THE FORCES BEHIND
WAVES AND LAKE TSUNAMIS

Lake Taupō, one of New Zealand's most inland spots, experienced a rare tsunami in 2022 when an earthquake sent swells across the moana. Pumice washed a few metres inland—except at one beach, where a significant chunk of shoreline and car park vanished beneath the lake's surface. Science communicator Ceana Priest examines the causes behind waves and lake tsunamis.

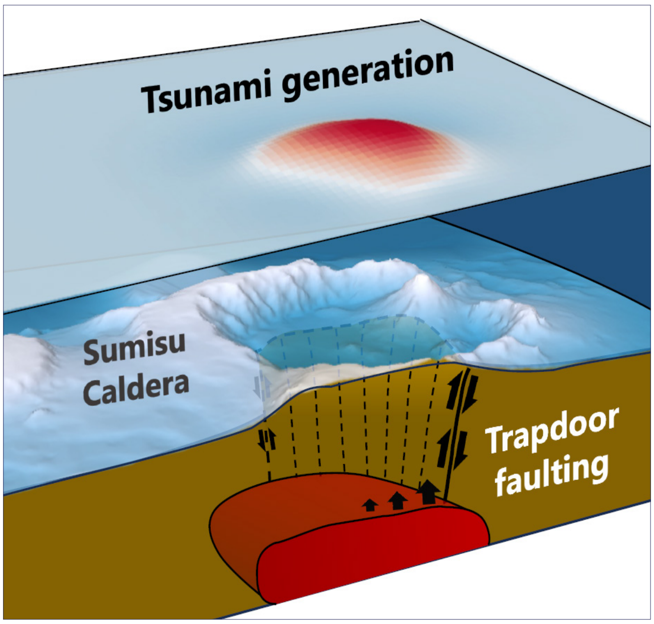
ABOVE: Mark Bascand from Glacier Explorers shows passengers an iceberg that calved into Tasman Lake as a result of the 2011 Christchurch M6.2 earthquake.

Just before midnight on 30 November 2022, a M5.7 earthquake rumbled deep within the caldera of Lake Taupō's supervolcano, approximately 20km southwest of Taupō township. For scientists, this quake was particularly intriguing. Unlike the typical tectonic grinding that drives most earthquakes in New Zealand, they believe this was a rare 'trapdoor' earthquake—something that occurs in only a handful of volcanoes worldwide. Instead of fault lines slipping past one another, a vast section of the earth beneath the lake, located near the Hatepe caldera beneath the Horomatangi Reef, heaved upward at least 180mm and horizontally 250mm, displacing water and sending waves rippling across the surface.

GNS tsunami scientist Jean Roger says that within the caldera, there's almost a bottle cork-like structure that moves up and down with the pressure generated by underground magma.

"And when it moves, it triggers some volcanic earthquakes. If you move the bottom of the lake suddenly, depending on the speed, you potentially trigger a deformation of the water column, and then it can trigger a tsunami wave propagating at the lake surface.

"But this earthquake was of a small magnitude. Compared to what we can observe in the sea when we have a tsunami, for example, a sea tsunami would be triggered most of the time by a magnitude above six. This magnitude was not big, but the mechanism involved was enough to trigger a very small tsunami in the lake."



ABOVE: Example of trapdoor faulting within the Sumisu Caldera. Credit Dr. Osamu Sandanbata.

