Using microfossils to understand earthquakes could be ground-breaking

Dr Jessica Pilarczyk at the University of Southern Mississippi, USA and **Dr Kate Clark**, GNS Science, New Zealand, are working together to detail the history of earthquakes and tsunamis along the Hikurangi Margin. In their collaborative project, they analyse sediment samples across sites of the Hikurangi coast of New Zealand's North Island, to uncover records of past earthquakes and tsunamis hidden within them. This can tell them more about the past behaviour of the Hikurangi subduction zone, and its hazard to New Zealand and the nations of the wider Pacific Rim.

Over half of the world's population resides by the coastline. However, in many of these locations, earthquakes and tsunamis pose hazards. Such events are related to strain caused by the collision of tectonic plates. When an oceanic plate is forced below a continental plate, it is called a 'subduction zone'. This activity causes megathrust earthquakes, which are the most powerful type of earthquake. Subduction-zone earthquakes cause changes to the structure of the land and the sea level, which are preserved in the geological record. To prepare for the potential hazards near active subduction zones, we should first understand the seismic history of the region – by identifying when ancient earthquakes and tsunamis occurred, and at what magnitude.

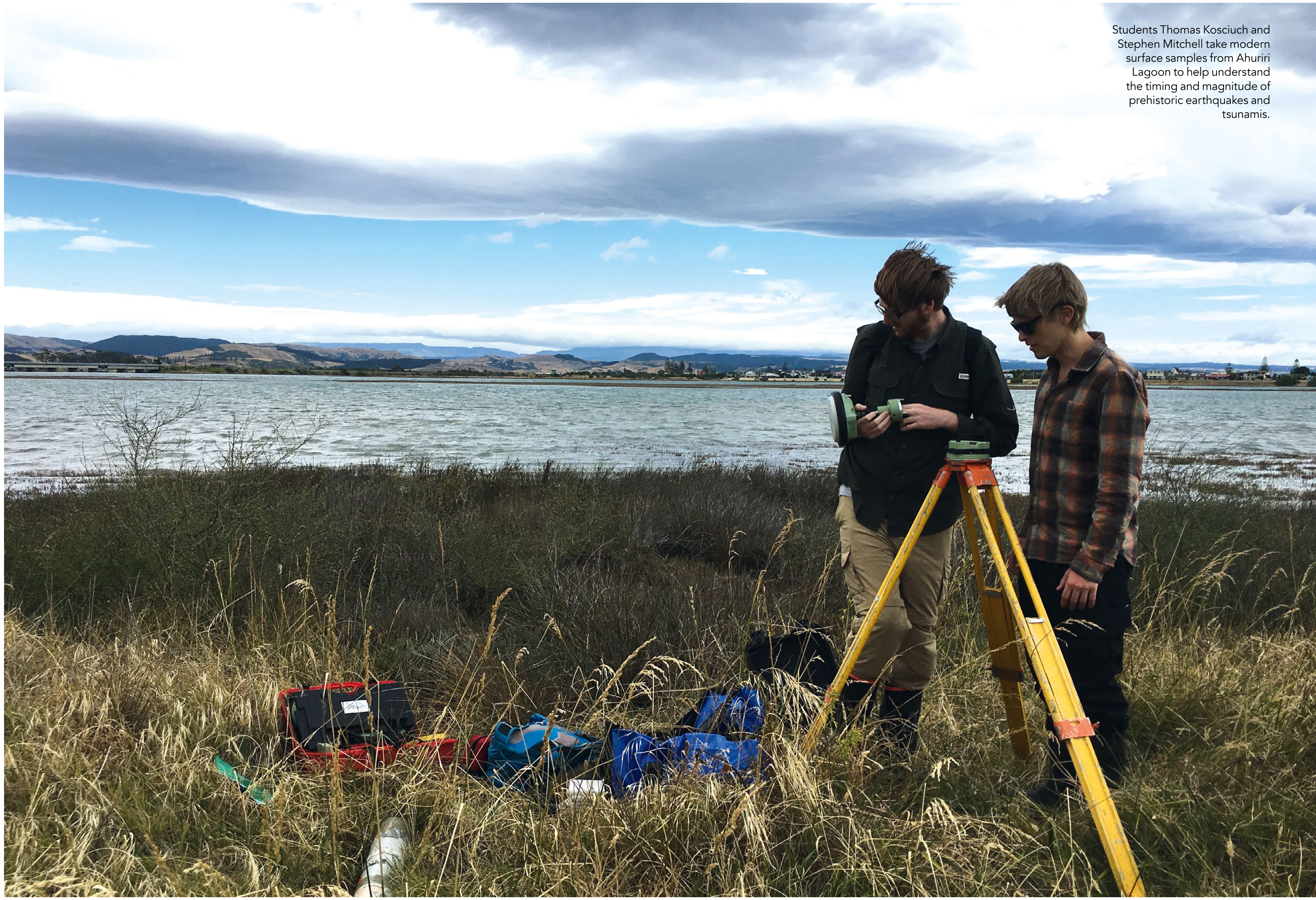
Sediments which are buried and preserved in low-energy settings (where waters are calm, such as in a lake or lagoon) are known to archive past records of earthquakes and tsunamis, which can be detected by unusual sedimentary layers. In the East of New Zealand's North Island, the Hawke's Bay sedimentary record may indicate up to six great earthquakes since around 7000 years ago.

