our CoRE (earthquake distribution and mechanisms, slow slip, sedimentary basin structure and crust-upper mantle structure) but can also be extended to observations beyond the immediate focus of the CoRE including oceanography, marine biology and paleoclimate studies.

Kiwi Array will have an offshore component of borrowed Ocean Bottom Seismometers (OBSs) added to it when it encounters the coastline. Other offshore components to the Kiwi Array will include MT instrumentation, and there will also be capacity to integrate entirely new offshore technologies as they come on stream. For example, new technologies are being developed on regional cabled observatories in offshore areas of the US, Japan, Canada and Europe (http://www.whoi.edu/page.do?pid=24396). These observatories are linked by fibre optic cables to establish a grid of sensors on the ocean floor and/or in the water column. A wide range of science can be done with such observatories ranging from geophysics to oceanography to marine life studies.

We see the Kiwi Array as starting off in a largely seismological-MT role but evolving as technology, opportunities and science imperatives change. It is our intent to ensure that Kiwi Array is open to new initiatives, can change its focus, and can seamlessly cross from onshore to offshore. Moreover, it may be that in some localities it is better to align instruments in a linear rather than a rectangular pattern (Figure 7). Thus we want to emphasize that the flexibility of Kiwi Array will allow objectives to change as new methods come on stream.

In the first 5 years of the CoRE we intend to start two deployments of Kiwi Array. The first will be a conventional array using known technologies across central Otago, including the offshore region (2015-2017). The second array, a northern swath from the East Cape to Northland then west to cross Cape Reinga Basin and the southern end of the New Caledonia Trough (Figure 8), will bring in newer developments from here and abroad (2018-2020).

Hardware for the array will be purchased by the host institution and then paid off by the CoRE over a period to be negotiated. Maintenance and installation of the array is budgeted for in our operational spending and spending on a technical officer.

Central Otago Swath (*Figure 9*): *Contributing PIs: Craw, Lamb, Toy, Little*

The geology of the lower South Island has played a vital role in the economic development of New Zealand, from the pounamu that was eagerly sought in pre-European days to the coal that was vital for the establishment of early settlers in Otago and Southland to the gold that opened up the country to immigration and funded the development of public and private business. The geology of the south has continued to play a vital role in New Zealand over the last century with the development of hydroelectric power schemes and large-scale mining operations. Petroleum exploration in the Great South Basin in the eastern margin of the swath is seen by many to be the next big development on the horizon.

All of this development, however, has been built on the back of a geological framework that is still poorly understood. A central component for the Otago swath will be onshore seismic profiling for crust and upper mantle structure using explosions in deep drill holes. This profiling will temporarily supplement Kiwi Array with closely-spaced seismometers in the manner previously done in SIGHT and SAHKE (Henrys et al., 2013). Central Otago appears to have an unusually thick crust, based on a spot measurement near Wanaka, and its uplift history is also unconventional (Bourguignon et al., 2007). Crustal structure results, which will show the sense (compression or extension) of major fault movements, will be a key element in our efforts to resolve the history of vertical movements here.

We will make passive seismic and MT measurements on Kiwi Array throughout central Otago in order to help build a 3D crustal structure image. Ocean Bottom Seismometers will be used offshore to complement onshore Kiwi Array activities. We will also undertake xenolith (samples of mantle entrained volcanic eruptives) studies of volcanic regions in eastern Otago that will help constrain crustal mineralogy and crustal structure. We will finish the aeromagnetic survey of central Otago that was started with the gold prospecting company Glass Earth, and extend and densify the GPS array of Geonet within central Otago. Both the aeromagnetic and GPS data will help us understand the internal deformation processes in the Otago schist.

The southern swath covers the Otago schist and its margins, one of the most productive mineral belts in New Zealand. In order to aid further mineral exploration and understanding of the mineral deposit system, we will target three structural zones:

1. The Hyde-Macraes Shear Zone and gold-tungsten mineralisation.
2. The surface expression of the Otago Schist belt.
3. The schist boundary of the Dun Mountain Ophiolite Belt.

Kiwi array will be designed to image these zones down to the depth of the upper mantle with geophysical methods. Our data will contribute to a big-picture understanding of onshore fluid flow and mineralisation, particularly with respect to gold deposits in the South Island (Koons & Craw, 1991).

Earthquakes in central and western Otago are also of importance to theme 2 described below. Kiwi Array will collect data that will allow us to study that part of the Alpine fault that passes through western Otago, where there will an interest to see if the tremor and low frequency earthquakes of the central portion of the Alpine fault persist further south (Wech et al, 2012).

<u>The Northern Swath</u>: *contributing PIs: Pecher, Rowlands, Henrys, Betrand*

Northern New Zealand is an exceptional location in which to study the influence of subduction and its associated processes on the development, localisation and preservation of natural resources within the overriding plate (*Figure 11*). Here, Miocene-to-present convergence at the Australian-Pacific plate margin has involved a complex suite of events, including current diversity of fault slip behaviour at the active Hikurangi margin subduction zone (Wallace et al 2009), rapid lateral migration and rotation of the plate boundary, its attendant arc systems, rift basins and mineralising environments (Rowland & Simmons, 2012; Seebeck et al., 2014), imposition of a slice of young ocean floor over the top of the sequence (Schellart, 2007), and back-thrusting and folding of Eocene hydrocarbon-rich sediments along the Taranaki Fault (King & Thrasher, 1992). Fortuitously, roll-back of the subduction margin has resulted in a parallel alignment of active and paleo-fluid flow regimes that are accessible for scientific study in both continental and oceanic lithosphere. This affords a rare opportunity to compare and contrast mature and active hydrocarbon systems and epithermal mineralizing environments, thereby unravelling the controls on the transport, entrapment and preservation of metals and hydrocarbons from source to surface. At the heart of such studies is the simple question of how heat and mass is transferred through the lithosphere. Our combined expertise and established international collaborations ensure that we are well-placed to address this problem through the integration of a diverse suite of land-and marine-based studies including seismology, magnetotellurics, geochemistry, heat flow, and structural mapping along four corridors.

The Northern Kiwi Array (*Figure 11*) is designed around four corridors, which will address the following questions:

1. How is evolution and rotation of the North Island linked to spatial-temporal deformation along the northern Hikurangi margin, mineralization in Northland and on the Coromandel Peninsula and the evolution and hydrocarbon generation of the Northland, Taranaki, and East Coast Basins?
2. How does the southward migration of the ~17-km-thick Hikurangi Plateau along the current backarc system affect the generation of melts, associated seafloor volcanic activity, concomitant hydrothermal systems and metal deposition?

Corridor 1 consists of largely geochemical studies focussing on the effect of subduction of the Hikurangi Plateau and southward movement of its northern edge for magma generation, metal accumulation and structure related to tension in the back arc, large-scale permeability and location of volcanoes.

Corridor 2 crosses from the forearc to the backarc via the uplifted Raukumara Peninsula with the objective of imaging the active plate boundary beneath the forearc and the deep crustal structure across the back arc using a combination of active- and passive-source seismic deployments. Magnetotelluric surveys will focus on dewatering of the subducting slab and the upward migration of these fluids through the lithosphere. The effect of these fluids on thermal evolution and hydrocarbon potential of the East Coast Basin will be studied.   Comparison of results with those from previous surveys across the Taupo Volcanic Zone (TVZ) further south will improve our understanding of evolution of forearc and backarc in time.

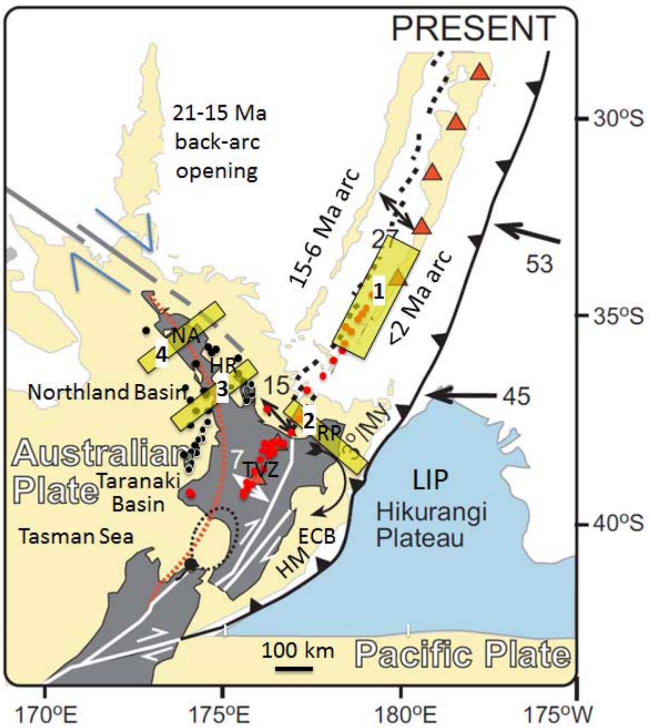


Figure 11: Location of proposed corridors.  ECB: East Coast Basin, HM: Hikurangi Margin, HR: Hauraki Rift, LIP: Large Igneous Province, NA: Northland Allochton, RP: Raukumara Peninsula, TVZ: Taupo Volcanic Zone.

Corridor 3 focuses on the role of the Hauraki Rift in the evolution of the plate boundary. Passive- and active-source seismic surveys aim at imaging terrane boundaries and determine their role on localisation of deformation and fluid flow in the overriding plate.

Corridor 4 targets the deeper Northland Allochton with the aim of resolving the pre-24 Ma configuration of the plate boundary by imaging terrane boundaries and determining their relationship to structures in the overlying sequence.  We plan passive- and active-source seismic surveys and a magnetotelluric survey, as well as evaluation of recently acquired aeromagnetic data.  This will improve our understanding of internal deformation processes and potential mineralisation, identify the deep heat source of the Ngawha geothermal system, New Zealand's only high-temperature geothermal system outside of the TVZ and better constrain evolution and hydrocarbon generation in the Northland and Taranaki Basins.

A large number of international surveys are planned, or at advanced proposal stage in particular covering the forearc and backarc region. These including drilling (International Ocean Discovery Programme and remote drilling with the German MeBo system) and an active-source seismic on-shore offshore survey east of the Raukumara Peninsula. These surveys are directly relevant to the proposed studies. Mobilization of equipment for these surveys combined with the coordination provided by a New Zealand CoRE will on the other hand facilitate proposals for additional surveys. Furthermore, hydrocarbon exploration is likely to provide vessels of opportunity for seismic studies for large parts of the northern swath.

