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TOP SCHOLAR

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

Scholarship 2013
Earth and Space Science

9.30 am Tuesday 3 December 2013
Time allowed: Three hours
Total marks: 24

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

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

You should answer ALL the 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 2–15 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.

Note: ⇨ indicates a paragraph break

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QUESTION ONE: NEW ZEALAND AND THE GLOBAL CARBON CYCLE

New Zealand and the surrounding ocean contribute between 1% and 2% of the global sediment, and therefore play a part in the long-term cycling of carbon.

Discuss how relevant geological, oceanic and atmospheric processes on and around New Zealand contribute to the global carbon cycle.

molluscs + phytoplankton

In your answer, consider the role of:

- the interaction of atmosphere and ocean — DICs $\rightleftharpoons CO_2(g)$; photosynthesis → POCs → ACC + thermohaline upwelling / surface currents
- geological processes such as tectonic activity, weathering and erosion → sedimentation → mag, then subduction (south)
- the role of carbon cycling in the maintenance of a stable temperature range. — consistent atmospheric CO_2; sequestering of C → "buffer"

Note: a detailed discussion of climate is not required here.

In the atmosphere, carbon exists predominantly as $CO_2(g)$, and in the oceans, inorganically as CO_3^{2-}, HCO_3^- or $CO_2(aq)$, and organically in biological structures.

By the reactions $CO_2(g) \rightleftharpoons CO_2(aq)$, $CO_2(aq) + H_2O \rightleftharpoons H_2CO_3$, $H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$, carbon dioxide dissolves in the ocean at the ocean-atmosphere interface, forming dissolved inorganic carbon (DIC). This process occurs more readily at low temperatures, such as on the southern coasts of New Zealand (NZ) where cold water is provided by the Antarctic Circumpolar Current (ACC). Thus, mostly in the oceans south of NZ, the physical (solubility) pump sequesters carbon from the atmosphere.

the biological pump

Plants on land and phytoplankton in the oceans convert CO_2 to organic matter by photosynthesis, and certain phytoplankton species and molluscs produce hard shells of carbonate (usually $CaCO_3$). When these organisms die, they form particulate organic carbon (POC) and sometimes marine snow (by clumping together). Currents such as the ACC remove both POC and DIC to areas where the thermohaline circulation forms, taking this carbon into deep ocean water for hundreds of years. This process around NZ can contribute significantly to this part of the carbon cycle. Northeast of NZ, there are also upwellings in the Pacific ocean where CO_2

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is released as POC and DIC emerge from the deep circulation.
→ Regarding the land on and around NZ, dead marine organisms may sink to the sea/lake floor ~~ground~~ (e.g. plant matter in lakes or near shores / coasts), gradually sedimenting and compressed under pressure to form sedimentary rock (e.g. limestone). Rocks exposed to the atmosphere may also absorb CO_2 and become eroded by wind, rivers ~~water~~ or glaciers (especially: the westerlies; along the Southern Alps) or weathered by plant roots / freeze-thaw processes, transported to the sea by rivers where the material may sediment and form rock. This is a part of the rock cycle interacting with the carbon cycle as more carbon is in this way sequestered.
→ South of New Zealand, the Australian plate subducts under the Pacific plate, and vice versa north of NZ. In these regions, sedimentary rock may descend into the mantle and stimulate volcanic activity where CO_2 may be again released. Alternatively, over thousands of years, sedimentary rock may experience sufficient pressure to convert to metamorphic rock.
→ The carbon cycle, overall, provides a network of processes between different "compartments" of long term carbon storage, regulated by negative feedback. For instance, large amounts of carbon converted into hard tissue (carbonate shells) increase the activity of the carbonate counter pump:

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + H_2O + CO_2$$

which releases carbon into the atmosphere. More importantly, this network therefore behaves as a "buffer" to maintain consistent levels of atmospheric carbon dioxide. When atmospheric CO_2 increases, more carbon is sequestered, decreasing CO_2 levels. This plays an important role in temperature maintenance: CO_2 is a greenhouse gas, meaning that it resonates strongly

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when infrared radiation is incident, where the IR radiation is of similar frequencies to those re-emitted by the ~~sea~~ Earth after the Sun's radiation is incident. Overall, the effect is to decrease the amount of ~~em~~ electromagnetic (EM) radiation reflected into space, causing a warming effect on the Earth. The carbon cycle regulates atmospheric CO_2, hence temperature ranges in global climate, but at the expense of increasing ocean acidity, which affects sensitive marine organisms such as corals. //

→ NZ is an area of high levels of tectonic activity, and possesses glaciers and many rivers which contribute to erosion, ultimately ~~sedimentation~~ sedimentation. As many of these sediments also become mixed with vegetation or animal life, carbon is sequestered into the ocean, or into sedimentary rock on the sea bed. //

→ Over ~~time~~ time, tectonic activity, especially at collision boundaries such as the Alpine Fault, may cause the uprising of carbon-containing sedimentary rock, which may release carbon back into the atmosphere. If ~~the~~ organic matter is sufficiently compressed, the result may be fossil fuels, which, when burned, returns CO_2 to the atmosphere. //

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QUESTION TWO: TECTONIC ACTIVITY ON MARS

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Use the information provided on pages 2 and 3 of your Resource Booklet to answer this question.