This area is affected by the Hikurangi subduction zone, located off the East Coast of the North Island – where the Pacific Plate subducts beneath the continental crust of the Australian Plate. This zone can produce earthquakes and tsunamis, though the scientists do not know how frequently these occur, or at what intensity. Because the country has a short recent history of seismic activity (less than 170 years), little has been known of what future hazards may occur. Information from historical records is limited (dating less than 200 years old) and GPS data is even more restricted (only spanning the last 20 years).

RESEARCH ALONG THE HIKURANGI COAST

Dr Jessica Pilarczyk and Dr Kate Clark are looking to coastal sediments to fill in gaps in the seismic record. The team seeks to understand the magnitude and timing of past deformation caused by the Hikurangi subduction zone, by studying the geological record of changes to the land level and sea level fluctuations. Previous researchers have suggested that an earthquake at a similar magnitude to the 2011 Tōhoku-Oki earthquake could be plausible for the Hikurangi margin, resulting in a tsunami

Measuring the magnitude and timing of Hikurangi plate boundary deformation improves assessments of earthquake and tsunami hazards in New Zealand



Students Thomas Kosciuch and Stephen Mitchell take modern surface samples from Ahuriri Lagoon to help understand the timing and magnitude of prehistoric earthquakes and tsunamis.

Left: Stephen Mitchell and Thomas Kosciuch examine microfossils from prehistoric tsunami deposits, which can only be seen under the microscope.

Centre: Sediments at the bottom of lagoons archive evidence for past Hikurangi Margin earthquakes and tsunamis.

Right: Dr Jessica Pilarczyk and students with Dr Ursula Cochran from GNS Science in New Zealand.

that could inundate low-lying parts of the East coast of New Zealand's North Island, including parts of major cities such as Wellington and Napier. As the researchers state: "Inferring the magnitude and timing of Hikurangi plate boundary deformation along the coastline improves assessments of earthquake and tsunami hazards in New Zealand".

The team are looking for evidence of crustal deformation that occurred in response to past earthquakes. Their goal is to provide an improved record of seismic activity in the area, by defining past timing and magnitudes of events. Earlier this year, they investigated various sites along the East Coast to find such evidence. One study site was the Ohuia lagoon, near Wairoa, where the scientists took sediment samples for analysis in the laboratory, and applied high-resolution grain size, palaeontological and geochemical analysis.

USING MICROSCOPIC FOSSILS TO UNCOVER PAST EARTHQUAKES

Hikurangi has a history of tectonic change and periods where the coastline shifted below sea level (during subsidence), where space was made for sediments to build up. The team state that "multiple cycles of tectonic subsidence have been preserved in the sedimentary record". Among the sediments, microscopic fossils (microfossils) can be found. Marine protists such as foraminifera leave behind their calcium carbonate shells, and diatoms leave their glassy (siliceous) cell walls. When analysed under the microscope, these microfossils tell us about the age and environment of the sediments they were laid among. Particular species of these microfossil groups prefer certain environments over others. For example, some species of foraminifera prefer shallow marine conditions, over the lower salinities of inland lakes. When these foraminifera are found in inland lakes they indicate marine incursion, such as tsunamis.

During earthquakes, changes to the elevation of the coastline (known as land level change) can occur and be reflected in the sedimentary record as changes in sea level. The research team infer past land level change using microfossils that have a known close relationship to tidal elevation. When sediments are washed over during tsunamis, they are deposited where they would not normally occur, as 'overwash' deposits. Tsunami assemblages may have a more 'mixed' assemblage of microfossils,

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Above: Dr Jessica Pilarczyk and students core coastal sediments in Northern Hawke's Bay.