### 3.3 Theme 2: Earthquakes, fluid flow, tremor and slow slip

*Theme leader: Professor David Prior. Contributing PIs: Townend, Little, Bannister, Ellis, Quigley, Lamb, Lamarche*

Within the CoRE there will be a concerted push to understand the fundamental physics of earthquakes and earth deformation in general. Kiwi Array will collect new earthquake data that will feed into this theme. Under this theme we will co-ordinate programmes to measure microseismicity in the Hikurangi margin (project 33), in central South Island (projects 18, 34), in Otago (project 14), in the Taupo Volcanic Zone (projects 14, 26) and in the Wellington region (project 19). These projects will be informed by a major drilling programme and associated sample analysis on the central Alpine Fault (projects 8, 15) that will explore rock properties deep on a fault zone (projects 40, 41, 57, 58). In a further project we will investigate the link between water table levels and earthquakes (project 11), while in a combined seismic and electrical resistivity project, we will seek to understand the link between slow slip and fluids along the subduction thrust beneath the eastern North Island (project 12). In this theme we take a material science approach to rocks and fault zones, involving laboratory rock mechanics experiments, to understand the physics of rupture and to constrain how geophysical observations link to physical properties and rupture processes (projects 15, 40, 41, 57, 58).

Information about the physics of earthquakes and probable impacts of future earthquakes can be obtained from geologic investigations of fault ruptures and shaking-induced features (e.g., rockfalls and liquefaction) combined with acquisition of high-resolution geospatial data (e.g., light detection and ranging data (LIDAR)). We will develop projects on the back of presently funded work (projects 22, 23) in the Canterbury area to address these topics. In particular, we will better characterise rupture direction from combined LIDAR analysis of active faults and analogue modelling of surface ruptures. Linked to this will be research leading to better quantification for the timing and characteristics of past earthquakes from dating of paleo-rockfalls and paleo-liquefaction features. These data will be combined with seismicity analysis to feed into the economic research and to the Hazard Platform.

Within this theme we will undertake seismological research that uses ambient noise (wave action, wind noise, human-made noise etc) as a source for surface wave dispersion studies. These studies are at the heart of research into deeper crustal structure (Behr et al., 2011), but also have proven application to shallow (top 30 m) investigation of the shear modulus and liquefaction potential in urban areas (Louie, 2001). This type of research is of great importance to New Zealand and links our fundamental research into some of the objectives of the National Science Challenges that tackle resilience and housing.

A final aim of this theme will be to develop research expertise and co-ordinate expert knowledge on earthquake-related phenomena of hydraulic fracturing (fracking) and reservoir loading (Reyners, 1987). Members of the CoRE have expertise in running seismic networks to measure micro-earthquakes (Rawlinson et al., 2012, Boese et al, 2013). One oil and gas company is willing to let us monitor a fracking programme if they get permission to go ahead. These observations will provide new data on fracking in New Zealand and enable us to make informed and independent comment on the process. We propose that the CoRE will eventually be seen as a source of independent advice on these matters.

### 3.4 Theme 3: Margins of Zealandia

*Theme leader: Dr Rupert Sutherland; PIs Henrys, Pecher, Rowland, Stern, Lamarche, Barnes, de Ronde*

Under this theme we will set in place a long-term programme to carry out fundamental research on Zealandia that will underpin knowledge on the resource potential of our offshore regions. Here resources refer to minerals from the seabed as well as oil and gas. Data collected from Kiwi Array will contribute to this theme through the input of ocean bottom seismology and electrical exploration with the magnetotelluric method. Data from the proposed northern swath will provide new knowledge on the Raukumara Basin, the Reinga basin and southern extent of the New Caledonian Basin (*Figure 8*). Looking out beyond 2020 we identify at least 3 more swaths that would provide key strategic science outcomes for New Zealand (*Figure 8*).

Our research on Zealandia will involve geophysical surveys, the sampling of the seabed with dredges, remotely operated vehicles, or by drilling, and analysis of data collected by the petroleum industry (held by NZPM). Our aim will be to better understand the present-day structure and tectonic history. Some focussed geophysical studies will be funded from the CoRE, but much of the work in this theme will come from the coordination of leveraged international studies. Work will include joint projects with US, French, Japanese, German, and Australian scientists (project 5), and at least two projects being proposed to IODP. In all, 15 projects are planned in our EEZ that can be aligned to this theme.

Members of the CoRE have solid track records of work in offshore regions that provide examples of how academic interests can work side by side with international partners, industry, and government for a common cause and then feed the results to end users in a clear manner. One such example discussed above was the SAHKE project and another was the Raukumara Basin (Figure *7*) experiment of 2008 (Bassett et al., 2010). With regard to the latter, members of the CoRE worked with German colleagues and the then MED (forerunner to MBIE) to collect onshore and offshore data from around the East Cape of the North Island. This project made a substantial discovery about the subduction process at active continental margins and also published the first full stratigraphy of Raukumara Basin (Sutherland et al., 2009). The first licence for hydrocarbon exploration within the basin was made shortly after. This type of project sets a template for how the CoRE can operate within this theme.

Our EEZ also offers substantial science challenges linked to plate tectonics, and thus offers us the opportunity to connect with and contribute to the international science community. How do subduction zones form and affect global plate motions? How has plate tectonics influenced regional geography, climate, and species distribution? How do sedimentary basins form and fill? To the northwest of New Zealand there are elongate basins over 1000 km long (such as the New Caledonia Trough) that that have unclear origins (Figure 9). The sedimentary basins contain archives of past events and conditions in their strata, and our general understanding of them will allow evaluation of the resource potential of New Zealand's EEZ. There may also be important consequences for understanding the thermal history of this basin and possibly for a significant portion of deep-water basins of the Earth in general (Baur et al., 2013).

### 3.5 Economics

We chose earth deformation and resources as parallel foci for our CoRE because we see them as the most important parts of earth science to affect our safety and wealth. In order to enhance this link we plan to build related economic research into the CoRE. To this end we have two economists on the CoRE as AIs who will complement our research in the natural hazards and the resources area.

Topics of study include: 1) the interplay between earthquake hazards and insurance, including the way time-dependent hazards such as aftershocks affect reinsurance; 2) the likely effects on the economy of huge plate-interface earthquakes such as the one along the Alpine Fault that is considered overdue, and a potential subduction interface earthquake that could rupture from Marlborough up through East Cape, approaching the size of the 2011 Tohoku earthquake (Cavallo, 2011); 3) the economic potential of the resources under the seabed and factoring in costs of extraction and environmental damage; 4) the concept of resource extraction and intergenerational equity (Chichilnisky, 1996).

## 4. Contributions to the Tertiary Sector

### 4.1 Introduction

In its Statement of Intent, the Tertiary Education Commission identifies six priorities for the years 2014-2019. We will contribute directly to four of these. Priority 1: Delivering skills for industry; Priority 3: Boosting achievement of Maori and Pasifika; Priority 5: Strengthening research-based institutions: Priority 6: Growing international linkages. We will also contribute indirectly to the other two (Priority 2: Getting at-risk young people into a career and Priority 4: Improving adult literacy and numeracy). By collaborating with our industry partners to provide graduate education in marine and land-based earth sciences, we will deliver skills for industry.

Our Iwi partnership scholarships will boost the achievement of Maori and Pasifika. The international connections and research that the graduate students will focus on will ensure that Priorities 5 and 6 are reached. By providing information on career pathways and connections to scientists, the community outreach in the swaths will help to motivate people to improve their numeracy and career prospects as in priorities 2 and 4.

### 4.2 Earth scientists and the Tertiary Sector

Employment for graduates in geophysics and related fields has been strong worldwide in the past two decades. While a number of globally significant mega-earthquakes and tsunami disasters in recent years (e.g., Sumatra 2004; Japan 2011) have been prompting interest in geohazards research, most of the demand for geoscientists is driven by the increasing demand for natural resources. The American Geological Institute (AGI) projected in its latest workforce report that the demand for geoscientists in the oil and gas industry in the USA alone would increase from ~40,000 in 2009 to almost 60,000 in 2029. In New Zealand, the high demand for geophysicists is best demonstrated by CareersNZ's assessment of employment chances for geophysicists as 'good,' the best category.

Petroleum is New Zealand's fourth largest export commodity and geophysics is the key discipline underpinning hydrocarbon exploration. Yet, only a small number of students graduate from New Zealand universities in geophysics and related subjects. Consequently, New Zealand universities cannot meet the country's demand for geophysics graduates, and Immigration New Zealand lists geophysicists on their immediate skill shortage list. High and increasing international salary levels ($US100k within 0-2 yr of starting[2] ), however, make it difficult to attract geophysicists to New Zealand. Hence, there is a strong need for New Zealand universities to educate graduates in modern geophysical exploration.

The shortage of graduates is particularly pronounced in marine geophysics. Given that New Zealand has stewardship over one of the world's largest economic zones (Figure *4*), the number of experts in marine geophysics graduating from New Zealand universities is worrying. We estimate that fewer than five students a year graduate with sea-going geophysical experience. At least equally important, New Zealand universities are only marginally involved in marine geophysical research, which limits the scope of student research.

[2] Data from web site of American Association of Petroleum Geologists (2013)

We are missing opportunities for students to get hands-on experience and to perform world-class research. Part of the problem is that marine research in New Zealand is led by the Crown Research Institutes (CRIs), and cooperation between CRIs and the tertiary sector on marine geophysics is inadequately developed. Marine research facilities, especially ships, are also very expensive. Facilities are available on a user-pays basis, and this user-pays system generally makes usage of marine facilities prohibitively expensive for university research and teaching-related purposes.

We now propose advancing opportunities for New Zealand geophysical students to gain hands-on experience with marine geophysical tools on New Zealand research vessels as part of this CoRE bid. As part of this proposed CoRE, we aim at improving access to marine voyages for research and education by two cost-efficient and simple measures.

The first measure involves collaboration with the CRIs. Most of the CRI-led marine research projects have had some involvement of post-graduate research students. Research voyages often involve significant international collaboration, generally after rigorous international peer review that ensures cutting-edge research questions. Student participation therefore not only increases New Zealand’s education in marine geophysics but significantly enhances our academic excellence. Students are multipliers for research activities.

We aim to improve this tertiary student involvement by increasing coordination between CoRE partners in order to maximise opportunities for students to participate in geological research voyages and conduct research on the collected data. Supervision of students will be shared amongst PIs and AIs. The CoRE will maintain a database for upcoming research voyages, both by New Zealand and international vessels that may offer student participation. The CoRE will then provide funding for related student expenses, both for cruise and post-cruise research. Funding will be allocated on a proposal-driven system similar to the successful system in place for the IODP.

