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OUTSTANDING SCHOLARSHIP EXEMPLAR



Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Scholarship 2024 Earth and Space Science

Time allowed: Three hours
Total score: 24

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should answer ALL the questions in this booklet.

Pull out Resource Booklet 93104R from the centre of this booklet.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–16 in the correct order and that none of these pages is blank.

Do not write in any cross-hatched area (⚡⚡⚡). This area may be cut off when the booklet is marked.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

QUESTION ONE: RIVERS IN THE SKY

Evaluate the effects of atmospheric rivers on the North and South Islands by considering two regions – west Auckland, and the West Coast of the South Island.

Furthermore, explore how atmospheric rivers would be affected by the El Niño Southern Oscillation (ENSO), and discuss some measures that could be taken in the way we use land to minimise the effects of atmospheric rivers.

Atmospheric rivers are produced by the evaporation of water near the equator, which are carried by the high altitude warm air winds of the Hadley cell towards the poles. In these atmospheric rivers, water vapour is concentrated in a long, relatively narrow area of the atmosphere. As the water vapour is transported along the rivers, it will reach the dew point as temperatures decrease, condensing into clouds and eventually precipitating out as rain, causing heavy rainfall and potentially flooding in the North Island, due to the relatively small area of water vapour.

For the North Island, the atmospheric rivers are carried by northwesterly winds, reaching the West coast first, in areas such as West Auckland, which contains the Waitakere ranges. ~~Due to the~~ While some orographic lifting will occur, with the water vapour quickly reaching the dew point as it is forced up by the mountains, condensing and precipitating along the West coast, due to the relatively lower height of the mountains, with the tallest being Te Tōtikau at 474m, much of the water vapour will still make it beyond the Waitakere ranges, precipitating ~~into~~ over mainland like Auckland. Furthermore, the short length of the Waitakere ranges means much of the water vapour will be able to go around it, so most of the precipitation will occur over the mainland North Island.

For the South Island, the atmospheric rivers are carried by the westerly winds across the Southern Ocean, produced in the Ferrel cell. Because the Ferrel cell winds are a result of friction with the Hadley and Polar cells, the winds are relatively weaker, and are more easily affected by high and low pressure

and longer systems passing through. The Southern Alps, being much taller than the Waitakere ranges, will cause more significant orographic lifting, precipitating most of the water vapor as rain or snow on the west coast of the South Island, and leaving little water vapor to be transported over the mountains and into the eastern side, resulting in little rainfall in areas such as the Canterbury plains.

During El Niño, NZ tends to experience stronger westerlies in summer, which would cause atmospheric rivers to come from the west, which prevents the same situation as described previously, with heavier rainfall on the west West Auckland compared to East Auckland, and heavy rainfall on the west coast of the South Island with the Eastern side staying quite dry. During winter, southerlies are more prevalent, which means ~~less a stronger~~ higher integrated vapor transport value for the southern atmospheric rivers, and thus greater ~~rainfall in the~~ precipitation in the South Island. As the southerly winds reach the North Island, it will bring about colder temperatures, though most of the precipitation would have been over the South Island.

During La Niña, the trade winds in the subtropics are strengthened, causing northeasterly winds to be prevalent ^{in summer}. In this case, the atmospheric rivers will be carried by the northeasterlies, bypassing the initial orographic lifting in the North Island from the Waitakere ranges. As such, there will be greater precipitation on the eastern side of the North Island, especially near the north, as the water vapor will condense there and precipitate, leaving less ~~water vapor and clouds~~ and thus rainfall for the southern North Island. This time, orographic lifting will occur on the other side of the Waitakere ranges, with much less water vapor, causing most of the rainfall to remain on the eastern side of the mountains, leaving the west coast quite dry.

The same applies for the South Island, where during winter the prevailing southeasterlies bring precipitation to the east coast first, then are orographically lifted by the east side of the Southern Alps, precipitating entirely due to the large height of the mountains. This leaves little to no rainfall for the west coast, resulting in droughts.

During winter, less water vapor reaches the North Island, so there is less rainfall, especially in northern regions.