Until recently, scientists thought that there had never been any plate tectonic activity on Mars. It was assumed that because Mars has only 10.7% the mass of Earth, it lost internal heat from its formation quickly and the crust grew too strong for plate tectonic activity. Also, a substantial amount of water is probably needed to lubricate plate motion.

Discuss and evaluate the evidence for plate tectonic activity on Mars using the features shown in the photos and magnetic field evidence on pages 2 and 3 of your Resource Booklet.

In your answer, consider:

- whether the evidence from key Martian features is strengthened by the similarity to certain features on Earth
- whether plate tectonic activity was present in the early history of Mars
- whether plate tectonic activity could be occurring today on Mars
- what other evidence would need to be gathered to strengthen the evidence for plate tectonic activity
- the presence and physical state of water
- the thin, carbon dioxide rich atmosphere of Mars.

As Mars and Earth are both rocky planets, the presence of tectonic activity would produce general features which are common to both planets. //

→ There is ample evidence to suggest that Mars at least once had active vulcanism: Olympus Mons, Tharsis Montes, and Alba Mons all possess an apical depression, strongly suggesting that these features arose from volcanic activity due to a partially molten mantle. Olympus Mons overlaps an impact crater, suggesting that this volcano was sufficiently recent that the surface had ~~become~~ solidified before the eruption. Similarly on Earth, overlapping features give indications to their relative order of ~~occur~~ formation. //

→ Valles Marineris shows very clearly the lateral movement of crust material along what seems to be an ancient fault line: the top rim has shifted west about 150 km, indicating crust movement ~~be~~ after solidification - it seems highly unlikely that this feature arose ~~[illegible]~~ as the crust solidified. The equivalent on Earth is the conservative plate boundary, which also produces lateral shifting – shown by matching ~~rock~~ ~~large~~ vertical rock structures at points very far apart – e.g. along the fault line in California.

→ Chains of volcanoes such as the Tharsis Montes may be due to the movement of crust over hotspots. For instance, the volcanic island arc northeast of NZ lies on a line or curve northwest, suggesting that the Pacific plate moved northwest in that region.

→ The map of the magnetism of the Martian surface rock shows distinct bands of dark red and blue from about 150° to 210° east and 30° to 90° south. This is strikingly similar – i.e. the reversal of magnetic field direction in bands of rock – to those found on either side of the oceanic ridge in the Atlantic Ocean on Earth. On Earth, this has served as evidence for the separation of crust ~~outside~~ outwards from this ridge, and strengthens this evidence found on Mars.

suggests a constructive plate boundary

→ All these features provide strong evidence for the presence of plate tectonic activity in early Martian history, but closer examination suggests that this activity has now mostly ceased: there are very few prominent volcanoes, no recent (uneroded) fissures along lines such as the Valles Marineris and largely distorted lines of alternating directions of magnetic fields. Furthermore, the majority of the surface water is in solid form at the polar ice caps, and any (unconfirmed) underground water is likely to also be frozen (due to the low temperature and ~~seeing~~ ceased volcanic – hence mantle – activity) and unable to lubricate plate motion. The thin atmosphere has not been added to by

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volcanic eruptions for long enough to allow solar wind to strip the atmosphere (due to the absence of a strong magnetic field like Earth's) and accelerate cooling. The absence of: volcanic activity, a strong magnetic field, and thick atmosphere - all suggest that the core has largely cooled and can no longer stimulate crustal movements.

→ To strengthen the evidence for historic plate tectonics, rock samples may be taken and analysed from either side of the series of stripes (around 0° ~~latitude~~ and -90° longitude) to compare rock composition and the vertical structure of the crust. Matching compositions and structures would strengthen this theory. In addition, ~~rock~~ crust material at each point along the stripes (following 180° east) could be dated to determine their age. If the ages of the rock correspond and get older ~~a~~ spreading out from a specific midpoint, the theory is again supported. On the line of rock analysis, representative samples from the three Tharsis Montes could be analysed to determine rock composition - similar composition will suggest that they formed from the same hotspot ~~~~ and will support the (former) presence of ancient plate tectonic activity.

→ Note: the map of surface magnetism shows strong evidence where the distinct stripes are present. The evidence is weakened, however, by the large amount of scattering and distortion, ~~~~ and weakening strength of, the variations in surface magnetism.

→ The stripes occur on Earth because over time, the magnetic poles frequently reverse direction while new crust containing traces of iron is continually forming at the constructive margin. When the crust is molten, magnetic domains are free to rotate to align with the external magnetic field, but when the rock solidifies, the dipoles remain locked, becoming a historic marker for the magnetic field direction at that point. The map of Mars' crustal magnetism suggests that similarly, convection cells in the core ~~caused~~ produced a magnetic field which slowly ~~turned~~ changed direction over time as new crust material was formed.