Secondly, we propose offering students annual one-day courses on a research vessel in state-of-the art marine geophysical techniques. Depending on availability, this vessel could be the R/V Tangaroa or the R/V Polaris II (Otago University). Funding would cover student expenses to travel to the vessel’s port of call. We envisage a week-long block course, which includes the one day working on a research vessel, focussing on planning and acquisition of seismic, gravity, and other geophysical data, followed by post-cruise data analysis. The course would be open to third-year and post-graduate students. This programme is modelled partly after IODP’s “Masterclass” (a course offered by IODP to Marine Geoscience students of participating universities) and the University of Otago’s successful field programme on the R/V Polaris II. A similar programme is operated on the R/V Nathaniel B Palmer by our collaborators at the California Institute of Technology, and we will investigate potential synergies.

These initiatives provide a cost-efficient way to significantly enhance marine geophysics and geological education in New Zealand, boost academic research, enhance our competitiveness in attracting top-performing international post-graduate students, and deepen collaboration between New Zealand and overseas universities and research institutions. Importantly, both initiatives will also enhance collaboration between CRIs and New Zealand’s universities. A Centre of Research Excellence is an ideal way of coordinating and funding these initiatives.

### 4.3 Training of Graduates in Earth Sciences by the CoRE

Within the CoRE we will provide funding for 10 PhD students and six post-doctoral positions. We anticipate supporting at least another 10 students who would earn their own external PhD scholarships via the host university they are attached to. For example, over the past 21 years, the Institute of Geophysics at Victoria University of Wellington (VUW) has typically had 20-25 graduate students in any one year. Sixty per cent of these students are foreign students, typically from Europe, and most earn PhD scholarships.

Maori and Pacifica students are poorly represented in the earth sciences in New Zealand as either professionals or students. To enhance their participation in research we will develop scholarships for Maori and Pasifika (see Section 8).

We will also foster international connections among young researchers by having exchanges of research students and young investigators. This allows both groups to experience different research cultures and methodologies.

### 4.4 Activities within schools

Members of the CoRE are involved with a "seismometers in schools" programme (van Wijk and Adam, 2013). In this programme, funding has been sought to produce cheap and simple seismometers that can be placed in high schools and the data from them fed by the web back to a central processing unit. This initiative not only increases the reach of GeoNet for seismic monitoring, but also links our science directly to high school students. Recent trends in New Zealand education suggest that science has not been well received by senior students because it is seen as too remote and abstract. This initiative will provide senior high school students with a hands on activity that relates to the real work of living on a plate boundary, and it will give the students the opportunity to do some high-level science with the data collected.

We will make a particular effort to engage the schools near the Kiwi Array in this initiative. We will also engage primary school teachers by offering to host teachers in the Royal Society's Science Teaching Leadership Programme. Past results with such teachers have been positive (e.g., Barbara Ryan of Eastbourne worked with VUW researchers John Townend and Martha Savage in 2010).

## 5. Connections to International Groups

Our work programme (Table 1, section 9c) is closely linked to international research organisations from the USA, Germany, France, Japan, UK and Australia. All the 58 projects listed in Table 1 have international collaboration or are co-led by PIs funded from overseas. IODP has already approved drilling (c. $30M project) offshore the eastern North Island that is directly aligned to our CoRE bid, and ICDP has approved funds (>USD1M) for drilling in the South Island onshore.

Over the next four years NSF has committed to funding US researchers studying New Zealand as a primary site for their GeoPrisms program (US$5 million per year), which is focussed on the same underlying questions as our CoRE http://geoprisms.org/initiatives-sites/scd/new-zealand/.

Our neighbouring EEZ with Australia and France offers opportunities to form international collaborations. The offshore region northwest of New Zealand, the 'Tasman Frontier', has already been the focus of data compilation, joint analyses, publications, and new data acquisition (Sutherland et al., 2010; Bache et al., 2012; Sutherland et al., 2012; Hackney et al., 2012; OS2020 voyage of November 2013). France funded two geoscience voyages with *RV L'Atalante* to explore the region, which are scheduled for 2014/2015. IODP has a highly-ranked proposal to drill in the same region that includes collaborators from France, Australia, New Caledonia, as well as USA and Japan. Our link with Australia (project 14) gives us access to large 3D computing facilities and expertise, linked to AusScope (http://www.auscope.org.au/site/) and we plan to join their ANSIR equipment pool.

Europe (especially Germany, UK, and France) and Japan have both funded significant work offshore that is aligned to our CoRE work. Multiple voyages for geophysical exploration, submarine dives, and shallow drilling or dredging have already been funded and several further voyages are scheduled or proposed. The 10s of millions of dollars of funding covers studies that relate to all three themes of our CoRE and address issues such as seismic or aseismic behaviour of the subduction interface, gas hydrates, and mineralisation and crust-forming processes.

The international community has also funded some onshore work. The SAHKE project (Henrys et al., 2013) was an onshore-offshore project that had data acquisition conducted in parallel with petroleum exploration, but which had a science focus on the risk of great subduction zone earthquakes. The project was jointly funded by Japan and USA, and substantial Japanese funding (>USD $500k) stemmed from the very similar hazard issues faced by Wellington and Tokyo. Alpine Fault drilling onshore South Island (started in October, 2014) is funded by the International Continental Scientific Drilling Programme (leveraged off Marsden and other funding) to the value of >USD $1M. The aim is to understand the nature of large earthquake faults and the ambient geothermal conditions in the western South Island.

The existence of a CoRE will greatly enhance our ability to bring quality international science to New Zealand. The CoRE will also ensure that the results of such science are utilised and dispersed to end users in a timely and effective manner.

## 6. Applicability of Research to Wider Community

Adaptation to earthquake hazards and discovery and safe utilisation of natural resources are the strategic outcomes that we address, and are key issues facing New Zealand today. The CoRE has a research programme focussed on science that will provide a long-term foundation of data, understanding, and people to address both issues.

Technology transfer from our activities with our international colleagues will include new seismic methods for estimating shaking; seismic methods for exploring across coast lines; new technology for micro-earthquake arrays; innovative methods of remotely imaging faults; geological sampling beneath the oceans with submersibles, and new ways of drilling for scientific research. Technology transfer also takes place with new software applications that members of the CoRE will be learning from international sources, such as AusScope.

Our research on earth deformation will help underpin downstream work by the ‘Natural Hazards Platform’ and GNS Science to create an improved Building Code, better land use, early-warning systems and time-varying hazard predictions. Our work with geodetic data (theme 2) will underpin downstream work by Land Information NZ (LINZ) and GNS Science to improve surveying systems and a geodetic datum for New Zealand. Geophysical exploration projects will provide data and ideas that will underpin long-term assessment and utilisation of our natural resource base, and we will provide expert advice to GNS Science and MBIE that will contribute to effective utilisation and wise custodianship of these resources.

Fundamental research within the CoRE will serve to underpin the applied research done in the Oceans and Resilience National Science Challenges.

Students and young researchers trained by this CoRE will play a key role in the future development of New Zealand. If New Zealand is to adapt to its hazards and benefit from its resources, we need highly-trained people with relevant knowledge in leadership positions throughout society. Our CoRE will provide practical knowledgeable people that will be in demand for a wide range of roles within New Zealand society.

An important user of new knowledge developed by the CoRE is the international science community. In order to sustain the high level of international science investment into New Zealand, we must maintain our reputation as a credible science partner. Accordingly, a driving motivation at all levels of the CoRE will be to make new discoveries about the earth and report them through international science publications and at international conferences and workshops.

## 7. KNOWLEDGE TRANSFER

Although our CoRE will fund some new data acquisition, we will also spend time coordinating the large international and/or industry groups needed to conduct experiments, and will achieve outcomes through effective connection and communication with users of knowledge in New Zealand. In many cases, research will not be accessible or understandable to potential end-users without synthesis and decoding by CoRE members. Theme leaders will play a key role in knowledge transfer to applied end-users. We will maintain or/and form solid linkages with key end-users such as: the Natural Hazards Research Platform (NHRP); EQC; New Zealand Society of Earthquake Engineering; PEPANZ (petroleum); Straterra (minerals); and NZPM (MBIE). We will have an annual users workshop where results are reported to end-users and other members of the CoRE’s host institutions.

CoRE principal investigators will provide a source of independent expert advice that will assist in making decisions on ‘social licence’ for government initiatives associated with hazard issues and resource exploration and extraction. We will proactively demystify the resources and hazards sectors, and provide easily-identified and credible spokespeople who can assist with technical evaluation of high-level issues that arise. The questions we will be able to address include: What happens during fracking, and is drilling going to generate a large earthquake? What happens during an earthquake aftershock sequence? What is the effect of marine seismic acquisition on whales? Is New Zealand as dangerous to drill in as the Gulf of Mexico? These are all areas that CoRE members have expertise in.

We will communicate to the general community with presentations in the provinces and larger cities. Members of the CoRE have been prominent in lecture series organised by the Royal Society, and will be encouraged to continue their involvement in the future. A feature of these lecture series is their popularity in the provinces as well as major cities. For example, public talks in the Christchurch area in the aftermath of the Canterbury earthquakes attracted in excess of 1000 people, and a public Royal Society lecture in a small town like Wanaka (in 2013) on “Earthquakes and the Alpine Fault” attracted ~ 300 attendees. In the CoRE we have several well-known science communicators, including the 2012 winner of the Prime Minister’s Science Media Communication Prize (Mark Quigley) and the winner of the American Geophysical Union Spilhaus Award in science communication for 2014 (Simon Lamb). Each year we will harness this talent for communication and get out and spread the message of exiting and meaningful science from one end of New Zealand to the other.

## 8. FUTURE RESEARCH DIRECTIONS

Financial and natural events over the few past decades show that the future well being of New Zealand depends heavily on two key issues: resilience to disasters and our ability to develop and diversify our economy through the sustainable use of natural resources. We identify mitigation of earthquake hazard, and exploration of the crustal geology within onshore New Zealand and the wider offshore continental area of Zealandia, as the primary earth science research outcomes that will bring maximum benefit to New Zealand. These are scientifically linked and make for a coherent focus of our CoRE. Mitigation of earthquake hazard requires detailed understanding of the physics of earthquakes in a New Zealand setting, and the geological exploration of Zealandia requires ~~a~~ broad based collaborative research-both at the national and international level. Achieving this is too big a task for any one institution in New Zealand, but is ideally suited to a CoRE. Our CoRE will be populated with the top academic earth scientists in the country, all who have strong international links.

Future research in the CoRE will revolve around the implementation and development of new research techniques for observing the crust beneath the New Zealand region. A focus on imaging the geothermal areas of the central North Island is likely after the first 5 years of the CoRE. We also anticipate that in the next decade carbon capture and sequestration (CCS) will become one of the significant Earth Science challenges of the 21st century (Bickle, 2009). The techniques and infrastructure that we will develop in the CoRE potentially can be used to explore sub surface geological reservoirs in our sedimentary basins. We envisage expanding our capability, together with new fundamental science/engineering research and local oil-industry knowledge, to build links with power companies and identify places and methods for carbon sequestration in New Zealand.

