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SCHOLARSHIP EXEMPLAR

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

New Zealand Scholarship
Earth and Space Science

Time allowed: Three hours
Total marks: 24

Question	Mark
ONE	6
TWO	6
THREE	6
TOTAL	18/24

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EXAMINATION BOOKLET

You should answer ALL questions in 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.

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

QUESTION ONE: THE KAIKOURA CANYON

The Kaikoura Canyon is a submarine canyon that starts 500 metres off the Kaikoura coast, cuts across the continental shelf and connects with the deep ocean. It is 60 km long, up to 1200 m deep and has steep sides. The canyon is adjacent to the Marlborough fault zone and opens into the southern end of the Hikurangi Trough, to the north-east of Kaikoura.

Eroded rock and sediment is transported by the prevailing current up the Otago-Canterbury coast. This debris accumulates in the Kaikoura Canyon forming an unstable slope which periodically collapses, resulting in large submarine avalanches. Such collapses have almost definitely caused devastating tsunamis along the Canterbury and Marlborough coastlines in the past. Archaeological sites have uncovered evidence of marine sediments overlying Maori occupation sites.

The return period for magnitude 8 earthquakes at Kaikoura is estimated to be 150 years. Also, it is estimated to take 100 years to accumulate enough sediment at the start of the Kaikoura Canyon to generate a major collapse.

Discuss and evaluate the threat of major tsunamis along the Canterbury and Marlborough coastlines.

Consider in your answer:

- the origin of the eroded rock and sediment and how it is transported to the sea
- the tectonic conditions that could trigger and generate a tsunami
- the evidence that could be gathered and analysed to determine how often major earthquakes and tsunamis occur.

The Marlborough fault zone
http://upload.wikimedia.org/wikipedia/commons/1/19/MarlboroughFaultSystem.png

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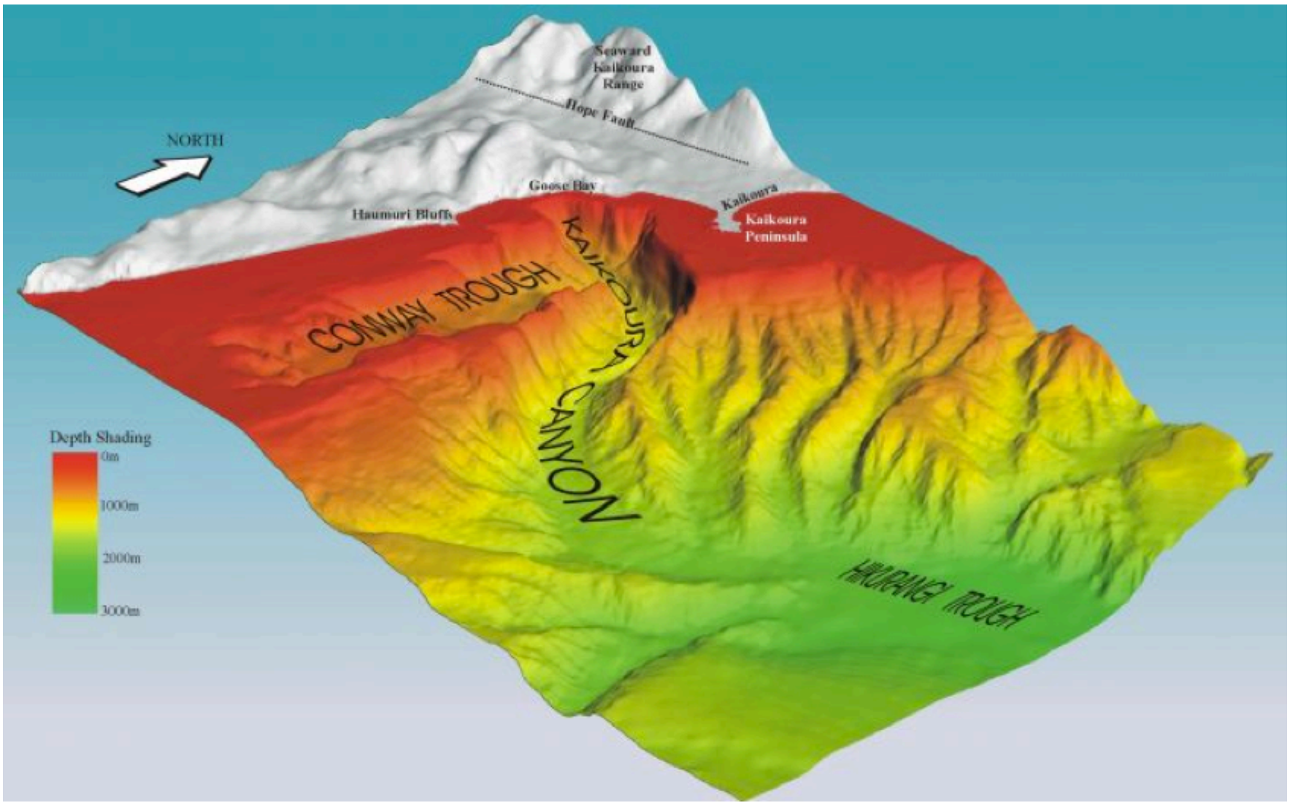

The Kaikoura canyon
http://www.niwa.co.nz/our-science/aquatic-biodiversity-and-biosecurity/research-projects/all/kaikoura-canyon

Sample answer without annotations.

