***Resource for***

**QUESTION ONE: IO AND EUROPA**

*Use these photos and images to help you answer Question One on page 2 of your Exam Booklet.*

In order of closest to furthest away from Jupiter:

Io

Europa

Ganymede

Callisto

**The four Galilean moons and Jupiter.**

http://upload.wikimedia.org/wikipedia/commons/8/87/Jupitermoon.jpg

Io and Europa are two of Jupiter's four Galilean moons.

Both moons:

- orbit Jupiter in non-circular (elliptical) orbits
- are affected by tidal flexing and heating
- have surfaces that are continuously being renewed, and are therefore geologically new.

Io has a rocky core, and a silicate mantle and crust with highly active volcanoes. Io has no sign of water in any state.

**Io, showing many volcanic craters.**

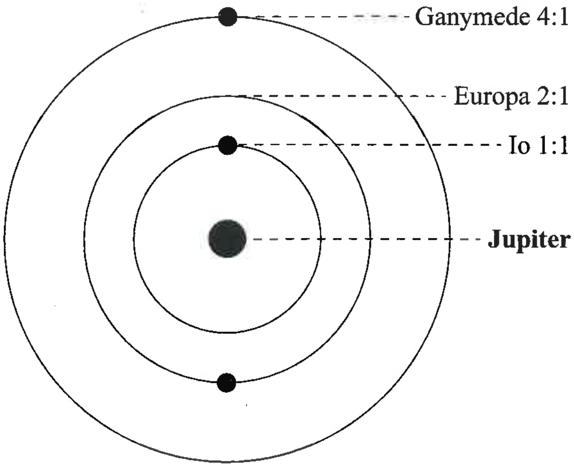
http://www.redorbit.com/media/uploads/2004/10/4_30f5d7b511dbed3c6f2b818ac38069f22.jpg

Europa has a smooth, icy, cracked crust with possibly a liquid ocean beneath, and a smaller silicate mantle and rocky core compared with Io. The thickness of the ice and ocean are unknown, and may depend on the presence or absence of volcanism under the ice and ocean.

**Europa, showing the many cracks on the surface.**

http://upload.wikimedia.org/wikipedia/commons/5/54/Europa-moon.jpg

The orbits of Io, Europa and Ganymede are locked in a 1:2:4 orbital resonance. This makes the orbits of the three moons non-circular or eccentric.




**Representation of the orbits of Io, Europa and Ganymede.**

http://upload.wikimedia.org/wikipedia/commons/8/83/Galilean_moon_Laplace_resonance_animation.gif

The times these moons take to orbit Jupiter are:

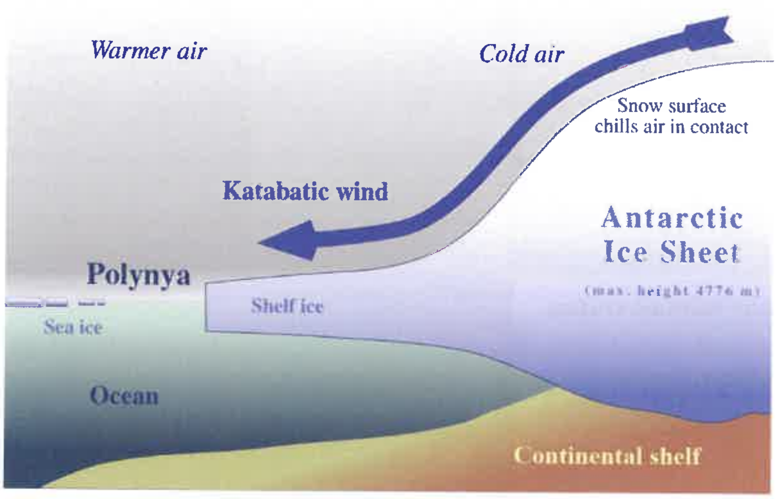
- Io: 1.8 days
- Europa: 3.6 days
- Ganymede: 7.2 days

***Resource for***
## QUESTION TWO: POLYNYAS, NATURE'S SEA ICE FACTORIES

*Use this information to help you answer Question Two on page 6 of your Exam Booklet.*

Around the Antarctic continent coastal sea ice can become very thick, especially in winter. However, there are coastal areas, called polynyas, which are regions of open water covered only by very thin sea ice, if any ice at all. Such coastal polynyas are important areas of sea ice formation.