In the offshore realm we propose using ocean bottom technologies (underwater observatories, ocean bottom GPS), which have been developed overseas by countries like Japan. Japan has paid a heavy price for not being prepared for their magnitude 9 earthquake in 2011 and is now rapidly developing the know-how to build state-of the-art Earth observatories, particular in their offshore regions. New Zealand needs to take heed of the lessons learned in Japan and also the USA - the most effective way to do this is to fund a CoRE in the Earth Sciences which can be forward looking enough to adapt the latest technologies to our particular setting and circumstances. From the point of view of understanding and developing our natural resources, particularly in the offshore regions, the planned activities of the International Ocean Discovery Program (IODP) in New Zealand and Australian waters in the next 5 years present New Zealand with enormous opportunities, which are best exploited through the infrastructure of our proposed CoRE. For example, New Zealand involvement in this through the CoRE will provide the vital clues necessary to interpret the many 1000s of kilometres of off shore seismic data we already have, significantly enhancing our understanding of the geological resource base that New Zealand now owns. Our CoRE will also be ideally configured to seek and provide partnerships with industry and international partners to achieve this outcome.

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## 8. Ka Hikitia and Vision Mātauranga:

Our Centre will address both Ka Hikitia and Vision Mātauranga. We have developed these policies in coordination with the Pou Hautu, Paul Meredith and the Assistant Vice Chancellor Māori Research, Professor Rawinia Higgins.

### Ka Hikitia: Accelerating Māori success

Māori and Pasifika students are poorly represented in the earth sciences in New Zealand as either professionals or students. To enhance Māori and Pasifika students' participation in research we will have two scholarships for Māori and Pasifika in a similar vein to those developed recently at VUW. In these, we will work with Iwi to develop scholarships, in which the Iwi works directly with the Centre and the scholarship funding comes partly from the Iwi and partly from the Centre. We will make one scholarship for research students (PhD or MSc) and another for an undergraduate to ensure that we have adequate pathways at all levels.

### Vision Mātauranga:

Our research impacts directly on Indigenous Innovation through contributions to economic growth through understanding of exploitation of natural resources. It also impacts on Taiao, through learning about the Earth and marine sciences.

Public concern about offshore exploration and fracking as well as geothermal exploitation has become strong in recent years, for both Pākehā and Māori. As independent authorities we plan to conduct research and then host information exchanges to help to bring geologic understanding to the debate. We plan to run public meetings/workshops in the towns or communities that are directly affected.

Māori oral traditions and place names are potential sources of information about past seismic events and their impact on Māori communities and the landscape. The archaeology of the Māori, addressing the interaction between pre-European Māori and their environment, has the potential to clarify the traditional data, and provide independent data about the timing and impact of seismic events. We would seek engagement with Māori on this by running a workshop within the first 12 months of the CoRE starting. We will seek advice from our User Advisory Group and from the School of Māori studies at VUW on who should be invited and where the workshop should be held.

## VISION MĀTAURANGA

### Themes

| | |
|---|---|
| Indigenous Innovation (economic sustainability) | |
| Taiao (environmental sustainability) | ✓ |
| Hauora/Oranga (health and social wellbeing) | |
| Matauranga (indigenous knowledge) | ✓ |
| N/A | |

# 9. GOVERNANCE, STRATEGIC MANAGEMENT AND RESOURCES

## 9A. GOVERNANCE PLAN

### 9A.1 Composition, roles and responsibilities of the Governance Board

The Governance Board will comprise between 8 and 10 members, the aim being to have sufficient members to give the Centre for Earth Deformation, Resources and Geophysical Exploration access to the depth and breadth of talent necessary to ensure its success while limiting its size to that of an effective operating unit. The Governance Board will be assisted by two advisory groups: a Users Advisory Group (UAG) and an International Science Advisory Group (ISAG).

Membership of the Board will be based on ability in the first instance, but with provision for representative membership by significant private and provider investment partners. The Board will have representatives from the host organisation (Victoria University) and the partners (Auckland, Otago, and Canterbury universities, and NIWA and GNS Science). The Governance Board will be chaired by a member who is independent of the host organisation and the partners. We have already contacted Dr Helen Anderson (former CEO of MoRST, geoscientist and now professional director) as a possible chair of the Board and she has indicated her willingness to take on the role).

The skills and experience considered relevant to the Governance Board include science and management as applied to earth science, intellectual property (IP) management, business management (including strategy, investment, and delivery), financial management, communications and relationship management, and human resource development (including teaching, training and capability development). We will include a member with links to Maori or Pasifika to facilitate our Vision Mātauranga. We have been in contact with Dr Dan Hikuroa (Nga Pae o te Maramatanga, University of Auckland) and he has agreed to fill this role.

The role of the Governance Board is to focus on policy, strategy and operational oversight of the CoRE. The Board will be guided by the Funding Agreement with Tertiary Education Commission (TEC) and the Guidelines for CoREs published by TEC. As such, Board members will be expected to operate in good faith and in the best interests of the CoRE in terms of its purpose.

The specific responsibilities of the Governance Board will include:

- ***Policy***: The Board will set policies to provide high-level guidance (but not detailed prescription) to the way in which the Centre operates. Areas for consideration include finance, conflicts of interest, dispute resolution, intellectual property management, business continuity, reporting regimes, and resource management.
- ***Strategy***: The Board has overall responsibility for ensuring that the Centre achieves its purpose, and so will set the overarching framework for success. It will first establish a strategy that will guide the Centre towards successful attainment of its goals for research and international investment. Management teams will later develop detailed implementation plans pursuant to the strategy.
- ***Performance***: Another key responsibility of the Board will be to measure and monitor performance. Such measuring and monitoring will cover the full range of strategic objectives set by the Board including scientific research, capability development, outreach and research translation.

### 9A.2 Performance measures

We have selected a series of key performance indicators for the CoRE. These will be distributed to the Board and biennially to the International Science Advisory Group. Performance measures will follow the guidelines in the TEC's "Centres of Research Excellence Performance Measurement Framework Guidelines," dated 25 July 2014. We will report annually on our performance in relation to the strategic outcomes, impacts, outputs and activities delineated in Section 6.

Strategic Outcomes: The Centre aims to increase the future wealth and safety of New Zealand through increased understanding of earth deformation, crustal fluid flow and resource deposition. Because these are long-term goals, we do not expect to be able to give specific measures of wealth and safety that are directly related to our Centre, but we will instead provide measures of the outputs and activities that will lead to these outcomes. We will provide commentary in our annual report on how the activities are leading to the greater goals. The annual report will also outline the research plan for the next year and how it has evolved from the initial proposal. We will report on what kind and how much data we have collected and how it has been archived, as one of our aims is to provide a strategically important database on New Zealand earth science in the swaths that our array of observations will cover.

Translation and knowledge exchange: This will be facilitated through the usual scientific channels and also through our workshops and meetings with the advisory boards. We will keep track of all the journal articles submitted and talks and posters given at national and international conferences. In addition we will keep track of any work with the local schools and schoolteachers, including any Royal Society Teacher fellowships and seismometers placed in schools. An annual research translation plan will be drawn up each year and will be commented upon at the end of the year. We will keep track of the public talks given, and any interactions that we have with the media or general public. Meetings with Iwi to discuss our programs will also be documented.

Research excellence: This will be evidenced by external grants achieved, any honours attained by our students, postdoctoral fellows, AIs and PIs, and journal article citations.

Research commercialisation: We do not expect many patents, although it is possible that methods will be developed that could be commercialised. Since we will make all our data freely available, it is also possible that some of the data we collect could be used by a commercial company, and if so we will include that in our report. We will report on any spin-off companies we establish.

Collaboration: We will report every year on our collaborations, including research proposals, conference presentations and journal articles, as well as visits by CoRE members between institutions.

Human Capital Development: We will report using the standardised method advocated in the TEC's performance measurement framework. We will keep track of our students in the long term and report on that as well.

Management: Minutes of our meetings will be kept for examination if desired, and we will provide summaries of the important concerns and report on the general activities of the group. The universities and CRIs will monitor the performance of their employees. In addition, the management team will perform a self-evaluation exercise at the end of every year to help to prepare for the three-yearly CoRE reviews. These self-evaluations will consider the performance of the different teams as well as the individual performance of the PIs and the AIs that are associated with the specific projects.

Financial Management: This will be carried out according to the standardised requirements.

The table below summarises the performance measures and metrics we will produce.

| **Theme** | **Metric** | Descriptor and notes |
|---|---|---|
| Research Excellence | External Research Income (ERI) per FTE | ERI/FTE |
| Research Excellence | Level of International Science Leverage (ISL) to NZ | ISL/FTE |

| | | |
|---|---|---|
| Research Excellence | Academic Impact | Citation indices |
| Research output | Total research outputs per FTE | |
| Human capital development | Number of students aligned to CoRE who graduate per FTE | |
| Human capital development | Destination of graduating students | |
| Collaboration | Newly created collaboration networks | Indicated by journal articles |
| Translation | Attendance at public lectures<br>Attendance at user workshops | |
| Translation | Invitations to speak at industry or other user forums | |

## 9B. MANAGEMENT PLAN

### 9b.1 Composition and person description of management structure

In the interests of efficiency and economy, existing structures and processes of both the host and partners will, by preference, be used to provide management services to the CoRE. However, rather than just making such existing structures and processes available, they will be adapted and integrated to meet the CoRE's requirements.

The Director will be Professor Tim Stern and the Deputy Directors will be the theme leaders: Professor Martha Savage, Professor David Prior and A/Professor Rupert Sutherland. They will form the Senior Leadership Team together with a representative each from the Emerging Researchers Group, the PIs and AIs. The Director will oversee the normal operations of the team with the assistance of a Centre Manager and an administrative assistant. The Kiwi Array technician will have overall responsibilities for the operation and maintenance of the instrumentation, with some operational support from the administrators. The Senior Leadership Team will meet with the Director at least monthly to discuss any issues that affect the CoRE's operation. This team will also be responsible for forming committees to evaluate proposals when rounds are called for. A major focus of the Senior Leadership Team is to develop high quality research/translation plans. These rolling three-year plans will be modified yearly.

The Theme Leaders will have overall responsibility for their theme, coordinating the activities and delegating tasks to PIs or AIs as appropriate. PIs and Theme Leaders are expected to be supervising postgraduate students and/or Postdoctoral Fellows working on the project.

Once the Governance Board is in place, the team operation will be reviewed and any changes made. The Director will ultimately be hired and monitored by the Governance Board. The governance Board will take advice from the two advisory groups described below.