The rock and sediment that ends up in the Kaikoura canyon comes from the Southern Alps. The Alps are very high and sharply pointed and have been formed from the collision of the continental crust of the Pacific Plate (PP) with the continental crust of the Australian Plate (AP) along most of the South Island. The PP overrides the AP along the length of the Southern Alps. Rainwater, plus ice from the water freezing, causes a lot of erosion. Water gets into cracks and freezes, expanding cracks in the rocks until the rock shatters. The rain plus gravity washes the rocks into streams and rivers where they are swept down braided rivers and out to sea. The action of the rivers knocks small particles off the rocks, smoothing the rocks and forming sediment. When the rocks and sediment reach the sea a coastal current takes them northwards to the Kaikoura canyon.

Once the sediment is in the canyon it accumulates on the side until something makes it fall off. Gravity may be enough to cause the slope to slide but usually seismic waves from an earthquake vibrate the slope and cause an underwater avalanche.

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This part of New Zealand is tectonically active. The Pacific plate enters the South Island at Kaikoura and changes to continental crust. This continental crust of the PP starts sliding past the AP which is also made of continental crust. Collision is still occurring. The large fault lines in this area have formed to relieve the continual movement of the PP and AP.

One of these fault lines suddenly releasing stored energy would cause a violent earthquake that would severely shake the land and canyon. The sediment would fall off the slope, rush down the rest of the canyon and enter the Hikurangi Trough. This would result in the displacement of a huge amount of water that will move out to sea and towards the coast, forming a devastating tsunami.

Scientists need to work out how often the fault lines move. Road cuttings may show strata that don't line up, river terraces may be cut through by a fault scarp, rivers realigned and landslides disturb vegetation. The best way is to dig long trenches through such areas and to look for disturbance of sediment layers, or sediment that may quickly have covered up rips and tears in the land. Vegetation destroyed by landslides can be dated with radiocarbon techniques to determine when the prehistoric earthquakes occurred.

Evidence for tsunamis would need to be looked for right along the affected coastlines as the surge from a tsunami may run inland for quite a long way. Marine gravels and sediment would be looked for at sites where there may have been early human settlements. Again, radiocarbon dating could be used to date organic matter from early settlements or from vegetation affected by the tsunami.

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QUESTION TWO: DISCOVERING KUIPER BELT OBJECTS

The Kuiper Belt, beyond the orbit of Neptune, is a region of very faint, icy objects 30-60 AU from the Sun. The first Kuiper Belt object (KBO) was discovered in 1992. Most KBOs are the size of small asteroids, and there are probably about 70,000 KBOs larger than 100 km across.

The size and distance of KBOs from the Sun make them very difficult to find and to accurately determine their size and composition. Also, many KBOs have highly elliptical orbits which are also tilted with respect to the planetary orbits.

Because the surface details of KBOs cannot be easily seen with telescopes, their albedos provide valuable information.

Albedo measures the reflectivity of the KBOs. The amount of light that strikes the KBO is calculated and the reflected light measured. Because the KBOs are so far away the albedo of the whole body is measured. An albedo of almost 1.0 indicates a bright object that reflects most of the light that strikes it, whereas an object with an albedo of almost zero would absorb most of the light.

Although they're icy, most KBOs do not reflect much light and have low albedos, down to about 0.05, probably because their surfaces are heavily weathered and contain dark organic compounds. However, larger KBOs, such as Pluto and Eris, have atmospheres and relatively high albedos.

Discuss and analyse the use of albedo to determine the size and composition of KBOs.

Consider in your answer:

- the presence or absence of any atmosphere
- the mineral composition and reflectivity of the surface
- the presence of surface ice
- surface features
- the relative distance from the KBO to the Sun
- the relative angles of the Sun, Earth and the KBO.