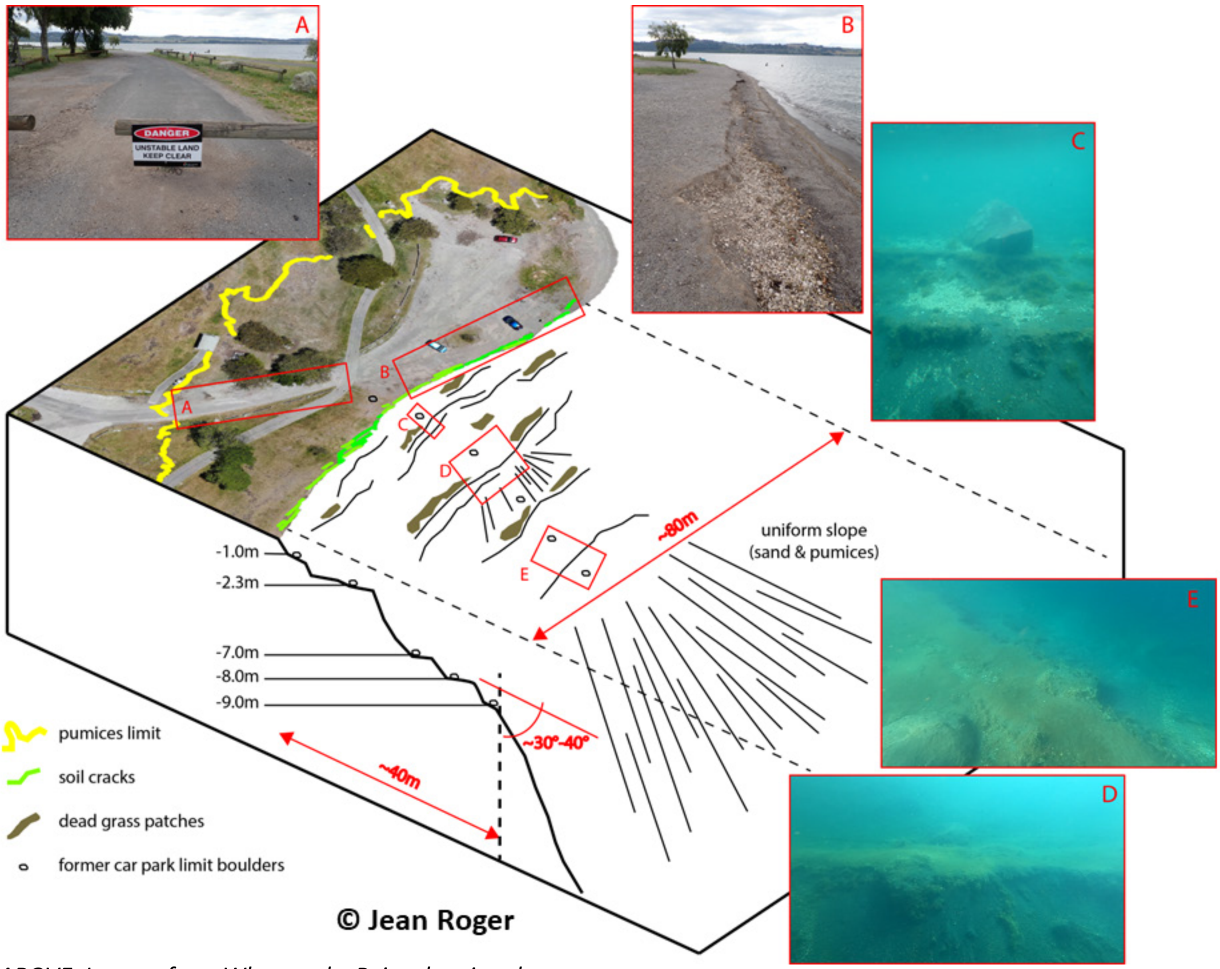
The waves it produced were relatively gentle, rising about 10 - 20cm as they swept pumice a couple of metres onto some south-western and eastern shorelines. The western shorelines escaped damage possibly due to the contours of the lake bed and the tsunami's short wavelengths, which dissipate energy more quickly compared to long waves such as those in powerful ocean tsunamis that travel long distances and dissipate energy slower.

However, one popular swimming beach, Wharewaka Point, located approximately 15km north of the epicentre, was severely affected during the earthquake. A 170-metre-long stretch of beach and car park vanished beneath the water, while debris was washed up to ~42m inland.

Jean says high-definition drone footage after the earthquake showed that something significantly different had impacted the point.

So why did this section of shoreline take the brunt of the impact? Jean and his colleagues suspect the initial tsunami didn't cause it. Instead, the 11.47pm earthquake caused an underwater landslide (rotational slump) at the beach (which potentially rests on an unstable alluvial plain) and also triggered a localised tsunami that swept debris so far inland.