### 9b.3 Roles and responsibilities of advisory boards

**Introduction:**

The Centre will assemble two advisory boards: a Users Advisory Group (UAG) and an International Science Advisory Group (ISAG). This division reflects the twin goals of the Centre: to undertake both fundamental research of benefit to the international community and research that has applications to New Zealand-specific issues.

The UAG will consist of representatives from industry, hazard mitigation organisations, government (both local and national) and tangata whenua. A prime role of the UAG is to provide guidance on how the CoRE can best interface with industry, provide relevant research and prepare students for the workforce of the 21st century. Members who have already agreed to participate are: Dr Mac Beggs (New Zealand Oil and Gas); Dr Robert Crookbain (Shell Oil, New Plymouth), and Richard Smith, Head of Research and Education at EQC, and Dr Bruce McFadgen, Research Associate and archaeologist in the School of Maori Studies at VUW. Straterra (minerals industry) has also agreed to provide a representative. We will seek representatives from NZ Petroleum and Minerals (NZPM), representing MBIE, and Local Government New Zealand. We plan on biannual meetings of the UAG, to be held just before one of the board meetings, which the Chair of the UAG will attend to summarize the advice of the Group.

The ISAG will assess the quality and volume of Centre's research output within the context of international science, and will make suggestions about possible scientific directions. Members of ISAG will be eminent researchers from abroad but with strong New Zealand connections. We will organise annual video conferences for the ISAG, timed to provide maximum input to the Governance Board. Every two years the whole group will be brought to New Zealand in conjunction with the Centre conference and workshop. At this time the UAG and ISAG will meet together to exchange views. If there is a specific technical matter that the Governance Board needs advice on, special meetings of either the UAG or ISAG will be called. The ISAG may also help to find suitable referees for proposals to the Centre.

**Roles and responsibilities**
The following sets out the conditions of appointment and terms of reference for the advisory boards:

| **Conditions of Appointment** | |
| --- | --- |
| **Term** | Appointments to advisory boards will be for up to 3 years, renewable for a further 3 years, but both board members and the Centre have the right to conclude appointments with one month’s written notice. |
| **Time commitment** | Members of advisory boards will be expected to participate in 2-4 meetings per year (to discuss the management’s proposed annual research/translation plan, to assess progress, to contribute to an annual report, and to conduct general and special business). There may be an increased time requirement for inaugural meetings as the boards develop their approach (and contribution) to planning, and their own modus operandi. Individual members and in particular the chairs of advisory boards may be called upon from time to time to assist with contacts and advocacy. |
| **Costs** | Actual and reasonable costs associated with participating in meetings and assisting with the conduct of the Centre’s business will be reimbursed against presentation of receipts. |
| **Not employment** | The Centre will not enter into any partnership, agency, employment or joint venture relationship with members serving on advisory boards. |
| **Scope** | While advisory boards may need to be aware of the financial position of the Centre in order to properly execute their advisory roles, financial management and HR issues will be the responsibility of Centre management. |
| **Intellectual property** | No intellectual property residing in or generated by (or in association with) the Centre is available to advisory board members personally or collectively. All such intellectual property (including but not limited to trade marks, patent rights, inventions, designs, know-how, trade secrets or an application relating to any such rights, whether registrable or unregistrable) is owned and managed by the Centre in accordance with its contractual arrangements with its funders and partners. |
| **Confidentiality** | Advisory board members are required to keep all ‘Confidential Information’ confidential. ‘Confidential Information’ means any and all information concerning the activities, business, finances, software, know-how, data (technical or non-technical), trade secrets, projects, forecasts, systems or processes, marketing, customers or any other information relating to Victoria University and received by advisory board members, except for any such information that is legally required to be disclosed, or which is generally known by the public other than by a breach of this confidentiality requirement. |
| **Conflicts of interest** | Advisory board members should declare any conflicts of interest that may arise during their tenure. |

| **Terms of Reference** | |
| --- | --- |
| **Overall** | The overall focus of the advisory boards is to make recommendations to the Centre’s Governance Board and Management Team on the development of a high quality research/translation plan such that the Centre becomes recognised as a world-class facility that delivers excellent and relevant research that is successfully adopted by end-users. |
| **Counsel** | The advisory boards will provide informed and considered recommendations in relation to the quality and structure of research programmes and the delivery of research results to end-users. They will critically assess research performance |

| | |
|---|---|
| | against the Centre's purpose and the strategic intent established by the Governance Board. |
| **Planning** | Boards will advise on the development of the annual research and translation plans. |
| **Profile** | Advisory board members will be respected and well connected individuals in their fields of expertise. They will, by agreement with the Centre and as opportunities arise, network at senior levels with relevant groups such as the Earthquake Commission, local councils, NZOG, industry, research, government, and media organisations to reinforce initiatives by the Governance Board and management team to profile the Centre. They should communicate the purpose, positioning and research and translational strategies of the Centre. |
| **Advocacy** | Advisory board members should advocate for the Centre amongst members' networks as circumstances allow and provide feedback to the Centre on its performance. |
| **Contacts** | Advisory boards members will assist with introductions for the Centre to facilitate its work and funding. |

**9b.4 Lead Contractor (Host) contributions:**
**Accommodation**: Victoria University will provide suitable space to accommodate the Centre directorate and research staff. Branding of the space (together with directional signage) will give the Centre a physical presence and visibility to the wider public. Access to facilities such as meeting rooms, lecture theatres and conference venues will be available subject to Victoria booking requirements.

Space for housing and maintaining equipment used in the rolling array will be sought at institutions closest to the array to minimise transport costs.

**Support services**: The management structure discussed in section 9b.1 provides for support services to meet the needs of the central financial system, to facilitate the smooth operation of advisory boards, and to provide general administrative back-up for the Centre.

**Specialist facilities**: Access to specialist facilities owned by Victoria University will be on terms and conditions agreed under the funding agreement and partnership subcontracts. Any dedicated specialist equipment will be recorded in the Centre's balance sheet and depreciated in accordance with standard accounting rules.

**Financial systems (CoRE, external, and partner costs and revenues)**: Victoria University, through its Research Office, will establish a budget centre for the Centre, which will include a record of all costs and revenues, a balance sheet and depreciation schedule.

The budget centre will show all budgeted and actual revenues received by the Centre from TEC, other public and private funders and Centre partners. It will also show all expenditures by category (people, operating and overheads) and by Victoria University or partners.

The resulting financial statements will show all budgeted and actual revenues by source, and expenditures by category and user.

**Intellectual property management**: The funding agreement with TEC and the subcontracts with Centre partners will provide for the ownership and management of IP. Victoria University, will ensure that the provisions of the funding agreement and subcontracts are adhered to.

Existing structures and expertise already exist within Victoria University for managing IP, and these will be used.

**9b.5 Partner contributions:**

**Accommodation**: Partners will make suitable space available for the conduct of their responsibilities in relation to the Centre. Provision is made in the budget to fund space that is unique to the Centre and is required to accommodate new activities arising as a result of the Centre.

**Local support services**: Partners will contribute support services necessary to sustain CoRE activities on their sites. These are expected to be minimal and will integrate with the support services provided by Victoria University.

**Local specialist facilities**: Access to specialist facilities owned by the partners will be on terms and conditions agreed under the partnership subcontracts. Any dedicated specialist equipment supplied by the partners will be recorded in the Centre's balance sheet and depreciated in accordance with standard accounting rules.

**Interaction with the CoRE's financial systems (CoRE, external, and partner costs and revenues)**: While Victoria University will manage the Centre's central financial records, the partners will integrate their financial records with Victoria's.
For example, Victoria University's records will show expenditure by category attributed to partners. The partners' accounts will show this as CoRE revenue to them and then detail expenditure by cost category.

**Engagement with intellectual property management**: If IP commercialisation appears viable, Victoria University will link closely with the Centre Management Team and with the other institutions in the Centre.

## 9C. TABLE OF AGREEMENTS

### 9c.1

| Institutions involved | Timeframe of agreement | Nature of agreement |
|---|---|---|
| Victoria University of Wellington and University of Otago | Upon Signing and until the outcome for the CoRE funding round. | Heads of Agreement outlining the foundation for a formal Participation Agreement should the bid be successful |
| Victoria University of Wellington and University of Auckland | Upon Signing and until the outcome for the CoRE funding round. | Heads of Agreement outlining the foundation for a formal Participation Agreement should the bid be successful |
| Victoria University of Wellington and University of Canterbury | Upon Signing and until the outcome for the CoRE funding round. | Heads of Agreement outlining the foundation for a formal Participation Agreement should the bid be successful |
| Victoria University of Wellington and GNS Science | Upon Signing and until the outcome for the CoRE funding round. | Heads of Agreement outlining the foundation for a formal Participation Agreement should the bid be successful |
| Victoria University of Wellington and NIWA | Upon Signing and until the outcome for the CoRE funding round. | Heads of Agreement outlining the foundation for a formal Participation Agreement should the bid be successful |

### 9c.2 Tables of existing and proposed projects in New Zealand: 2014 - 2018

Below are two tables that summarise existing and proposed projects in the New Zealand/Zealandia out to 2018. Both New Zealand and internationally funded projects are listed. Members of the CoRE are linked to many of theses projects. The existence of a CoRE is crucial for these projects to be coordinated and for maximum benefit to accrue to New Zealand. The existence of a CoRE will further enhance quality science investment to New Zealand earth science.