Sample albedos

Surface	Typical albedo
charcoal	0.04
deep shadowed cavities	0.01
clouds	0–0.8
ocean	0.09
rock	0–0.7
ice	0.5–0.7
fresh snow	0.8–0.9

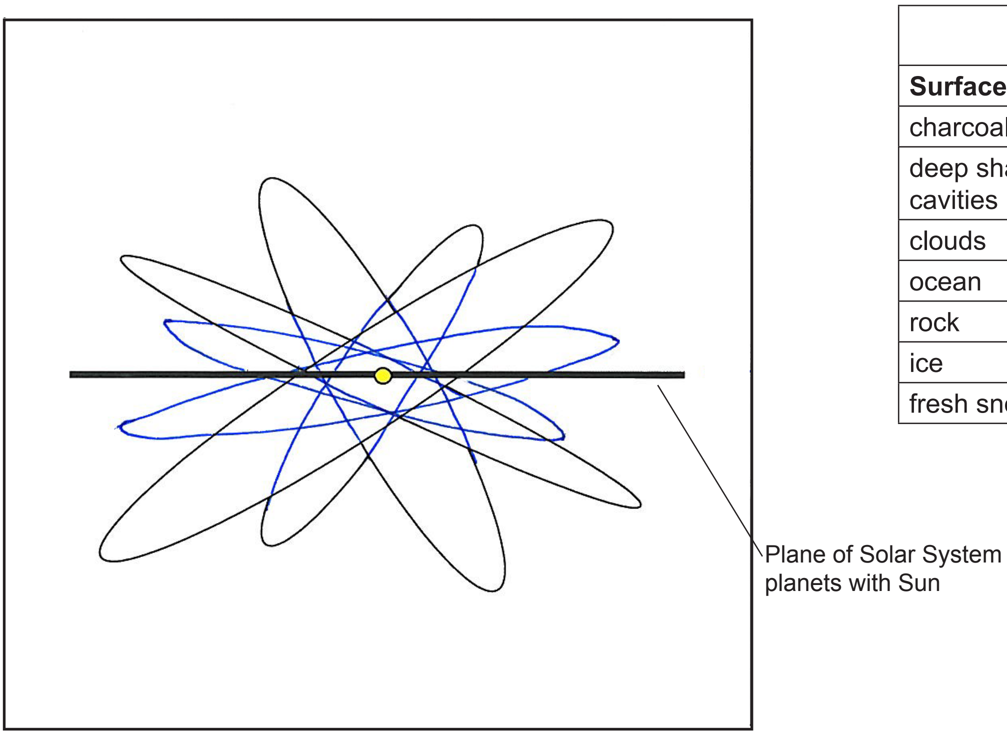

Diagram showing the highly elliptical and tilted orbits of KBOs
(adapted) http://news.softpedia.com/images/news2/45-New-Kuiper-Belt-Objects-2.jpg

Sample answer without annotations.

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Kuiper Belt objects (KBOs) are 30–60 astronomical units away from the Sun beyond Neptune and are very small. Telescopes can't be used to find out information about them, such as how far they are away from the Sun, what their surfaces are like and whether there is any atmosphere, so albedo becomes important.

Albedo can help find out, for each KBO, its distance from the Sun, the composition and features of the surface and whether it has an atmosphere.

The surfaces of KBOs can vary and this affects the albedo. This also means that the albedo can give an indication of the composition and features of the KBO. A table could be made giving standard measures – that it, known albedo for known surfaces and KBOs.

The darker and rougher the surface, such as dull rock, organic compounds and a rough or cratered surface, the lower the albedo will be. So conversely, shiny rocks, smooth surfaces and the presence of ice will all raise the albedo.

An atmosphere around a KBO gives a relatively high albedo because clouds and droplets of certain gases are very reflective and they also can hide the surface. Ice made from frozen atmosphere has a very high reflectivity and so a high albedo.

The albedo provides an average value for the reflectivity over the whole surface of the KBO. KBOs are too far away for the detection of the normal variations in a body's albedo.

There is no relationship between distance and albedo. A KBO with a higher albedo is not necessarily closer to the Sun compared with one that has a low albedo. Another factor to be considered is that most KBOs have highly elliptical orbits which means that at times a KBO is closer to the Sun and other times further away. This may change the albedo, because atmospheric gases that may be solid when the KBO is furthest away from the Sun may melt closer to the Sun, reducing the albedo.

Albedo doesn't always give an accurate indication of size either. Eris was once thought to be bigger than Pluto but Eris has a high albedo because its surface is probably covered with frozen atmosphere. This high albedo meant that its diameter was wrongly calculated. The diameter was more accurately measured when Eris passed in front of a dim star momentarily dimming the star's light, therefore showing that Eris is a similar size to Pluto.

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QUESTION THREE: ANTHROPOGENIC NOISE IN THE OCEAN

The vast biological diversity and the acoustic complexity of the ocean makes research into the effects of anthropogenic (human generated) noise on marine species very difficult. The levels of natural noise remain the same but anthropogenic noise is increasing significantly and, like natural noise, can travel long distances.

Each marine species has its own unique thresholds at which it can sense and respond to noise, and at which injury from sound can occur. Marine research has found links between some types of noise and some injury and has established that significant harm could happen, especially to mammals, fish, and invertebrates. But there is not yet enough data to fully understand which sounds affect which species under which circumstances.