So, one earthquake, two tsunamis and a missing car park later, what forces—strong or otherwise—lie inside waves?



ABOVE: Images from Wharewaka Point showing the rotational slump caused by the M5.7 Taupō earthquake.

WAVE TYPES

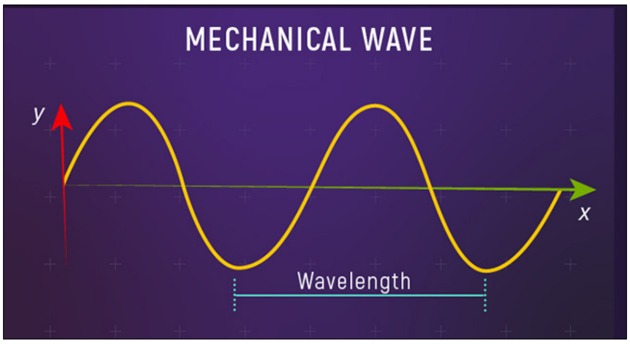
MECHANICAL WAVES

A tsunami is an excellent example of a **mechanical wave**. A mechanical wave (also known as a matter wave) is the propagation of energy through matter—for a tsunami, that's water, but other types of mechanical waves can transport energy through air and solids: sound waves, ripples on the surface of the water, vibrations in a guitar string and Mexican waves in a sports stadium. The wavelength is the distance between two consecutive peaks (the highest part of the wave). On the graph (right) the x-axis is distance and the y-axis is the displacement of matter.

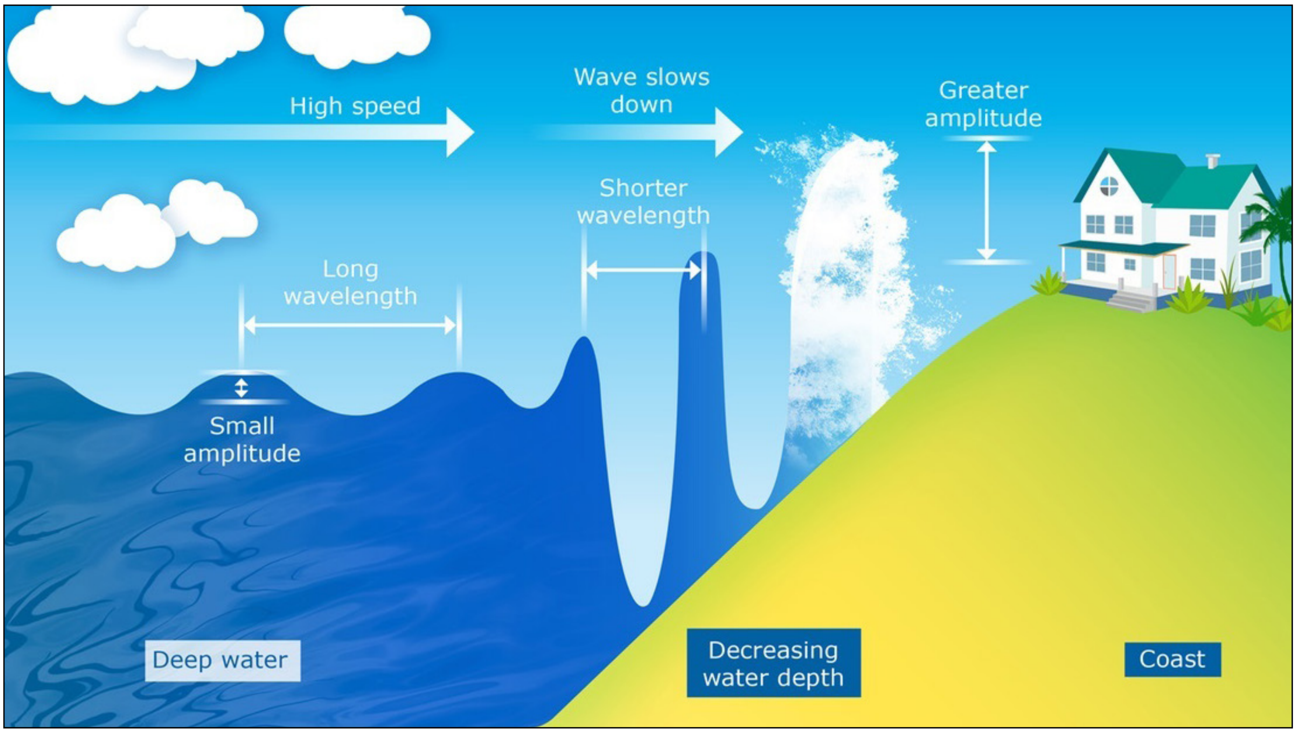
Tsunamis are caused by sudden drops or rises of water, typically due to earthquakes, asteroids, explosions, underwater landslides or volcanic eruptions. In deep ocean water, tsunamis travel fast with long wavelengths but remain low in amplitude (the displacement of a wave from its resting position). As they reach shallower coastal areas, the waves slow down and grow dramatically taller (shoaling), leading to potentially devastating impacts as the water travels inland (inundation).