*Table 1. Projects funded and proposed by members of CoRE and associated institutions. Yellow coloured = Marsden funds, Shades of brown colour = directed core funding (DCF) for CRIs.*

| Title | Proj no. | Agency | Institution | Lead PI | Status | Planned |
|---|---|---|---|---|---|---|
| ***IODP Proposals*** | | | | | | |
| *Multiphase Drilling Project: Unlocking the secrets of slow slip by drilling at the northern Hikurangi subduction margin, New Zealand* | *1* | *IODP* | *UTIG* | *L Wallace* | *umbrella prop. for 781A and 781B* | |
| *Unlocking the secrets of slow slip by drilling at the northern Hikurangi subduction margin, New Zealand* | *2* | *IODP* | *Penn State* | *D Saffer* | *Rated "excellent" by IODP* | *2016-2018* |
| *Unlocking the secrets of slow slip by drilling at the northern Hikurangi subduction margin, New Zealand: Riser drilling to intersect the plate interface* | *3* | *IODP* | *UTIG* | *L Wallace* | *Under review* | *2020-2025* |
| *Creeping Gas Hydrate Slides: Slow Deformation of Submarine Landslides on the Hikurangi Margin* | *4* | *IODP* | *University of Auckland* | *I Pecher* | *Submitted* | *2016-2018* |
| *Paleogeographic link between southwest Pacific subduction initiation and Paleogene climate (SIPC)* | *5* | *IODP* | *GNS Science* | *R Sutherland* | *Submitted* | *2016-2018* |

| Title | Proj no. | Agency | Institution | Lead PI | Status | Planned |
|---|---|---|---|---|---|---|
| *Gateway to the Sub-Arc Mantle: Volatile Flux, Metal Transport, and Conditions for Early Life* | *6* | *IODP* | *GNS Science* | *C de Ronde* | *Submitted* | *2016-2018* |
| ***New Zealand*** | | | | | | |
| *Subductions Slippery Slope* | *7* | *Marsden* | *GNS Science* | *S Henrys* | *Funded* | *2009-2013* |
| *Deep Fault Drilling Project* | *8* | *Marsden* | *GNS Science* | *R Sutherland* | *Funded* | *2010-2014* |
| *Uncorking the Hydrate Bottle* | *9* | *Marsden* | *U of Auckland* | *I Pecher* | *Funded* | *2010-2014* |
| *Sticky or Creepy? What causes abrupt variations in seismic behavior along subduction margins* | *10* | *Marsden* | *GNS Science* | *S Ellis* | *Funded* | *2013-2016* |
| *Earthquake hydrology: seismic pumps or broken pipes?* | *11* | *Marsden* | *GNS Science* | *S Cox* | *Funded* | *2012-15* |
| *Capturing the gurgling and chatter from slow slip deformation: Unlocking the role of fluids with magnetotellurics and seismology.* | *12* | *Marsden* | *GNS Science* | *S Bannister & G Caldwell* | *Funded* | *2012-2015* |
| *Does the southern edge of the Hikurangi Plateau control Otago tectonics?* | *13* | *Marsden* | *GNS Science* | *M Reyners* | *Funded* | *2013-2016* |
| *Ups and Downs of subduction* | *14* | *Marsden* | *VUW* | *T Stern & S Lamb* | *Funded* | *2012-15* |
| *Episodic creep at the brittle-ductile transition during the seismic cycle of great earthquakes* | *15* | *Marsden* | *Otago* | *D Prior* | *Funded* | *2012=15* |
| *Gold growth in situ: nanoparticles to nuggets* | *16* | *Marsden* | *Otago* | *D Craw* | *funded* | *2014-17* |
| *Using the world's most rapidly slipping normal fault to understand the mechanics of low-angle normal faults and the dynamics of continental extension* | *17* | *Marsden* | *VUW* | *T Little* | *funded* | *2014-17* |
| *Locked and loaded? Effects of deep seismic and aseismic deformation on Alpine Fault earthquakes* | *18* | *Marsden* | *VUW* | *J Townend* | *Funded* | *2014-2017* |
| *Crust and mantle structure of NZ- residual fund* | *19* | *VUW-RO* | *VUW* | *T Stern* | *funded* | *2013-15* |
| *Harnessing New Zealand Gas Hydrate Resources* | *20* | *MBIE* | *GNS Science* | *I Pecher* | *Funded* | *2012-18* |
| *Geothermal supermodels : Integrated modelling tools for geothermal systems* | *21* | *MBIE* | *GNS Science* | *J Burnell* | *Funded* | *2013-2016* |
| *Living in the colour-coded city* | *22* | *MBIE* | *UC and ESR* | *A Winnstanley* | *Funded* | *2012-2014* |
| *Paleoseismology in Canterbury* | *23* | *EQC* | *UC* | *M Quigley* | *Funded* | *Continuing* |
| *Petroleum Source Rocks and Fluids* | *24* | *MBIE* | *GNS Science* | *R Sykes* | *Funded* | |
| *Geological Exploration Of New Zealands EEZ* | *25* | *DCF* | *GNS Science* | *S Henrys* | *DCF* | |
| *Seismic imaging of New Zealand's deep geothermal resource* | *26* | *DCF* | *GNS Science* | *S Bannister* | *DCF* | |
| *Tectonics and Structure of Zealandia* | *27* | *DCF* | *GNS Science* | *R Sutherland* | *DCF* | |
| *Petroleum Basin Research* | *28* | *DCF* | *GNS Science* | *P King* | *DCF* | |

| Title | Proj no. | Agency | Institution | Lead PI | Status | Planned |
|---|---|---|---|---|---|---|
| *Marine Physical Resources* | *29* | *NIWA* | | *G Lamarche* | *DCF* | |
| *Enabling Management of Offshore Mining* | *30* | *MBIE* | *NIWA* | *G Lamarche* | *MBIE Contestable* | *2012-2016* |
| *Active submarine faulting and earthquake potential in near-shore coastal regions northern South Island* | *31* | *NIWA* | *CRI* | *P Barnes* | *Hazard Platform* | *2012-2015* |
| *Quantifying the landslide-generated tsunami hazard in central New Zealand: A workflow for probabilistic landslide tsunami hazard assessment* | *32* | *NHRP* | *NIWA/GNS* | *J Mountjoy* | *Hazard Platform* | *2012-15* |
| ***United States*** | | | | | | |
| *HOBITSS: Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip* | *33* | *NSF* | *UTIG* | *L Wallace* | *Funded* | *2014-2016* |
| *Unlocking the secrets of slow slip at the Northern Hikurangi Subduction margin, New Zealand: CORK observatory development and installation* | *34* | *NSF* | *UTIG* | *L Wallace* | *submitted* | *2016-2018* |
| *The Thermal Regime of the Hikurangi Subduction Zone and Shallow Slow Slip Events, New Zealand.* | *35* | *NSF* | *Oregon State University* | *R Harris* | *submitted* | *2015* |
| *A community 3D seismic investigation of fault property controls on slow-slip along the Hikurangi megathrust* | *36* | *NSF* | *UTIG* | *N Bangs* | *submitted* | *2016-2018* |
| *Interdisciplinary study of the Hikurangi margin and the underplating of subducted sediment (HIKUPSS)* | *37* | *NSF* | *UTIG* | *K McIntosh* | *submitted* | |
| *Collaborative Research: Elucidating conduit, eruption and pyroclast transport dynamics of large silicic submarine eruptions.* | *38* | *NSF* | *U Hawaii* | *R Carey* | *submitted* | *2014-2015* |
| *WIZARD: seismic array in Central Southern Alps, New Zealand* | *39* | *NSF* | *U of Wisconsin* | *C Thurber* | *funded* | *2011-2014* |
| *Physical properties of Alpine fault: mechanical and hydrological* | *40* | *NSF* | *U of Wisconsin* | *H Tobin* | *Funded* | *2012-15* |
| *Physical properties of Alpine fault: mechanical and hydrological* | *41* | *NSF* | *Penn State* | *D Saffer* | *Funded* | *2012-15* |
| ***German*** | | | | | | |
| *Chatham Rise (New Zealand): compression, extension and termination mechanisms of submarine continental shelf* | *42* | *BMBF* | *AWI* | *K Gohl* | *Funded* | *2015* |
| *SlamZ -Slide activity on the Hikurangi margin, New Zealand* | *43* | *BMBF* | *U of Bremen* | *K Kuhn* | *Funded* | *2015* |
| *Kermaterm* | *44* | *BMBF* | | *A Koschinski* | *Funded* | *2015-2016* |
| *High-energy Margin Canyon Systems* | *45* | *BMBF* | *GEOMAR* | *J Bialas* | *submitted* | *2016-2018* |

| Title | Proj no. | Agency | Institution | Lead PI | Status | Planned |
|---|---|---|---|---|---|---|
| *Past, Present, Future Fluid Flow at the Hikurangi Margin; New Zealand* | *46* | *BMBF* | *GEOMAR* | *J Greinert* | *submitted* | *2016-2018* |
| *Vitiaz* | *47* | *BMBF* | *GEOMAR* | *K Hoernle* | *submitted* | *2015-2018* |
| *BGR* | *48* | *BGR* | | *U Schwartz-Schampera* | *planned* | *2014-2015* |
| ***French*** | | | | | | |
| *TECTA* | *49* | *French government* | *IFREMER* | *J Collot* | *Funded* | *2016-2018* |
| *VESPA* | *50* | *French government* | *IFREMER, UBO* | *M Patriat* | *Funded* | *2016-2018* |
| *GEORSTOM* | *51* | *French government* | *IRD* | *N Mortimer* | *Funded* | *2008-2014* |
| ***Japan*** | | | | | | |
| *Kermadec ROV Project: ABCD's of Kermadec "Architecture of an oceanic arc: building blocks of the Kermadec arc and Havre trough backarc system "* | *52* | *JSPS* | *JAMSTEC* | *Y Tamura* | *submitted* | *2014-2016* |
| *High-resolution seismic reflection project* | *53* | *JSPS* | *ERI* | *Ishiyama* | *submitted* | *2014-2016* |
| *Hikurangi slow slip monitoring and modeling* | *54* | *JSPS* | *DPRI, Kyoto Univ.* | *Y Ito* | *submitted* | *2014-2018* |
| ***Australia*** | | | | | | |
| *ECOSAT* | *55* | *ARC* | *U Syd, U Tas* | *M Seton* | *Funded* | *2012-2015* |
| *The ridge sources and spreading of hydrothermal plumes in the turbulent Antarctic Circumpolar Current* | *56* | *ARC* | *ANU* | *R Arculus/ S Downes* | *submitted* | *2014-2018* |
| **United Kingdom** | | | | | | |
| *physical, geochemical and mechanical properties of the Alpine Fault Zone:* | *57* | *NERC* | *U of Liverpool* | *D Faulkner* | *funded* | *2012-2017* |
| *physical, geochemical and mechanical properties of the Alpine Fault Zone:* | *58* | *NERC* | *U Southhampton* | *D Teagle* | *funded* | *2012-2017* |

*Table 2. Estimated levels of funding for NZ and leveraged International funding to NZ earth science.*