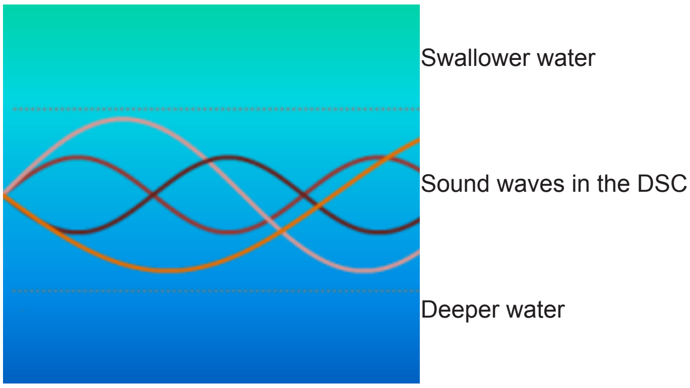
Many marine species are also highly sensitive to changes in temperature. The speed at which sound travels in the ocean depends primarily on temperature, with sound travelling faster in warm water. A 1°C change in temperature corresponds to about 4 ms^{-1} change in sound speed. Long-term trends in ocean temperature, both vertically and horizontally, can be monitored by precisely measuring the time sound takes to travel a defined distance in the ocean.

Changes in ocean temperature will also affect the depth of the Deep Sound Channel (DSC). This is a layer in the ocean where sound, especially low frequency sound, travels long distances. The DSC is at the depth where the speed of sound is the slowest. At shallower depths, the sound travels faster because the water is warmer; at deeper depths, sound travels faster because the water pressure is greater. Any sound that originates in the DSC doesn't spread out but is refracted back into the channel by this difference in speeds. Scientists use the DSC to remotely monitor marine life.

Analyse and evaluate the difficulties in researching the complex issue of the effect of anthropogenic noise on marine species.

Consider in your answer:

- the role of the DSC in the monitoring of marine life
- the role of the DSC in monitoring anthropogenic noise
- the effect of ocean warming on data gathering
- the problems with collecting reliable data
- how uncertainties in data can be managed
- possible societal and international responses.



Deep Sound Channel
http://shaunmccarthy.wordpress.com/2008/07/13/ww2-secrets-the-sound-channel/

Sample answer without annotations.

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Anthropogenic noise is increasing in the oceans, especially noise with a high decibel level, but the effect of this on marine species isn't well understood. This is because the number of species in the ocean is vast and studying them is full of problems, mainly due to the crushing pressure, lack of light and vast distances and depths. Only a few species have been studied to the point where damage due to anthropogenic sound could be detected.

To understand the effect of anthropogenic noise on marine species several lines of research need to be carried out and collated from other researchers. Research needs to be done on a large range of marine species, showing their normal food sources, behaviours, life cycles etc. Temperature profiles of the ocean at different depths and latitudes need to be known. Then the speed of sound in the ocean at different temperatures must be determined.

These data sets will establish some baseline data so that changes due to noise can be monitored.

The Deep Sound Channel (DSC) can be used for monitoring both marine life and anthropogenic noise because the speed of certain frequencies at the DSC depth is well known. Low frequency sound travels for long distances and so these are the frequencies that are monitored. Sound travels faster in warmer water, so increases in ocean temperature can also be detected.

If marine animals appear to be affected by environmental changes it is important to know whether this is because of noise or another factor, such as ocean warming due to climate change.

Uncertainties in data would be managed by having very good baseline data and by having accurate speeds of sounds at the relevant frequencies at a range of possible temperatures. Accurate models could be developed or enhanced using data from a range of sources to build up an accurate picture of at least the effect of noise on some marine species.

Individuals can't easily monitor the ocean, except for coastal areas, but they can put pressure on governments to sign international treaties limiting anthropogenic noise in the ocean. International treaties are urgently needed because the ocean has no boundaries and what happens in one part of the ocean can affect other parts. Education is also needed about the importance of the oceans and the value of marine life, not only for food but for the health of the planet.

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OUTSTANDING SCHOLARSHIP EXEMPLAR

NZQA
NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

New Zealand Scholarship Earth and Space Science

Time allowed: Three hours
Total marks: 24

Question	Mark
ONE	7
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THREE	7
TOTAL	21/24

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Eroded rock and sediment is transported by the prevailing current up the Otago-Canterbury coast. This debris accumulates in the Kaikoura Canyon forming an unstable slope which periodically collapses, resulting in large submarine avalanches. Such collapses have almost definitely caused devastating tsunamis along the Canterbury and Marlborough coastlines in the past. Archaeological sites have uncovered evidence of marine sediments overlying Maori occupation sites.

The return period for magnitude 8 earthquakes at Kaikoura is estimated to be 150 years. Also, it is estimated to take 100 years to accumulate enough sediment at the start of the Kaikoura Canyon to generate a major collapse.

Discuss and evaluate the threat of major tsunamis along the Canterbury and Marlborough coastlines.