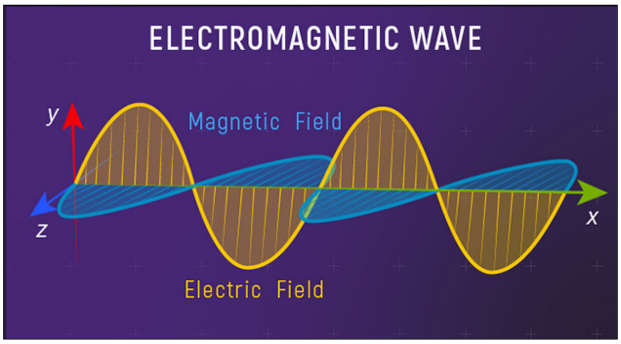
TAUPŌ SUPERVOLCANCO

Taupō is a large silicic caldera volcano located beneath Lake Taupō within the Taupō Volcanic Zone (TVZ) rift. It last erupted around 1800 years ago. It formed from the collapse of the ground surface after violent ejections of silica-rich magma during the Oruanui super-eruption approximately 25,500 years ago and is now largely obscured by Lake Taupō.



ABOVE: Credit NASA, ESA, CSA, Leah Hustak (STScI).
BELOW: Credit Science Learning Hub





ABOVE: Credit NASA, ESA, CSA, Leah Hustak (STScI).

ELECTROMAGNETIC WAVES

Another type of wave is the electromagnetic wave, which doesn't require a medium to travel, like X-rays. These waves are formed by charged particles, such as electrons and protons, creating electromagnetic fields when they move, transporting electromagnetic radiation or light, rather than oscillations of matter. Examples include gamma rays, X-rays, ultraviolet light, visible light, infrared light, microwaves and radio waves.

Then there are **aurora waves**, also known as Alfvén waves. They are a special kind of electromagnetic wave that travels along Earth's magnetic field lines and are closely linked to the aurora—those glowing curtains of light in the night sky.

Both mechanical and electromagnetic waves transfer energy from one place to another without transferring the medium's particles.

WAVE DIRECTION

Mechanical waves can further be categorised by the direction of travel of the wave.

Longitudinal waves, like sound waves, move horizontally in the direction of travel and include different areas of density: less (rarefactions) and high (compressions).

Transverse waves, move perpendicular to the direction of travel and include troughs and crests. All electromagnetic waves are transverse.

Surface waves, such as a tsunami, combine both transverse and longitudinal motion.

TSUNAMIS IN SPACE

Even space can have tsunamis! Powerful solar storms—known as Coronal Mass Ejections (CMEs)—can shake up Earth's magnetic field and send electric currents surging through power lines and gas pipelines. When those currents get too strong, they can damage transformers and cause pipelines to corrode much faster than normal.

