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NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

QUALIFY FOR THE FUTURE WORLD
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Scholarship 2020
Earth and Space Science

9.30 a.m. Wednesday 9 December 2020

RESOURCE BOOKLET

Refer to this booklet to answer the questions for Scholarship Earth and Space Science 93104.

Check that this booklet has pages 2–7 in the correct order and that none of these pages is blank.

YOU MAY KEEP THIS BOOKLET AT THE END OF THE EXAMINATION.

Resource for
QUESTION ONE: UNDERSEA VOLCANISM

Most of the world's undersea volcanoes are unstudied, yet they make up 80% of the Earth's volcanoes. In 2012, geoscientists were alerted to huge amounts of pumice floating in the Pacific Ocean. The pumice was likely to have come from an undersea eruption in the Kermadec Arc, which is a volcanic chain on the seafloor that extends for about 2500 kilometres to the north-east of New Zealand.

Source: https://advances.sciencemag.org/content/4/1/e1701121?utm_campaign=toc_advances_2018-01-12&et_rid=306406814&et_cid=1786929

Scientists with access to satellite data soon spotted the tell-tale signs of an undersea eruption from the Havre volcano in the Kermadec Arc – not lava flung into the sky, but an atmospheric ash plume and a thermal hot spot on the ocean's surface. Examining high-resolution satellite images, the scientists confirmed the presence of gigantic rafts of silica-rich pumice, covering an area of roughly 400 square kilometres. About 75% of the lava erupted from the Havre volcano made it to the ocean surface, and drifted away in the massive pumice raft.

Several months later, the NIWA research vessel *Tangaroa* mapped the Kermadec volcano. "When we mapped the area", says NIWA marine geologist Dr Joshu Mountjoy, "we found a new volcanic cone which has formed on the edge of the volcano, towering 240 metres above the crater rim. One side of the caldera wall is bulging in towards the volcano's centre. The bulging may indicate where an eruption may occur in the future."

NIWA first discovered and mapped the Havre volcano in 2002, a 1-kilometre-high undersea mountain at a depth of 1500 metres, with a 5-kilometre-wide, 800-metre-deep central crater. The following diagram shows a comparison between the 2002 and 2012 profiles.

Source: https://niwa.co.nz/news/first-sighting-of-volcano-responsible-for-undersea-eruption

"It is fantastic to be able to record the change on the seafloor following these kinds of events." Dr Richard Wysoczanski, NIWA marine geologist, says. "We know the shape of the volcano from previous research. Using the multibeam echosounder, we made a before and after comparison of the volcano to determine the size of the eruption and the change it has made to the seafloor."

Scanned image of the seamount

Source: www.sciencealert.com/almost-nobody-noticed-largest-underwater-volcano-eruption-ever-recorded-havre-seamount

The eruption hypothesis was later backed up using data from the French Polynesian seismic network. They confirmed that frequent earthquakes of magnitude 3 to 5 had occurred that year at Havre submarine volcano.

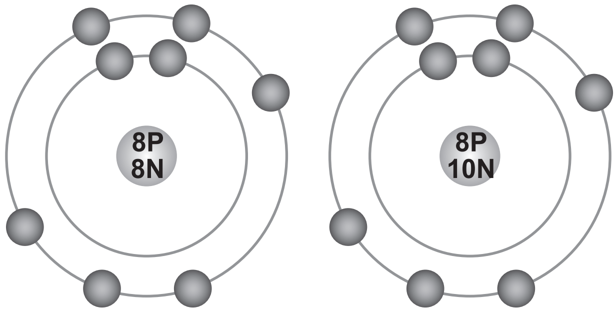
This discovery reveals that explosive eruptions at depths of at least 900 metres below sea level are possible, despite the huge pressure of the water column above it, making the eruption behave differently to a terrestrial eruption. Before this event, the deepest recorded eruption of a silica-rich volcano had been at 300 to 250 metres below sea level. (Pressure increases by 1 atmosphere per 10-metre increase in ocean depth.)

Over the last decade there has been one significant undersea eruption per year on average across the Kermadec trench area, which is about 1200 kilometres long.

In August 2019, another large raft of pumice was produced in the Pacific after an underwater volcanic eruption near Tonga. Sailors in the area described a "rubble slick made up of rocks from marble to basketball size such that water was not visible," as well as a smell of sulfur. The sailors first saw rising steam plumes, and then noticed the large masses of floating pumice.

Resource for
QUESTION TWO: ISOTOPES AS INDICATORS

Oxygen isotopes



^{16}O isotope ^{18}O isotope

An important method for the study of long-term climate change involves isotopes, which are different versions of the same element that have differing masses due to a change in number of neutrons. Oxygen is an element that has isotopes; the most common is oxygen which has a mass of 16 (8 protons and 8 neutrons). A small number of oxygen atoms have a mass of 18 (8 protons and 10 neutrons). Both of these isotopes are stable; they do not undergo radioactive decay.