Consider in your answer:

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- the evidence that could be gathered and analysed to determine how often major earthquakes and tsunamis occur.

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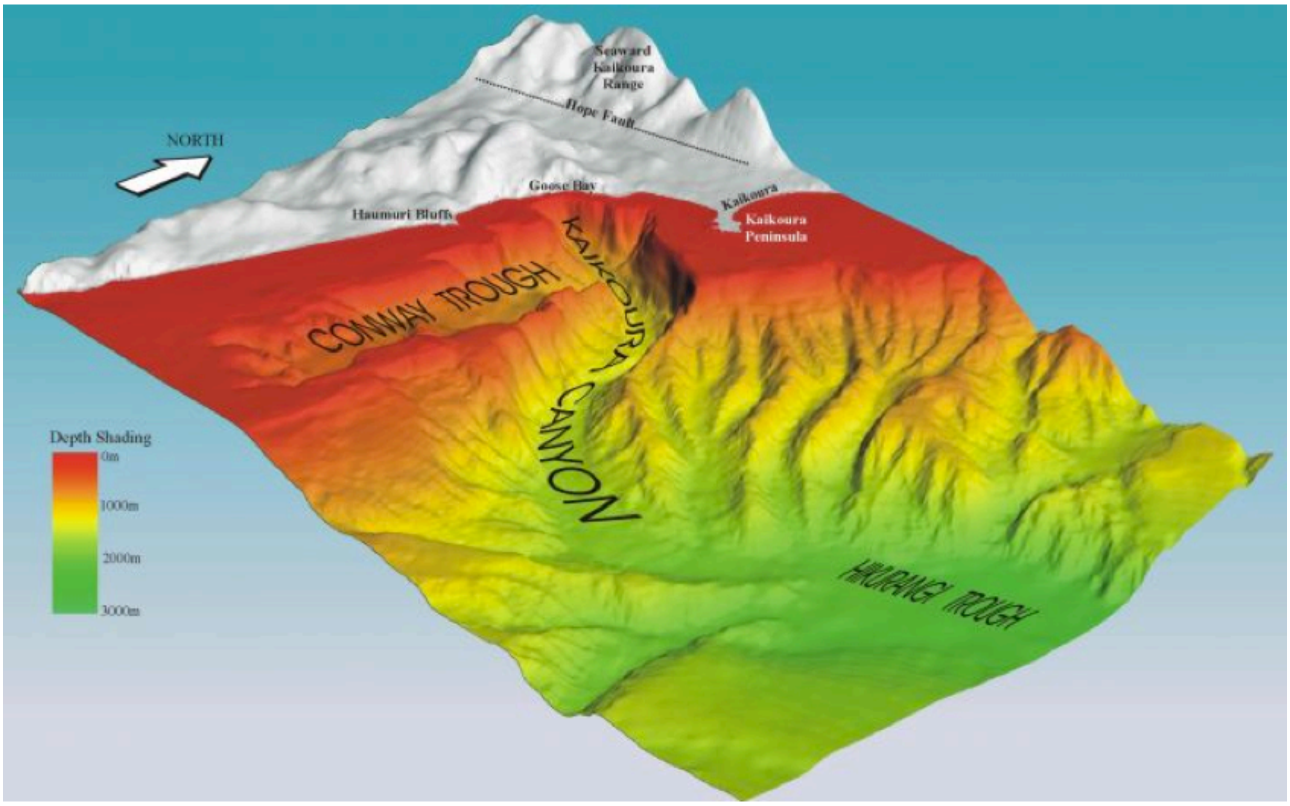

The Kaikoura canyon
http://www.niwa.co.nz/our-science/aquatic-biodiversity-and-biosecurity/research-projects/all/kaikoura-canyon

Sample answer without annotations.

Collision of the continental crust of the Pacific Plate (PP) with the continental crust of the Australian Plate (AP) along most of the South Island has resulted in the rapid uplift and formation of the high, sharply pointed Southern Alps over the last 5 million years or so. This, combined with the weathering effect of ice, snow, and wind has caused major erosion of the mountains. The resulting shattered rocks are washed into rivers where they are broken down even more and smoothed. The knocked off smaller rock particles are ground down to fine particles of sediment. Rock and sediment is transported in the braided rivers of Canterbury and Otago to the coast. Once in the sea the rocks and sediment are transported northwards by the prevailing current. Heavier rocks are deposited along the coast but much of the finer sediment reaches the Kaikoura Canyon where it is deposited on the side of the canyon. This is a continuous process.

The sediment accumulates over time until the sediment slope becomes unstable. Just gravity could destabilize the slope but an earthquake would vibrate the sediment, breaking up any compaction

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and causing it to collapse a lot more quickly.