~~At both planets~~

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QUESTION THREE: THE ANTHROPOCENE – A NEW GEOLOGICAL EPOCH

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Use the information provided on page 4 of your Resource Booklet to answer this question.

Discuss and analyse probable characteristics of a geological layer representing the Anthropocene epoch, as would be examined in the future in a sediment core, trench or road cutting.

In your answer, consider:

- how the geological layer could be dated
- the likely distinctive markers of the Anthropocene epoch in the geological record
- the implications for the geological record of certain species being distributed widely around the world — analysis for extinction
- possible evidence for climate change and ocean acidification.

Dating of the layer, after initial comparisons with major other geological markers such as layers of rocks whose ages are already known, could ~~...~~ involve the measurement of ratios of abundances of radioactive isotopes of elements, such as uranium or ~~...~~ silicon. As different isotopes may decay at different rates, the extent of decay ~~...~~ for several isotopes could indicate how old the rock sample is. * [see top of p. 11] →

→ Markers for layers from this epoch could include rock rich in radioisotopes, PCB residues and CFCs; ~~...~~ sedimentary rock containing plastics or organic plastic breakdown products; rock containing high amounts of aluminium ~~in its elemen~~ and iron (from corrosion-resistant steel) in their elemental states; high nitrogen content of sedimentary rock; high carbonate content of rocks which have absorbed CO_2, and greater ratios of C-12 to C-13 in these rocks; layers containing fossils of ~~many~~ unusually large numbers of tree stumps or of species ~~...~~ such as mice which have been distributed globally; layers which ~~...~~ contain fossils of marine organisms (e.g. molluscs) while layers below do not; layers containing large numbers of crop plants remnants; etc.

→ Although these markers will be useful, unless human civilisation changes to reverse these markers, all layers from the Anthropocene ~~epoch onwards~~

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Fossils in these layers may also be carbon dated, tree rings counted or, in Antarctic ice caps, light and dark bands counted due to annual oscillations in Antarctic CO_2 concentrations/levels in the atmosphere.

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epoch onwards will have these characteristics. The beginning of the epoch may be taken to be the first layer containing these markers.

→ The geological record of the global ~~distrib~~ distribution of certain species, such as mice or weed species, could indicate the beginning of mass human migration, and can determine the approximate time of settlement of particular land masses. The first appearance of mice fossils in a foreign environment's geological record is likely to correspond to the first human settlement of that region. Different fossils can then be examined to determine the effect of this species introduction on the ecosystem.

→ Changing biomes from the fossil records of various layers (e.g. boreal forest to tundra, or to temperate forest) could indicate climate changes ~~~~ as a result of ~~the~~ changing temperatures, relative humidities, and rainfall. Furthermore, different amounts of erosion or grain sizes in sedimentary layers, the amount of water necessary for the formation of particular types of rocks could be traced to find evidence for changing amounts of rainfall.

→ The loss of certain marine species from a particular sedimentary rock layer could show evidence of changing ocean temperatures, pH or composition. Also, the limestone saturation point could be evident in geological ~~fossil~~ records, and may be able to be traced to show the varying level as the ocean ~~be~~ becomes more acidic.

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→ Carbon dioxide concentration of the ocean could be obtained from relative amounts of phytoplankton, or from Antarctic ice cores; ~~[illegible]~~ – higher CO_2 levels lead to ocean acidification. Also ~~[illegible]~~, the dissolution of shells for marine organisms with carbonate ~~[illegible]~~ or silicate shells at different depths could provide evidence for increasing pH. That is, at the same depth, if marine shells have dissolved (either more or completely), the ocean has ~~[illegible]~~ become either more acidic or warmer. CO_2 content of ~~[illegible]~~ rock in these layers may also indicate local historic CO_2 levels. ~~[illegible]~~ //

→ Anthropocenic layers are also likely to contain evidence of human civilisation – e.g. remnants of concrete or steel structures which may seem out of place given the geographical context to have occurred naturally. ///

→ Landfills may turn into ~~[illegible]~~ sedimentary layers with specific and unusal characteristics – i.e. plastic/paper content, etc. //

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Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

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QUESTION NUMBER

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Rough working:

• ~~Features~~

The ocean ridge in the atlantic ocean

~~olympus mons analogous ? impact crater~~

stripes

~~canyons~~

few impact craters in Utopia Planitia

~~volcanoes may lie on parallel lines~~

features

~~shifted basin~~

~~presence of volcanoes~~

canyons: signs of power of water?

contains bands with hot water, more distorted ⇒ disrupted by other activity?

Evidence

also mean they seismic activity

no new fissures / volcanoes

Most H_2O at poles – frozen. Surface temp. below, no volcanic activity to keep liquid.

what is needed

analysis of rock composition and type from venus points to suggest they are more at similar geographic positions.

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