Bottom left: Dr Kate Clark and students document an uplifted sequence of tsunami deposits. These deposits will inform hazard assessment by indicating how often tsunamis impact the Hikurangi coastline.

Bottom right: Sandy tsunami deposits overlie darker paleosols in an uplifted beach exposure south of Hawke's Bay, New Zealand.

Statistical transfer functions will be developed to infer tidal elevations from microfossils such as diatoms, foraminifera, and pollen

Q&A

Q&A with Dr Jessica Pilarczyk

What challenges have you faced in using microfossils to indicate overwash from tsunamis?

The preservation of microfossils can sometimes make identifying tsunami deposits difficult. Environmental conditions such as chemical and subaerial exposure can degrade the microfossils to the point that they are unrecognisable.

How recent or unusual is the technique of using microfossils to uncover seismic histories in the sedimentary record?

Species of foraminifera and diatoms have long been used to document prehistoric earthquakes and tsunamis in the sedimentary record. This method is referred to as the "taxonomic approach" and provides insight into the origin of sediments. Recently, the "taphonomic approach" has been developed to supplement taxonomic data and uses the surface condition of individual microfossils (e.g., patterns of fragmentation and abrasion) to provide insight into transport history.

How can this research benefit other regions of the world that face the risk of earthquakes?

Large earthquakes and tsunamis originating from the Hikurangi Margin have the potential to impact other countries with coastlines facing the Pacific Ocean.

Have you found that your data better complies with or contradicts existing paleo-seismic records?

Every subduction zone is different in terms of what earthquake magnitudes and return periods can be expected. In this way, our data does not necessarily comply or contradict records developed from other margins. However, the Hikurangi marks a unique opportunity to study the "slow earthquake" phenomenon, which will be important to understanding other subduction zones that have/will experience the same thing.

What are the next steps for your research?

During our next field campaign in March 2018 we will explore coastal lagoons and ponds in the Hawke's Bay region for evidence of prehistoric earthquakes and tsunamis. Our goal is to catalogue, through sedimentary evidence and careful dating, Hikurangi earthquakes and tsunamis that have impacted New Zealand over the Holocene and to resolve what magnitudes and return periods can be expected in the future.

Large earthquakes and tsunamis originating from the Hikurangi Margin have the potential to impact other countries with coastlines facing the Pacific Ocean

as large volumes of oceanic and terrestrial sediments were scoured. Therefore, the origins and transport distance of the sediments can also be implied. For example, Dr Pilarczyk has discussed in a published review that sediments from the Sendai coastal plain in Japan contained foraminifera that linked a beach to a nearshore source for the deposit left behind by the 2011 Tōhoku-Oki tsunami.

Dr Pilarczyk and Dr Clark are filling in the gaps in the seismic record for the Hikurangi Margin. By inferring changes to sea level through sedimentary analysis and microfossil analysis, they are deducing the magnitude, frequency and location of past Hikurangi subduction thrust earthquakes, and related tsunamis. This way, the true extent of the deformation caused by this activity can be conveyed, and the mechanics of the subduction zone better understood. This information is valuable for coastal risk assessments and hazard mitigation in the North of New Zealand, and even further afield.

Detail

RESEARCH OBJECTIVES

Dr Pilarczyk's research interests fall into three broad themes: 1) the application of microfossils in monitoring and reconstructing coastal environments; 2) the role of storms and tsunamis on coastal evolution; and 3) hazard assessment of future great earthquakes along subduction zone coastlines. Her aim is to extend the short-term instrumental record by using the long-term geological record, and through this improved understanding of impacts and processes, enhance our ability to forecast how coastal systems will respond in the future.

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COLLABORATORS

GNS Science: Kate Clark, Ursula Cochran, Nicola Litchfield
Students: Thomas Kosciuch, Stephen Mitchell
SHIRE Team: Jeff Marshall, David Okaya, Demian Saffer, Harm Van Avendonk, Laura Wallace, Kirk McIntosh

BIO

Jessica Pilarczyk is an Assistant Professor of Marine Science at the University of Southern Mississippi located at the NASA Stennis Space Center. Jessica, along with students and collaborators, examines how coastal environments have been altered by extreme events (earthquakes, storms, tsunamis) in the Caribbean, Japan, New Zealand, Oman, the Philippines, Sumatra, and Vanuatu.

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