The tectonic plate boundary enters the South Island near Kaikoura. This is where the Pacific Plate stops being made of oceanic crust and starts being made of continental crust instead. The Pacific Plate stops subducting and starts moving laterally (as well as colliding) relative to the Australian Plate. Major faults have formed to relieve this pressure resulting in the Wairau, Awatere, Clarence, and the Hope Faults. These faults are active, so that because pressure is built up from continual plate movement, a fault line gives and strong earthquakes regularly occur. Such a large earthquake in this area is liable to be shallow too, causing even more shaking.

If a major earthquake occurring on one of these faults coincides with the accumulation of a maximum amount of sediment, a catastrophic collapse of the canyon wall occurs because the vibrational energy of the seismic waves from the earthquake shakes the sediment slope. The sediment falls off the slope and rushes down to the bottom of the canyon and out along the Hikurangi Trough, resulting in the displacement of a huge amount of water. This forms a tsunami that would inundate the coast. The whole depth of water moves (not just the surface-like waves formed from winds) and would probably cause huge surges of water inland.

Scientists can gather evidence to determine just how often major earthquakes and devastating tsunamis happen. To determine fault line movement one technique would be to look for evidence of displacement of strata exposed in road cuttings. Also, landforms such as river terraces may be cut through by fault line movement. Displacement, both horizontally and vertically can be easily measured. Also, streams or even rivers may have been realigned after a main event and that can also be measured. There may also be evidence of landslides caused by earthquakes, resulting in the destruction and regrowth of vegetation as well as the destruction of landscape. Also, any tears and rips in the land would be quickly covered up by sediment and this could be looked for too. Trenches would need to be cut to examine disturbances in the normal deposition of sediment.

Carbon–14 could be used to date vegetation killed as the result of an earthquake, which could be cross-correlated with tree ring data plus organic matter in sediment.

Evidence for tsunamis could be gathered along the coast as tsunami waves would spread out and affect the Canterbury and Marlborough coastlines as well as the Kaikoura one. Evidence can be found by examining the deposition of marine sediment and gravels not only on top of Māori settlements but also along other parts of the coastline. Places to look for evidence could be many metres above the normal high tide line because tsunamis may have swept inland for a long way. Trenches could be dug and cores taken to determine the presence of marine sediment where you wouldn't expect it. If marine sediment is found on top of Maori settlements organic material could be C–14 dated to give a possible date that the marine sediments were deposited. Cores of off-shore sediment may also show sand and gravel mixed up in a turbidity current, compared with compacted sediment, which would show regular horizontal deposits of sediment.

Determining the age of such evidence would be crucial. You can never determine exactly when a tsunami may occur but an approximation means that coastal communities and Civil Defence can have a rough idea of when to take extra precautions.

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QUESTION TWO: DISCOVERING KUIPER BELT OBJECTS

The Kuiper Belt, beyond the orbit of Neptune, is a region of very faint, icy objects 30-60 AU from the Sun. The first Kuiper Belt object (KBO) was discovered in 1992. Most KBOs are the size of small asteroids, and there are probably about 70,000 KBOs larger than 100 km across.

The size and distance of KBOs from the Sun make them very difficult to find and to accurately determine their size and composition. Also, many KBOs have highly elliptical orbits which are also tilted with respect to the planetary orbits.

Because the surface details of KBOs cannot be easily seen with telescopes, their albedos provide valuable information.

Albedo measures the reflectivity of the KBOs. The amount of light that strikes the KBO is calculated and the reflected light measured. Because the KBOs are so far away the albedo of the whole body is measured. An albedo of almost 1.0 indicates a bright object that reflects most of the light that strikes it, whereas an object with an albedo of almost zero would absorb most of the light.

Although they're icy, most KBOs do not reflect much light and have low albedos, down to about 0.05, probably because their surfaces are heavily weathered and contain dark organic compounds. However, larger KBOs, such as Pluto and Eris, have atmospheres and relatively high albedos.

Discuss and analyse the use of albedo to determine the size and composition of KBOs.

Consider in your answer:

- the presence or absence of any atmosphere
- the mineral composition and reflectivity of the surface
- the presence of surface ice
- surface features
- the relative distance from the KBO to the Sun
- the relative angles of the Sun, Earth and the KBO.