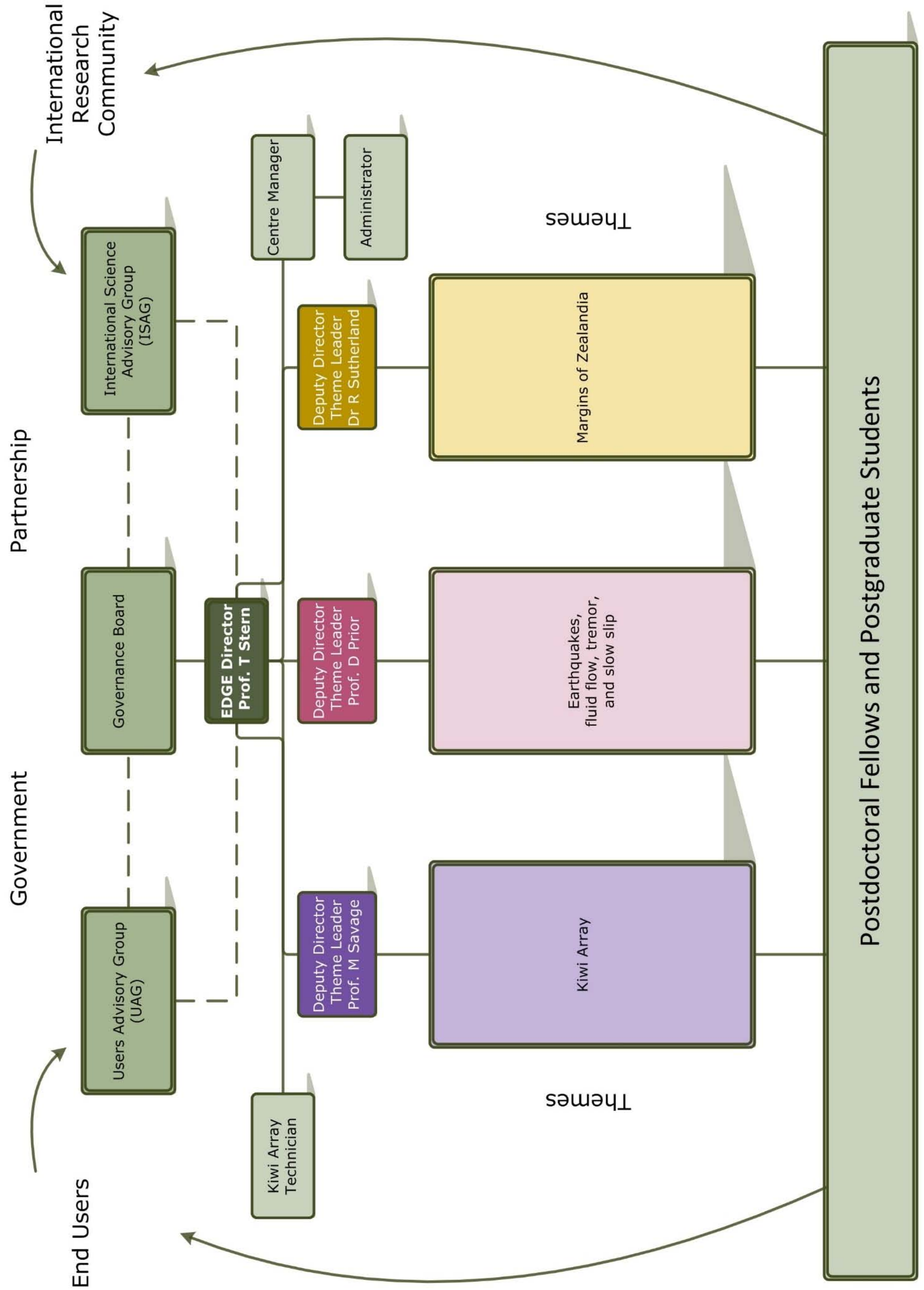
| **Funding levels** | | |
|---|---|---|
| *NZ funding* | *Directed Core(CRI) funding + Marsdens + MBIE* | *$15 mill/yr* |
| *Leveraged funding* | *US, Germany, Japan, Australia* | *$15 mill/yr* |
| *IODP 1 leg* | *International* | *$30 mill* |
| *Total over 3 years* | | *$120 mill* |

*Note: In this budget we have only included one IODP leg. Each leg costs around $30 mill and there are 7 legs proposed for New Zealand out to 2018. At least two projects have received favourable reviews.*

| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

## 9D. ORGANISATIONAL CHART

Provide an organisational chart for your proposed CoRE. This document may include, for example, relationships between any governance boards, scientific boards, management structures, etc.



## 9F. CURRENT RESOURCES AVAILABLE TO THE PROPOSED CoRE

Each of the partners has a pool of equipment that can be used by the CoRE. There will be agreements about rental rates made for access to this equipment. This equipment includes:

- 2 La Coste Gravity meters
- 3 Multichannel seismic acquisition systems (up to 240 channels)
- 2 Magnetometers
- 25 Reftek seismographs with broadband detectors.

One of our partners (NIWA) controls ships with facilities for marine geophysics and geology. We will be using one of the ships for a training course and will seek to book ship time for specific science projects.

## 9G. CAPITAL ITEM PURCHASES AND DEPRECIATION PLANS

KIWI ARRAY will cost about $800 k to purchase and the host institution has agreed to do this. Our CoRE will pay it off as depreciation at such a rate that it is fully paid after 10 years.

## 9H. OTHER FUNDING

Many of the CoRE’s researchers have strong track records in running joint international projects in New Zealand and Zealandia. These international projects leverage large amounts of funding into New Zealand science. Looking out over the next 3 years, we anticipate that about $45 mill will be spent in geophysics, scientific drilling and other operational activities in New Zealand by overseas partners. Part of the rationale for the CoRE is to facilitate and coordinate these international operations by becoming the face of fundamental earth science research in New Zealand. We aim to make it the principal entry point for international collaborators. The existence of the Centre for Earth Deformation, Resources and Geophysical Exploration will help make New Zealand more attractive to international partners and will encourage greater investment in New Zealand.

| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

## 12. PERSONNEL and 13. FTE TABLE

| | FTE for Year | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| **Director(s)** | | | | | |
| Professor Tim Stern | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| Professor DJ Prior | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Professor MK Savage | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Dr R Sutherland | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| **Principal Investigator(s)** | | | | | |
| Dr SC Bannister | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr Edward Bertrand | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Professor D Craw | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr SM Ellis | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Professor P England | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr SA Henrys | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr G Lamarche | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr SH Lamb | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Professor TA Little | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Professor PH Molnar | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr IA Pecher | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr MC Quigley | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Professor K Regenauer-Lieb | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dr JV Rowland | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr SY Schwartz | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Professor AF Sheehan | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr J Townend | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr VG Toy | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dr CEJ de Ronde | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| **Associate Investigator(s)** | | | | | |
| Dr L Adam | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr RA Arnold | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr SLL Barker | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr Philip Barnes | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr DJ Bennett | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr GH Browne | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr AMJ Coleman | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr SC Cox | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor PR Cummins | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr PH Denys | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor G Dresen | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr DM Eberhart-Phillips | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr JD Eccles | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor DR Faulkner | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |

| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

## 12. PERSONNEL and 13. FTE TABLE

| | FTE for Year | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Dr WN Fry | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr AR Gorman | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor J Greinert | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor M Gurnis | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr Christopher Hajzler | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr PR King | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor L Moresi | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor Ilan Noy | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr D Okaya | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr Martin Reyners | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor M Sandiford | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor H Sato | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor HM Savage | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr DR Shelly | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr N Shigematsu | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor RH Sibson | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor EGC Smith | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr SAF Smith | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Professor CH Thurber | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr K Van Wijk | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr LM Wallace | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Dr AG Wech | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| **Collaborator(s)** | | | | | |
| Professor SW Roecker | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| **Totals for Unnamed Directors(s)** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Totals for Unnamed Principal Investigators(s)** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Totals for Unnamed Associate Investigators(s)** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Totals for Research/Technical Assistants(s)** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Totals for Others(s)** | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| **Totals for Postdoctoral Fellows(s)** | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| **Totals for Postgraduate Students(s)** | 10.0 | 20.0 | 30.0 | 20.0 | 10.0 |

| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

Section 14

| | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE |
| **Salaries:** | | | | | | | | | | |
| Director and Principal Investigators | 336,000 | 2 | 336,000 | 2 | 336,000 | 2 | 336,000 | 2 | 336,000 | 2 |
| Associate Investigators | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Postdoctoral Fellows | 504,900 | 6 | 514,998 | 6 | 525,298 | 6 | 535,804 | 6 | 546,520 | 6 |
| Research or Technical Assistants | 88,000 | 1 | 88,000 | 1 | 88,000 | 1 | 88,000 | 1 | 88,000 | 1 |
| Others | 154,000 | 2 | 154,000 | 2 | 154,000 | 2 | 154,000 | 2 | 154,000 | 2 |
| **Total salaries & salary-related costs (a)** | **1,082,900** | **11.40** | **1,092,998** | **11.40** | **1,103,298** | **11.40** | **1,113,804** | **11.40** | **1,124,520** | **11.40** |
| **Other costs:** | | | | | | | | | | |
| Overheads | 1,212,848 | | 1,224,158 | | 1,235,694 | | 1,247,460 | | 1,259,462 | |
| Project costs | 1,000,000 | | 1,000,000 | | 1,000,000 | | 1,000,000 | | 1,000,000 | |
| Travel | 150,000 | | 150,000 | | 150,000 | | 150,000 | | 150,000 | |
| **Total other costs (b)** | **2,362,848** | | **2,374,158** | | **2,385,694** | | **2,397,460** | | **2,409,462** | |
| **Graduate education:** | | | | | | | | | | |
| Post-graduate Stipends | 270,000 | 10 | 540,000 | 20 | 810,000 | 30 | 540,000 | 20 | 270,000 | 10 |
| Post-graduate Fees | 81,600 | | 166,464 | | 254,690 | | 173,189 | | 88,326 | |
| **Total graduate education costs (c)** | **351,600** | **10.00** | **706,464** | **20.00** | **1,064,690** | **30.00** | **713,189** | **20.00** | **358,326** | **10.00** |
| **Sub Total (a + b + c)** | **3,797,348** | **21.40** | **4,173,620** | **31.40** | **4,553,682** | **41.40** | **4,224,453** | **31.40** | **3,892,309** | **21.40** |
| GST at 15% | 569,602 | | 626,043 | | 683,052 | | 633,668 | | 583,846 | |
| **TOTALS** | **4,366,950** | **21.40** | **4,799,663** | **31.40** | **5,236,734** | **41.40** | **4,858,121** | **31.40** | **4,476,155** | **21.40** |

**Total Operating Budget Request (ex GST):** 20,641,412

**Calculate Tertiary Sector (%):** 94%

| Applicant's Surname | Initials | Proposal | Panel |
| --- | --- | --- | --- |
| Stern | TA | 14-VUW-003 | EME |