It's impossible to say exactly when a major event like this will hit—it might be centuries away, or it could happen tomorrow—but when it does, the impacts could be huge. In the United States, the cost of a major space weather event is estimated between US$0.5 trillion - $2.7 trillion. For New Zealand, the rough annual risk has been put at around NZ$1 billion. As daily life becomes more dependent on technology, understanding and preparing for these risks is more important than ever.

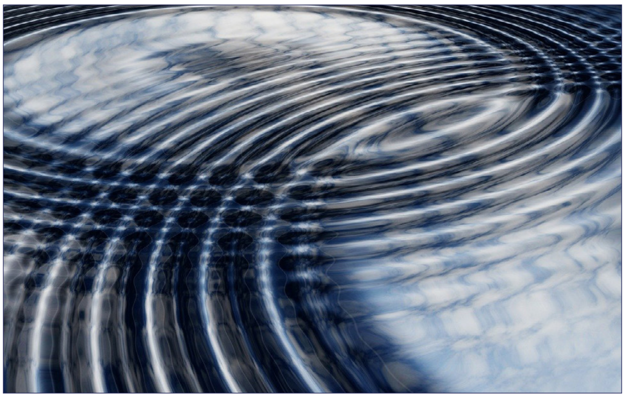
Find out more about the Solar Tsunami Endeavour Programme led by the University of Otago here which is focused on New Zealand's electricity grid and gas pipelines—the parts of our infrastructure most at risk from geomagnetic storms.

ABOVE: Aurora waves. Credit United States Air Force photo by Senior Airman Joshua Strang

WAVE BEHAVIOUR

Because the Lake Taupō tsunami was on the smaller side, many typical wave behaviours you'd expect to see in a larger tsunami weren't so easy to spot, like the behaviours below.

The shape of lakes can impact waves too: longitudinal lakes might be able to funnel the tsunami energy (Venturi effect) instead of allowing it to dissipate, which is probably what happened during the tsunami of Lake Taupō in 2022.



Credit: geralt (pixabay)

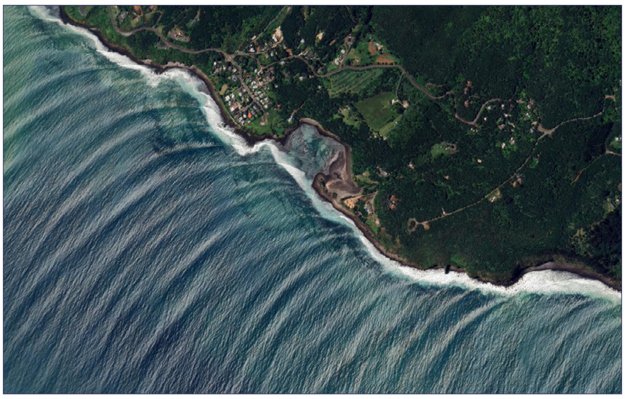
INTERFERENCE

When two waves overlap, they can interact, creating a wave that is either larger (constructive interference) or smaller (destructive interference) than the original waves. Constructive interference creates rogue waves—unusually large and unpredictable ocean waves. Try dropping pebbles into a swimming pool to see the effect.

Credit: Google Earth

REFLECTION

When a wave encounters a barrier, it can bounce back, changing direction. The angle of incidence (the angle at which the wave hits the surface) equals the angle of reflection (the angle at which the wave bounces off). At Te Kaha Point near Raglan it creates a messy, jumble of waves off the rocky point.



Credit: Google Earth

REFRACTION

When a wave travels from one medium (like deep water) to another (like shallow water), it can change speed and direction (bend). This happens because the wave's speed depends on the properties of the medium. At Whale Bay, Raglan (above) refraction creates a world-famous long left-hand point break for surfers.

Credit: J.Dronkers. Google Earth

DIFFRACTION

When a wave encounters an obstacle or passes through an opening, it can spread out or bend around the edges.

The amount of diffraction depends on the size of the obstacle or opening relative to the wavelength of the wave.