Many ice cores and sediment cores have been drilled in Greenland, Antarctica, and around the world's oceans, and these cores have been studied for information on variations in Earth's climate. The ratio of these two oxygen isotopes has changed over the ages and these changes can represent a changing climate, providing an indication whether there has been a cold (glacial) or warm (interglacial) period.
Water molecules (H_2O) may contain either isotope, oxygen-16 or oxygen-18. Water molecules containing oxygen-16 have a mass of 18 (hydrogen has a mass of 1) and are preferentially evaporated. Water molecules containing oxygen-18 have a mass of 20, and therefore are preferentially precipitated.

Adapted from: https://earthobservatory.nasa.gov/features/Paleoclimatology_OxygenBalance

The above diagram shows the water cycle during an interglacial period, such as the present day.

Milankovitch cycles are fluctuations, approximately every 100 000 years, that are caused by the eccentricity and wobble of the Earth's orbit. The cycle between glacial and interglacial periods is also approximately 100 000 years. Milankovitch cycles and the ice core records allow us to predict what the climate would do in the future if humans had not affected the climate.

The same isotopic analyses can be made in ocean sediment cores on the shells of dead marine organisms such as photosynthetic foraminifera. Some of these organisms' shells or skeletons are made up of calcite ($CaCO_3$), and the oxygen in the carbonate reflects the $^{18}O : {}^{16}O$ ratio in the shallow waters where the creatures lived, because the oxygen used is incorporated into their shells or skeletons. This is due to carbon dioxide providing two of the oxygen atoms in the calcite. The third oxygen atom comes from the surrounding sea water.

Examples of shells formed by some of the marine organisms that are used to determine sea surface temperatures.

Source: https://globalchange.umich.edu/globalchange1/current/lectures/kling/paleoclimate/index.html

A variety of modern planktonic foraminifera, some of which show internal shells or 'tests' made of calcite.

www.youtube.com/watch?v=oaOfeSJZ3lY&list=PLElB7nLNHZvhU1hu8Q441WHP_uryiKWBl&index=4&t=0s

Resource for
QUESTION THREE: GOLDILOCKS ZONES

K2-18b is an exoplanet that was discovered in 2015. It orbits a red dwarf star, known as K2-18, and is close enough to receive a similar amount of solar radiation from its star, as Earth does from our Sun. A red dwarf star is much smaller and dimmer than the Sun, and has unstable surfaces producing more solar flares, bathing the planet in high energy radiation.

Stars have different life stages; a pre-main sequence red dwarf star forms when the star has all of its mass, but fusion hasn't yet begun. Red dwarfs could be in this stage for up to 2.5 billion years. After fusion of hydrogen into helium starts, the red dwarfs shrink over their very long life spans. Red dwarf stars have estimates of their possible lifespans of up to tens of trillions of years. This must also be taken into account when considering planetary formation around these stars.

K2-18b completes one orbit every 33 Earth days. The far-off planet (around 110 light-years away) was discovered by NASA's Kepler space telescope. It marks the first successful atmospheric analysis of an exoplanet in the habitable zone of its star. Such studies have proven difficult, due to the distances of these worlds and their smaller sizes as compared to gas giants like Jupiter, which tend to be outside the much sought-after 'Goldilocks' zone.

The Earth and K2-18b and their respective habitable or 'Goldilocks' zones, indicated by the blue band.

Adapted from: https://www.raumfahrer.net/news/astronomie/08072014110944.shtml

K2-18b may be tidally locked, due to its close orbit to the star it orbits. Tidal locking is when a planet or a moon rotates once on its axis exactly as long as it takes to orbit once around the planet or star it is orbiting. If the planet is tidally locked to the star it is orbiting then it would always be orientated with the same hemisphere towards the star and the same hemisphere away from the star. This would also mean that its rotational speed would link to its orbit time.

K2-18b has a radius of about 2.3 times that of Earth, and a mass about nine times that of Earth. This means that the surface gravity is greater than that of Earth; 1.66g compared to 1g on Earth, where 1g is the normal gravitational force (9.8 N kg^{-1}).

Recently, scientists discovered that K2-18b had water vapour, as well as the likelihood of clouds and rain. The study revealed that as K2-18b crossed in front of its star, wavelengths of light that are absorbed by water suddenly dropped off, and then rose again as the planet moved further through its orbit. The effect is seen as an indicator for water vapour in the planet's atmosphere. In this analysis, the scientists also found atmospheric hydrogen and helium.

	Earth	**K2-18b**	**Mercury**
Temperature range °C	–89.2 °C to +56.7 °C	–73° C to +47 °C	–173 °C to +427 °C
Distance to star, average	149.6 million km	21.38 million km	58 million km
Density, average	5.51 g cm^{-3}	4.01 g cm^{-3}	5.427 g cm^{-3}
Surface gravity	1g	1.66g	0.38g
Orbit time	365.256 days	33 Earth days	88 Earth days

Artist's impression of the view from above K2-18b, looking towards the red dwarf star that it is orbiting.

Source: www.fr.de/wissen/exoplanet-k2-18b-forscher-entdecken-wasserdampf-atmosphaere-zr-12995620.html

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