Polynyas form where there are strong katabatic winds that blow off the continental Antarctic ice sheet. Sea ice is constantly being formed, especially in the winter, but is quickly pushed away to an outer area by these winds, leaving ice-free water.

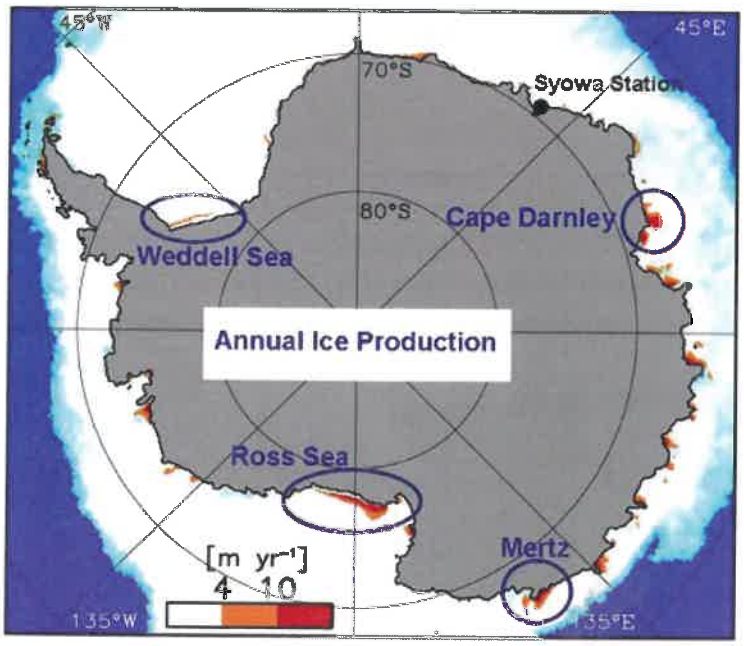



**The formation of sea-ice by coastal polynyas.**

Adapted from: http://upload.wikimedia.org/wikipedia/commons/7/76/Katabatic-wind_hg.png

Antarctic coastal polynyas, despite being small in total area, are important physically and biologically in the Southern Ocean. They have ideal conditions for seasonally early and vigorous phytoplankton blooms.

When sea ice is formed, dense brine (very salty water) also forms. There are only a few areas in the world where this dense water is formed.

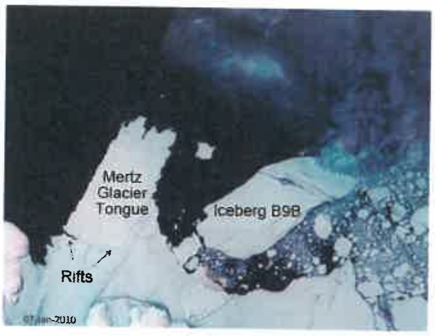



**Map of Antarctica showing the main areas of ice production. (Circled areas represent areas of brine formation.)**

http://www.sott.net/article/258803-New-source-found-for-cold-deep-Antarctic-currents

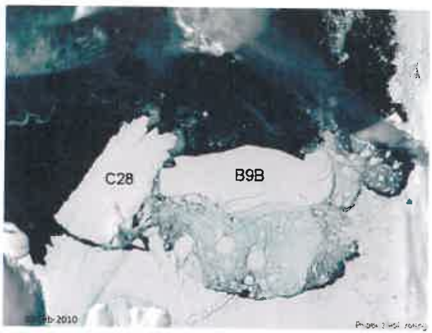
## The breaking off of the Mertz Glacier tongue in 2010