SCIENTIST SPOTLIGHT:

Jean Roger is a senior marine geophysicist at GNS Science | Te Pū Ao in Wellington, focusing on tsunami hazard assessment with an interest in historical events and how coastal ecosystems can protect communities against marine submersions.

Thanks to his parents, Jean's love for science began when he was a kid. They were always showing him fascinating things in nature, visiting museums and answering all his science questions. His interest in tsunamis started in 1999, after he began university, when a professor in oceanography mentioned a few examples of ocean waves, including tsunamis, which sparked his interest. After reading a few research papers, Jean realised it might be a great field to dive into, with the bonus of combining science, travel and future job opportunities.

Jean holds an MSc in Marine Geophysics from the European Institute for Marine Studies (Brest, France) and an MSc in Management of Natural and Technological Hazards from the Geography Faculty of the University of Strasbourg (France). He also holds a PhD in Marine Geosciences from École Normale Supérieure (Paris, France) and an undergraduate degree in Geology from the University of Rennes (France).

He worked in France, Portugal and New Caledonia before taking up a permanent position with GNS Science in 2020.

NEW ZEALAND LAKE TSUNAMIS

New Zealand is home to more than 3800 lakes (take a closer look at the health of our lakes as part of the Lakes380 project). From 1846 - 2022, at least 74 lake tsunamis have been recorded. These surging waves can be triggered by earthquakes, landslides, rock avalanches, volcanic eruptions, dam failures, and even the collapse of glaciers or ice fields. In the North Island, most lake tsunamis are earthquake-driven—no surprise given its position above colliding tectonic plates. However, not all; Crater Lake on Mount Ruapehu experiences ice-collapse tsunamis off a permanent ice field.

It's not just local events that set our lakes in motion. In 1883, the Krakatoa eruption in Indonesia triggered a volcano-meteorological tsunami on Lake Taupō. More recently, the M6.2 Christchurch earthquake in 2011 calved a massive chunk of ice off the 1.2-kilometre-long Tasman Glacier. The chunk was approximately 500 metres long and 70 metres high, weighing around 30 million tonnes, before breaking up into smaller pieces, generating swells that rocked tour boats for about 30 min. Even rock avalanches can create tsunamis—such as in May and September 1992, when massive rockfalls from Mount Fletcher at the head of the Godley River generated tsunamis that left icebergs stranded 20m above the usual water level.

HOW COMMON?

Previously, lake tsunamis were considered relatively rare, but population growth and lake activities like fishing and boating now provide more observable opportunities to witness tsunamis along shorelines.

Combined with global warming increasing the frequency of landslide, avalanche, and ice-calving events in the Southern Alps, these phenomena are likely to be reported more often.

ABOVE: Watch footage of a large iceberg in the Tasman Glacier terminal lake rolling and splitting [here](#).

NGĀ KUPU

aumoana - open sea

ngaru pae - secondary wave, transverse wave

ngaru pou - primary wave, longitudinal wave

parawhenua mea - flood, tsunami

tai āniwhaniwha - tsunami caused by an earthquake

toka haupapa - iceberg

tūātea - foaming, breaking of waves

wharenga - overhang (of a wave breaking), curling wave

HANDY TERMS

Alluvial plains are flat, fertile areas formed by the deposition of sediment over time by rivers or streams, often found near rivers or deltas.

Seiching refers to the phenomenon of standing waves, or sloshing, in a body of water, like a lake, harbour, or even a cup of coffee, where the water oscillates back and forth.

Wavelength is the distance between two consecutive crests or troughs of a wave.

Frequency is the number of wave cycles that pass a point in a given time.

Amplitude is the maximum displacement of a wave from its equilibrium position.

Speed is the distance a wave travels in a given time.

Medium is the material through which a wave travels.

CLASSROOM ACTIVITIES

Science Learning Hub: Modelling waves with slinkies to model how sound travels by sending waves along two stretched plastic slinkies tied together.

Science Learning Hub: Use a Mexican wave to demonstrate how waves transfer energy and to help students visualise wave behaviours: reflection, constructive interference and shoaling.

Science Learning Hub: Demonstrating longitudinal and transverse waves.