As such, the effects of atmospheric rivers on the North Island are relatively more severe during normal conditions and El Niño, as the 345000 people in West Auckland will experience extreme rainfall, potentially causing floods and landslides. With a very high population density, it is likely that large amounts of deforestation have occurred, destabilising the soil and increasing the chances of landslides, which will cause extensive damage to houses, roads, and other infrastructure. In order to reduce the possibility of this occurring, as El Niño tends to be more common than La Niña, the use of land should be regulated such that enough vegetation remains to hold soil together, and absorb excess groundwater, minimising the effects of heavy rainfall as infiltration and percolation will not destabilise the ground as much. As further precaution, scientists should regularly monitor the ground conditions in West Auckland for potential landslides or flooding due to precipitation not being able to infiltrate into the soil. Retaining walls can also be setup in case of landslides occurring.

For the South Island, due to the much lower population density in the west coast, events like landslides or flooding is less of a concern, as there should be enough vegetation to stabilise soil. However, during the drought during La Niña is more of a concern, as rain clouds are unable to bypass the Southern Alps. To mitigate the effects of atmospheric rivers in La Niña, it must be ensured that there is a large enough reservoir of water available for use during a drought, or at least houses should be mandated to store water in case of La Niña in summer.

QUESTION TWO: NEW ZEALAND'S GEOLOGICAL HISTORY

Explore why the geological history of New Zealand is different between the North Island and the South Island, considering tectonic and volcanic evidence.

Using extrapolation, discuss how the plate boundary in both islands might change in the future.

Firstly, the North Island is entirely part of the Australian plate, while the South Island is made up of the collision of both the Australian plate and the Pacific plate along the Alpine fault, which is a strike-slip fault. Near the North Island, the denser Pacific plate is subducting beneath the less dense Australian plate, with slabs of oceanic crust melting into the asthenosphere along the Kermadec trench, a convergent plate boundary.

In the North Island, volcanism occurs through both subduction volcanism, where the magma from the melted subducting plate rises, bursting through the lithosphere of the other plate, forming volcanoes, and hotspot volcanism, where a pocket of magma remains stationary under the lithosphere, and tectonic plates move over it, producing a chain of volcanoes intraplate, away from any plate boundaries. The Kapapa and Waihare volcanoes are an example of subduction volcanism, as roughly 20 million years ago, when the plate boundary was closer to the Northland region, the subducting Pacific plate rich in basalt would have melted underneath the Australian plate forming the line of volcano volcanoes parallel to the plate boundary. As the plate boundary moved towards the southeast over millions of years, the Koromandel volcanic zone was formed, another example of subduction volcanism, with volcanic activity occurring between 9 to 2 million years ago. The eruptions occurring were andesitic during the formation of the volcanic zone, indicating continental crust was subducting, but gradually became basaltic, ceasing 2 million years ago, as oceanic crust from the Pacific plate subducted which is rich in basalt, and the plate boundary moved eastward. Finally, the Taupo volcanic zone, which is only 2 million years old, was the last chain of subduction volcanoes in the North Island formed by the subducting Pacific plate. Just like before, the chain of ~~volcanoes~~ volcanoes which is parallel to the plate boundary provides evidence that the

Tauapo volcanic zone is the result of subduction volcanism rather than hotspot volcanism. Because of the linear chronological arrangements of the Waiotake volcano, Coromandel volcanic zone, and Tauapo volcanic zone, we can conclude that the Australian-Pacific plate boundary is ~~now~~ slowly moving towards the southeast. The Auckland volcanic province, which is much younger than the Tauapo volcanic zone, is a result of hotspot volcanism. This is evidenced by the fact it does not fit into the chronological order of the three volcanic zones discussed previously, and thus is not caused by subduction, but rather the Australian plate moving over a stationary "hotspot", a pocket of magma just beneath the lithosphere, which breaks through occasionally (by geological time standards) to form a series of volcanoes not parallel to the plate boundary.

The South Island in contrast to the North Island has a plate boundary running directly through it, forming the Southern Alps. The Alpine Fault is a strike-slip fault, and thus the Australian and Pacific plates slide past in opposite directions there. As neither plate is subducting, subduction volcanism cannot occur, so there are no subduction volcanoes in the South Island, as opposed to the many in the North Island. The Southern Alps began forming roughly 15 million years ago, around the same time as the Coromandel volcanic field, indicating that the continental crust of both plates would have collided some time around then, orogenically converging to create the mountain range. The strike-slip movement is further evidenced by the rock belts in Nelson, ~~that~~ ~~is~~ on the Australian plate, that matched with rock belts in Fiordland, on the Pacific plate, indicating the movement of the Australian plate north-west relative to the Pacific plate along the alpine fault at a rate of 2-10 cm per year. Volcanism in the South Island is limited to hotspot volcanism, as the alpine fault has not moved, so both the Ruapehu and Banks Peninsula volcanoes would have erupted subparallel, which is only possible with a hotspot. The shape of the Ruapehu volcano as a shield volcano further indicates that the magma was basaltic in nature, allowing it to flow quickly down the volcano to form a shield. Assuming that the Ruapehu and Banks volcanoes were formed by the same hotspot,