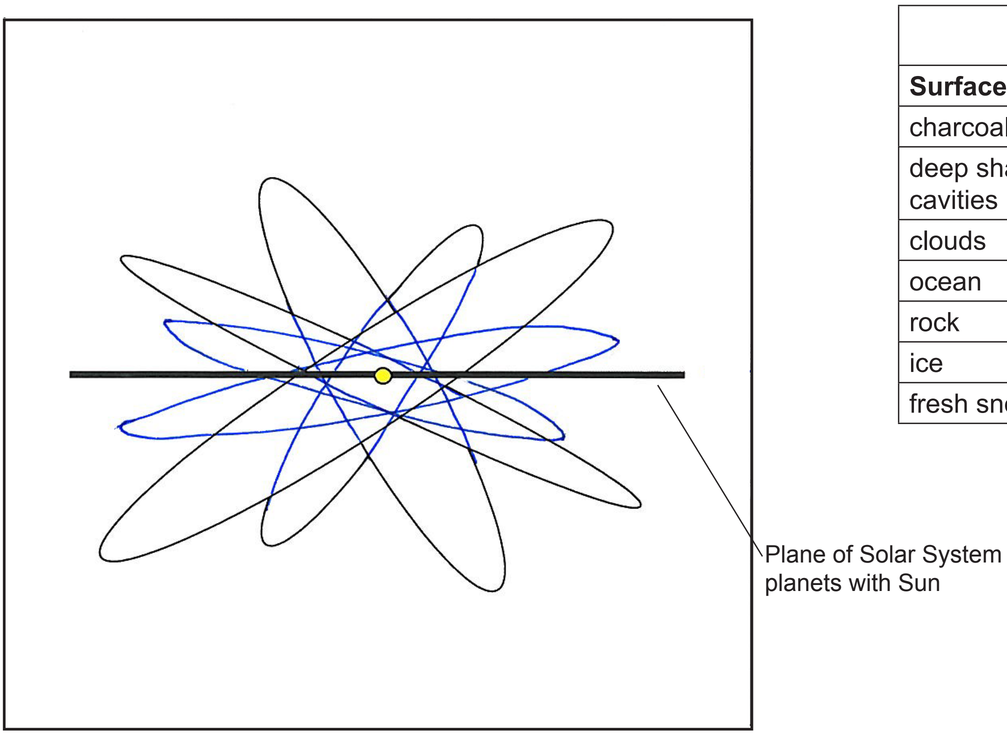

Diagram showing the highly elliptical and tilted orbits of KBOs
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Sample albedos

Surface	Typical albedo
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clouds	0–0.8
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ice	0.5–0.7
fresh snow	0.8–0.9

Sample answer without annotations.

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Because Kuiper Belt objects (KBOs) are 30–60 astronomical units away from the Sun and so small they are very hard to find. They can't be seen clearly with telescopes so albedo become an important way of finding out information.

Albedo can help find out, for each KBO, its distance from the Sun, the composition and features of the surface and whether it has an atmosphere.

The surface of each KBO may vary considerably depending on its composition. If the surface is made up of shiny minerals or rocks it will reflect more sunlight than a surface made of a dark minerals, rock or organic compounds. Data from the table shows that charcoal has an albedo of only 0.04. If the surface is smooth it will reflect more light than a rough surface, which will scatter light. An ice covered surface will have an even higher albedo. Eris, a KBO, has a very high albedo which indicates it may be completely covered with ice or frozen atmosphere.

The features of the surface will also affect albedo. A heavily scarred or cratered surface will scatter light and cause shadows, giving a low albedo (about 0.01) whereas a relatively smooth surface will scatter only a small amount of light, have fewer shadows, and will have a higher albedo.

Any atmosphere around a KBO can also affect its albedo. A dense atmosphere or clouds increase the albedo because any darker surface of the KBO is hidden. The clouds or atmosphere reflect light. Also, droplets of volatile gases such as methane and nitrogen scatter light so more reflects out to space. The gases can solidify, causing a very high albedo.

The albedo will provide an average value for the reflectivity over the surface of the KBO, eg by averaging the low reflectivity of a dull rocky part with the higher reflectivity of ice, or the reflectivity

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from rough and smooth surfaces.

The angle of the Sun relative to the KBO and Earth can also change. If the albedo changes as well this is an indication of how rough the surface of the KBO is: that is, the regolith properties. The rough surface not only scatters light, but also, with low angles of illumination, forms shadows. So a low angle of Sun relative to Earth increases the albedo.

There is no relationship between distance and albedo, meaning that a lower albedo doesn't mean that the object is further away. A KBO with a higher albedo may appear to be closer to the Sun, and one with a low albedo may appear further away when they are both a similar distance. Most KBOs have highly elliptical orbits which means that at times a KBO is closer to the Sun and other times further away. This means that an icy surface, especially when made of certain gases such as methane and nitrogen, may melt when the KBO is closer to the Sun, reducing the albedo. The reverse process will occur when the KBO is further away from the Sun.

Albedo can give an indication of size but may not be accurate, because the albedo may vary due to a highly elliptical orbit as mentioned above. Eris was once thought to be bigger than Pluto, but Eris's high albedo meant that its diameter was wrongly calculated. The diameter was able to be accurately measured when Eris passed in front of a dim star, causing the star's light to become even dimmer for the duration of the occultation. Observations from different parts of the Earth gave results showing that Eris is a very similar size to Pluto.

Albedo will become even more useful as tables showing known albedos related to known surfaces and sizes are developed as more KBOs are found. Such tables could be used as standard measures and baseline data.