**Institution Name:** Victoria University of Wellington
**Type:** Host organisation
**Request (ex GST):** **18,415,412**

| | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE |
| **Salaries:** | | | | | | | | | | |
| Director and Principal Investigators | 126,000 | 0.90 | 126,000 | 0.90 | 126,000 | 0.90 | 126,000 | 0.90 | 126,000 | 0.90 |
| Associate Investigators | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Postdoctoral Fellows | 504,900 | 6.00 | 514,998 | 6.00 | 525,298 | 6.00 | 535,804 | 6.00 | 546,520 | 6.00 |
| Research or Technical Assistants | 88,000 | 1.00 | 88,000 | 1.00 | 88,000 | 1.00 | 88,000 | 1.00 | 88,000 | 1.00 |
| Others | 154,000 | 2.00 | 154,000 | 2.00 | 154,000 | 2.00 | 154,000 | 2.00 | 154,000 | 2.00 |
| **Total salaries & salary-related costs (a)** | **872,900** | **9.90** | **882,998** | **9.90** | **893,298** | **9.90** | **903,804** | **9.90** | **914,520** | **9.90** |
| **Other costs:** | | | | | | | | | | |
| Overheads | 977,648 | | 988,958 | | 1,000,494 | | 1,012,260 | | 1,024,262 | |
| Project costs | 1,000,000 | | 1,000,000 | | 1,000,000 | | 1,000,000 | | 1,000,000 | |
| Travel | 150,000 | | 150,000 | | 150,000 | | 150,000 | | 150,000 | |
| **Total other costs (b)** | **2,127,648** | | **2,138,958** | | **2,150,494** | | **2,162,260** | | **2,174,262** | |
| **Graduate education:** | | | | | | | | | | |
| Post-graduate Stipends | 270,000 | 10.00 | 540,000 | 20.00 | 810,000 | 30.00 | 540,000 | 20.00 | 270,000 | 10.00 |
| Post-graduate Fees | 81,600 | | 166,464 | | 254,690 | | 173,189 | | 88,326 | |
| **Total graduate education costs (c)** | **351,600** | **10.00** | **706,464** | **20.00** | **1,064,690** | **30.00** | **713,189** | **20.00** | **358,326** | **10.00** |
| **Sub Total (a + b + c)** | **3,352,148** | **19.90** | **3,728,420** | **29.90** | **4,108,482** | **39.90** | **3,779,253** | **29.90** | **3,447,109** | **19.90** |
| GST at 15% | 502,822 | | 559,263 | | 616,272 | | 566,888 | | 517,066 | |
| **TOTALS** | **3,854,970** | **19.90** | **4,287,683** | **29.90** | **4,724,754** | **39.90** | **4,346,141** | **29.90** | **3,964,175** | **19.90** |

| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

**Institution Name:** University of Otago
**Type:** Tertiary partner
**Request (ex GST):** **593,600**

| | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE |
| **Salaries:** | | | | | | | | | | |
| Director and Principal Investigators | 56,000 | 0.40 | 56,000 | 0.40 | 56,000 | 0.40 | 56,000 | 0.40 | 56,000 | 0.40 |
| Associate Investigators | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Postdoctoral Fellows | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Research or Technical Assistants | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Others | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| **Total salaries & salary-related costs (a)** | **56,000** | **0.40** | **56,000** | **0.40** | **56,000** | **0.40** | **56,000** | **0.40** | **56,000** | **0.40** |
| **Other costs:** | | | | | | | | | | |
| Overheads | 62,720 | | 62,720 | | 62,720 | | 62,720 | | 62,720 | |
| Project costs | | | | | | | | | | |
| Travel | | | | | | | | | | |
| **Total other costs (b)** | **62,720** | | **62,720** | | **62,720** | | **62,720** | | **62,720** | |
| **Graduate education:** | | | | | | | | | | |
| Post-graduate Stipends | | | | | | | | | | |
| Post-graduate Fees | | | | | | | | | | |
| **Total graduate education costs (c)** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** |
| **Sub Total (a + b + c)** | **118,720** | **0.40** | **118,720** | **0.40** | **118,720** | **0.40** | **118,720** | **0.40** | **118,720** | **0.40** |
| GST at 15% | 17,808 | | 17,808 | | 17,808 | | 17,808 | | 17,808 | |
| **TOTALS** | **136,528** | **0.40** | **136,528** | **0.40** | **136,528** | **0.40** | **136,528** | **0.40** | **136,528** | **0.40** |

| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

**Institution Name:** University of Canterbury
**Type:** Tertiary partner
**Request (ex GST):** **148,400**

| | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE |
| **Salaries:** | | | | | | | | | | |
| Director and Principal Investigators | 14,000 | 0.10 | 14,000 | 0.10 | 14,000 | 0.10 | 14,000 | 0.10 | 14,000 | 0.10 |
| Associate Investigators | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Postdoctoral Fellows | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Research or Technical Assistants | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Others | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| **Total salaries & salary-related costs (a)** | **14,000** | **0.10** | **14,000** | **0.10** | **14,000** | **0.10** | **14,000** | **0.10** | **14,000** | **0.10** |
| **Other costs:** | | | | | | | | | | |
| Overheads | 15,680 | | 15,680 | | 15,680 | | 15,680 | | 15,680 | |
| Project costs | | | | | | | | | | |
| Travel | | | | | | | | | | |
| **Total other costs (b)** | **15,680** | | **15,680** | | **15,680** | | **15,680** | | **15,680** | |
| **Graduate education:** | | | | | | | | | | |
| Post-graduate Stipends | | | | | | | | | | |
| Post-graduate Fees | | | | | | | | | | |
| **Total graduate education costs (c)** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** |
| **Sub Total (a + b + c)** | **29,680** | **0.10** | **29,680** | **0.10** | **29,680** | **0.10** | **29,680** | **0.10** | **29,680** | **0.10** |
| GST at 15% | 4,452 | | 4,452 | | 4,452 | | 4,452 | | 4,452 | |
| **TOTALS** | **34,132** | **0.10** | **34,132** | **0.10** | **34,132** | **0.10** | **34,132** | **0.10** | **34,132** | **0.10** |

| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

**Institution Name:** University of Auckland
**Type:** Tertiary partner
**Request (ex GST):** **296,800**

| | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE |
| **Salaries:** | | | | | | | | | | |
| Director and Principal Investigators | 28,000 | 0.20 | 28,000 | 0.20 | 28,000 | 0.20 | 28,000 | 0.20 | 28,000 | 0.20 |
| Associate Investigators | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Postdoctoral Fellows | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Research or Technical Assistants | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Others | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| **Total salaries & salary-related costs (a)** | **28,000** | **0.20** | **28,000** | **0.20** | **28,000** | **0.20** | **28,000** | **0.20** | **28,000** | **0.20** |
| **Other costs:** | | | | | | | | | | |
| Overheads | 31,360 | | 31,360 | | 31,360 | | 31,360 | | 31,360 | |
| Project costs | | | | | | | | | | |
| Travel | | | | | | | | | | |
| **Total other costs (b)** | **31,360** | | **31,360** | | **31,360** | | **31,360** | | **31,360** | |
| **Graduate education:** | | | | | | | | | | |
| Post-graduate Stipends | | | | | | | | | | |
| Post-graduate Fees | | | | | | | | | | |
| **Total graduate education costs (c)** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** |
| **Sub Total (a + b + c)** | **59,360** | **0.20** | **59,360** | **0.20** | **59,360** | **0.20** | **59,360** | **0.20** | **59,360** | **0.20** |
| GST at 15% | 8,904 | | 8,904 | | 8,904 | | 8,904 | | 8,904 | |
| **TOTALS** | **68,264** | **0.20** | **68,264** | **0.20** | **68,264** | **0.20** | **68,264** | **0.20** | **68,264** | **0.20** |

| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

**Institution Name:** NIWA
**Type:** Non-tertiary partner
**Request (ex GST):** **148,400**

| | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE |
| **Salaries:** | | | | | | | | | | |
| Director and Principal Investigators | 14,000 | 0.10 | 14,000 | 0.10 | 14,000 | 0.10 | 14,000 | 0.10 | 14,000 | 0.10 |
| Associate Investigators | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Postdoctoral Fellows | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Research or Technical Assistants | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Others | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| **Total salaries & salary-related costs (a)** | **14,000** | **0.10** | **14,000** | **0.10** | **14,000** | **0.10** | **14,000** | **0.10** | **14,000** | **0.10** |
| **Other costs:** | | | | | | | | | | |
| Overheads | 15,680 | | 15,680 | | 15,680 | | 15,680 | | 15,680 | |
| Project costs | | | | | | | | | | |
| Travel | | | | | | | | | | |
| **Total other costs (b)** | **15,680** | | **15,680** | | **15,680** | | **15,680** | | **15,680** | |
| **Graduate education:** | | | | | | | | | | |
| Post-graduate Stipends | | | | | | | | | | |
| Post-graduate Fees | | | | | | | | | | |
| **Total graduate education costs (c)** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** |
| **Sub Total (a + b + c)** | **29,680** | **0.10** | **29,680** | **0.10** | **29,680** | **0.10** | **29,680** | **0.10** | **29,680** | **0.10** |
| GST at 15% | 4,452 | | 4,452 | | 4,452 | | 4,452 | | 4,452 | |
| **TOTALS** | **34,132** | **0.10** | **34,132** | **0.10** | **34,132** | **0.10** | **34,132** | **0.10** | **34,132** | **0.10** |

| Applicant's Surname | Initials | Proposal | Panel |
|---|---|---|---|
| Stern | TA | 14-VUW-003 | EME |

**Institution Name:** NIWA
**Type:** Non-tertiary partner
**Request (ex GST):** **1,038,800**

| | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE | Budget | FTE |
| **Salaries:** | | | | | | | | | | |
| Director and Principal Investigators | 98,000 | 0.70 | 98,000 | 0.70 | 98,000 | 0.70 | 98,000 | 0.70 | 98,000 | 0.70 |
| Associate Investigators | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Postdoctoral Fellows | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Research or Technical Assistants | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Others | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| **Total salaries & salary-related costs (a)** | **98,000** | **0.70** | **98,000** | **0.70** | **98,000** | **0.70** | **98,000** | **0.70** | **98,000** | **0.70** |
| **Other costs:** | | | | | | | | | | |
| Overheads | 109,760 | | 109,760 | | 109,760 | | 109,760 | | 109,760 | |
| Project costs | | | | | | | | | | |
| Travel | | | | | | | | | | |
| **Total other costs (b)** | **109,760** | | **109,760** | | **109,760** | | **109,760** | | **109,760** | |
| **Graduate education:** | | | | | | | | | | |
| Post-graduate Stipends | | | | | | | | | | |
| Post-graduate Fees | | | | | | | | | | |
| **Total graduate education costs (c)** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** | **0** | **0.00** |
| **Sub Total (a + b + c)** | **207,760** | **0.70** | **207,760** | **0.70** | **207,760** | **0.70** | **207,760** | **0.70** | **207,760** | **0.70** |
| GST at 15% | 31,164 | | 31,164 | | 31,164 | | 31,164 | | 31,164 | |
| **TOTALS** | **238,924** | **0.70** | **238,924** | **0.70** | **238,924** | **0.70** | **238,924** | **0.70** | **238,924** | **0.70** |