this would corroborate the evidence that the Australian plate was moving northeast relatively, or that the ~~Pacific~~ Pacific plate was moving southwest relatively, as the Banks volcanoes are more recent (6 million years ago) than the Dunedin volcano (16-10 million years ago).

As such, the geological history of the North and South Islands are different, because of the difference in the nature of the plate boundary, and the consequential volcanism ~~as a~~ leading from it. The North Island is comprised much more of igneous rock from all the volcanoes, while the South Island contains more metamorphic rock from the folding of rock along the Alpine Fault.

This information also provides evidence for the potential future movement of the Australian and Pacific tectonic plates, as well as the plate boundary between them. As described previously, the chronological chart of volcanic zones in the North Island indicate that the Australian-Pacific subducting plate boundary (Kermadec Trench) is moving towards the southeast, which means that in millions of years, active volcanoes like White Island/Whakaari will become extinct, as it ~~has~~ was the source of magma from the melting rock slab of the ~~x~~ Pacific plate would have moved away. This could also decrease the land impacts of a large Earthquake like the Hikurangi Subducting Zone, as it would be further out to sea. In the South Island, the Alpine Fault is unlikely to move, but the plates on either side will keep moving in opposite directions, elongating the South Island. After a certain point, perhaps in tens of millions of years, the ~~Australian~~ ^{Pacific} plate ~~over~~ at the Alpine Fault will become oceanic crust rather than continental crust, and begin subducting ~~as~~ like the Kermadec Trench, causing volcanic activity to occur more frequently in the South Island.

QUESTION THREE: THE TOI 270 SYSTEM

Analyse and compare the formation of the TOI 270 system to the formation of our own solar system.

Explore the possibility of having basic forms of life on the planets in the TOI 270 system, considering surface temperature, composition, likelihood of an atmosphere, and interaction with the star they orbit.

The formation of the TOI 270 system is similar to our solar system through the presence of both rocky and gaseous planets, as well as a main sequence star at the center. However, contrary to our solar system the star in the TOI 270 system is a red dwarf, as opposed to our Sun which is larger and brighter. The very close distance of 0.03 AU to the red dwarf provides enough energy for small rocks and asteroids caught by its gravity to smash and join together, forming a rocky planet like the Earth. Further away, where TOI 270c and TOI 270d are, only gases are able to be held together with a small rocky/metallic core, forming the mini-neptunes like the gas giants of our solar system, just of a much smaller size due to the weaker gravity of TOI 270 compared to our Sun.

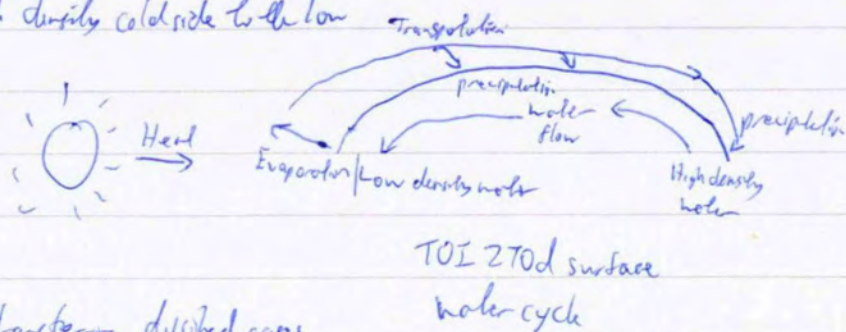
For planet TOI 270b, because it is a rocky planet similar to Earth, there is a chance it could support life. However, the surface temperature of 254°C is much too hot for liquid water to exist unless there is extreme pressure on the surface, which is ~~also~~ unlikely as the density of the planet is ~~actually~~ very similar to the Earth's (1.9x volume vs 2.0x mass). As a result, any liquid water on the surface would be evaporated and stored as water vapour in the atmosphere, unable to reach the dew point and precipitate. However, this is only the case if the planet is not tidally locked, as all sides receive equal heating. If the planet was tidally locked, which planets orbiting a red dwarf tend to be, one hemisphere would receive all of the radiation from TOI 270 while the other would receive none. The large temperature gradient would mean that there is a belt between the equator and the poles where liquid water can exist and also be evaporated, ~~providing~~ allowing for the existence of a water cycle. However, assuming an atmosphere can exist on TOI 270b (which is likely not), the pressure difference between the hot and cold side will produce winds that blow any water vapour produced to the cold pole, where it will be stored as long as