7

QUESTION THREE: ANTHROPOGENIC NOISE IN THE OCEAN

The vast biological diversity and the acoustic complexity of the ocean makes research into the effects of anthropogenic (human generated) noise on marine species very difficult. The levels of natural noise remain the same but anthropogenic noise is increasing significantly and, like natural noise, can travel long distances.

Each marine species has its own unique thresholds at which it can sense and respond to noise, and at which injury from sound can occur. Marine research has found links between some types of noise and some injury and has established that significant harm could happen, especially to mammals, fish, and invertebrates. But there is not yet enough data to fully understand which sounds affect which species under which circumstances.

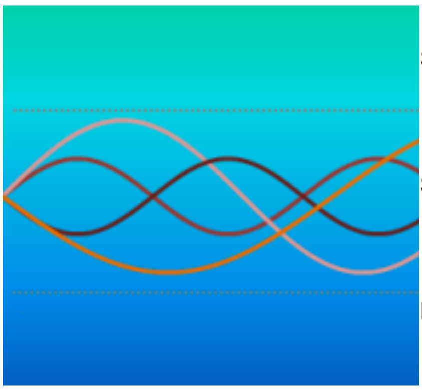
Many marine species are also highly sensitive to changes in temperature. The speed at which sound travels in the ocean depends primarily on temperature, with sound travelling faster in warm water. A 1°C change in temperature corresponds to about 4 ms^{-1} change in sound speed. Long-term trends in ocean temperature, both vertically and horizontally, can be monitored by precisely measuring the time sound takes to travel a defined distance in the ocean.

Changes in ocean temperature will also affect the depth of the Deep Sound Channel (DSC). This is a layer in the ocean where sound, especially low frequency sound, travels long distances. The DSC is at the depth where the speed of sound is the slowest. At shallower depths, the sound travels faster because the water is warmer; at deeper depths, sound travels faster because the water pressure is greater. Any sound that originates in the DSC doesn’t spread out but is refracted back into the channel by this difference in speeds. Scientists use the DSC to remotely monitor marine life.

Analyse and evaluate the difficulties in researching the complex issue of the effect of anthropogenic noise on marine species.

Consider in your answer:

- the role of the DSC in the monitoring of marine life
- the role of the DSC in monitoring anthropogenic noise
- the effect of ocean warming on data gathering
- the problems with collecting reliable data
- how uncertainties in data can be managed
- possible societal and international responses.



Deep Sound Channel
http://shaunmccarthy.wordpress.com/2008/07/13/ww2-secrets-the-sound-channel/

Sample answer without annotations.

Anthropogenic noise, such as shipping, oil exploration, and military activities, is increasing, but the effect on marine species isn't well understood. Life in the ocean is so varied and complex that no-one is even too sure how marine species react to any noise or are affected by it, natural or human generated, let alone an increase in noise. Also, no-one knows how warming of oceans will affect marine animals. Habitats, food sources and developmental changes may be affected, which may confuse interpretation of data collected to monitor the effect of sound.

Low frequency sound travels for long distances along the layer in the ocean called the Deep Sound Channel (DSC). The speed of certain frequencies at the DSC depth is known and can be used to monitor both marine life and anthropogenic noise over long distances, if they are emitting sound at those frequencies. Therefore the effect of the noise on the animals can be monitored, at least at the DSC depth, provided the scientists can distinguish between natural and anthropogenic sound.

Good data would need to be collected to form a base line so that when the ocean warms due to climate change, accurate comparisons can be made between the base line data and data from the warmer water. Also, regular monitoring using the DSC will show trends, especially by measuring the speed at which the sound is travelling, seeing sound travels faster in warmer water. Measurements don't have to be taken just in the DSC; horizontal and vertical sound speed measurements can be taken as well, which could help monitor the marine species that migrate vertically or horizontally.

Good data collection would need to involve very clearly identifying the different species of marine animals that are being detected so that these species could be monitored over time. Warmer water may mean that the originally monitored species has moved away from the DSC in order to stay in the range of temperature that it is adapted to. Also, the nature of the DSC may change with higher

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ocean temperatures. For example, if the ocean is warmer that may narrow or deepen the DSC, which may affect sound transmission and the monitoring of sound. Measurements of sound will need to be calibrated against sources of sound for which location, intensity and frequency are known.

Uncertainties in data would be managed by having very good baseline data and by having accurate speeds of sounds at the relevant frequencies at a range of possible temperatures. Temperature would probably be measured in small increases, may be between 0.1 and 0.5 0C. More research may also be needed on the temperature variations in the ocean so base line data and modelling, combined with data from other researchers, can give an accurate picture.

At a society level voluntary groups could be used to gather data, especially along the coast. However, the open ocean has no boundaries but individuals could put pressure on governments to ratify international agreements. Much more education is needed on the importance of oceans and marine life too.

Even though base line data may take a long time to accumulate, national and international action should be taken to prevent negative environmental impacts. Many of the sources of excessive anthropogenic noise could be controlled by international treaties.

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