the ice remains frozen. The rocky composition of the planet could indicate the presence of plate tectonics and convection currents in the mantle, where the residual heat from the planet's formation could ~~heat~~ transfer heat to deep ~~ocean~~ frozen oceans on the cold side, allowing liquid water to flow. The cold dense water would flow towards the warmer less dense water closer to the equator, similar to the Thermohaline Circulation on Earth, allowing gases like oxygen and nitrogen to and nutrients to be transported. This could potentially support life at the bottom of the ocean similar to the microorganisms that live around black smokers on Earth. The prerequisite to all of this, however, is the presence of an atmosphere large enough to keep water vapour from escaping into space. With the instability of the red dwarf surface and frequent solar flares, without a strong magnetic field any atmosphere will be vaporised by the ~~magnetic~~ solar flares and UV & X-ray radiation. The rocky composition of the planet could suggest a rotating liquid core like the Earth's, that produces an electric current generating a magnetic field, but not enough information is known to provide any concrete proof. Perhaps once the glaciologists determine a large atmosphere can form which can support basic life.

The planet TOI 270c is a mini-Neptune, composed of a ~~large layer of~~ ^{entirely} gas or a ^{large} layer of gas with a small rocky core. The ~~high~~ high surface temperature of 150°C is also past the boiling point of water, but the thick atmosphere should be able to contain the water vapour and transport it to the cold side of the planet where ~~the~~ water vapour will condense and freeze into ice. (Assuming tidally locked). The lack of a solid surface however will mean that liquid water not carried by wind will precipitate towards the planet's core, where it may then be heated by the residual heat of the core or friction with other particles in the atmosphere back into water vapour, creating ~~as~~ a water cycle that does not involve any solid surface. As such, even though the water cycle and an atmosphere do exist, life is unlikely to exist because of the lack of solid surfaces, preventing the buildup of water into oceans.

Finally, the planet TOI 270d, which is also a mini-Neptune, has a much

more reasonable average surface temperature of 5°C . Assuming the planet is tidally locked, first and foremost the solar flares will be much weaker at a distance of 0.07 AU than 0.03 AU , so any planetary magnetic field around TOI 270d produced by a rotating liquid core will be more effective in repelling the ions/plasma of a solar flare, preventing the atmosphere from being vaporised, and allowing water vapour to be stored in the atmosphere without flying into outer space. The hot side and the cold side of the planet would also have a smaller temperature gradient, so the winds from the hot side to the cold side will also be weaker, allowing more precipitation of water vapour from the atmosphere before the water freezes at the cold pole. ~~This water would contain dissolved~~ This could produce a water cycle where the water remains liquid for longer, potentially remaining liquid near the solid core due to a lower density compared to TOI 270c, pooling into oceans. The thick atmosphere would also have a higher albedo, reflecting more radiation from the star, preventing the temperature from being too high on the surface under the atmosphere, especially at a large distance away. As such, life could potentially be supported on TOI 270d as the presence of a water cycle, the thick atmosphere, and relative immunity towards solar flares ~~not~~ provide a relatively consistent climate. As shown below, the surface of the planet would have water vapour transported from hot to cold side, while the ~~ice~~ liquid water flows from the high density cold side to the low



density, hot side, transferring dissolved gases and materials around the surface, which could support life.

Outstanding Scholarship

Subject: Earth and Space Science

Standard: 93104

Total score: 20

Q	Score	Marker commentary
1	6	Candidate shows good integration of ideas and how El Nino and La Nina can affect the atmospheric rivers. However, their mitigation ideas to help reduce the risk were not detailed.
2	7	Candidate explores differences between the geological history of the North and South Island however needs more extrapolation about the future of our plate boundary.
3	7	The candidate has done very good analysis of the differences between our solar system and the TOI 270 system without covering a large amount of Level 2 material. Also, the candidate provided a good explanation about the possibility of black smokers at the bottom of a shaded side ice covered ocean which showed an outstanding level of understanding.