One area of coastal Antarctica, the Mertz Glacier polynya to the south of Tasmania, has been protected from sea ice drifting in from other areas by a tongue of ice from the Mertz Glacier. However, in February 2010, the tongue of the Mertz Glacier broke off after being rammed by a huge iceberg called B9B. The broken tongue became an iceberg called C28. Since then, sea-ice production by the Mertz polynya has decreased from 168 $km^3$ in 2000–2009 to 134 $km^3$ in 2011.



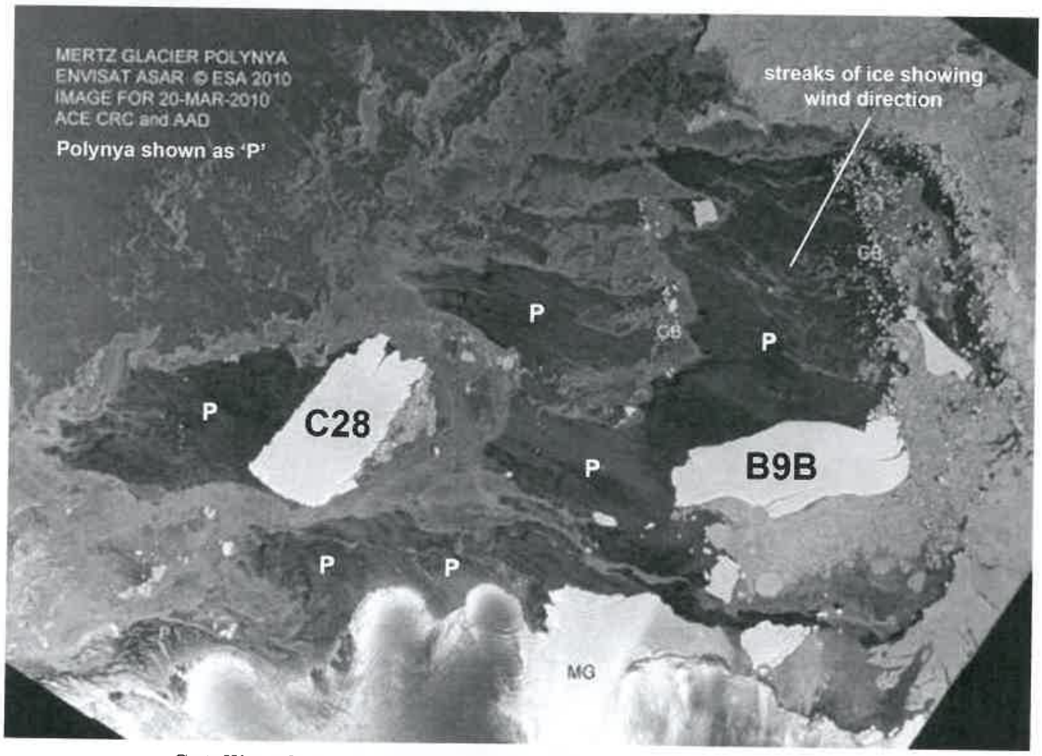

**B9B approaches the Mertz Glacier tongue, 7 January 2010.**


**B9B makes contact, 7 February 2010.**




**The Mertz Glacier tongue breaks off, 20 February 2010.**

Photos: Neal Young, www.antarctica.gov.au/news/2010/massive-iceberg-calves-from-the-mertz-glacier




**Satellite photo showing B9B and Mertz glacier tongue (C28) one month after tongue broke off.**

http://www.acecrc.org.au/access/repository/resource/81ddde22-bd0e-102e-bf5a-4040d04b55e4/797724_8320_march_2010.jpg

***Resource for***
**QUESTION THREE: TWO LINES OF VOLCANOES AND DEEP-SEA MINING**

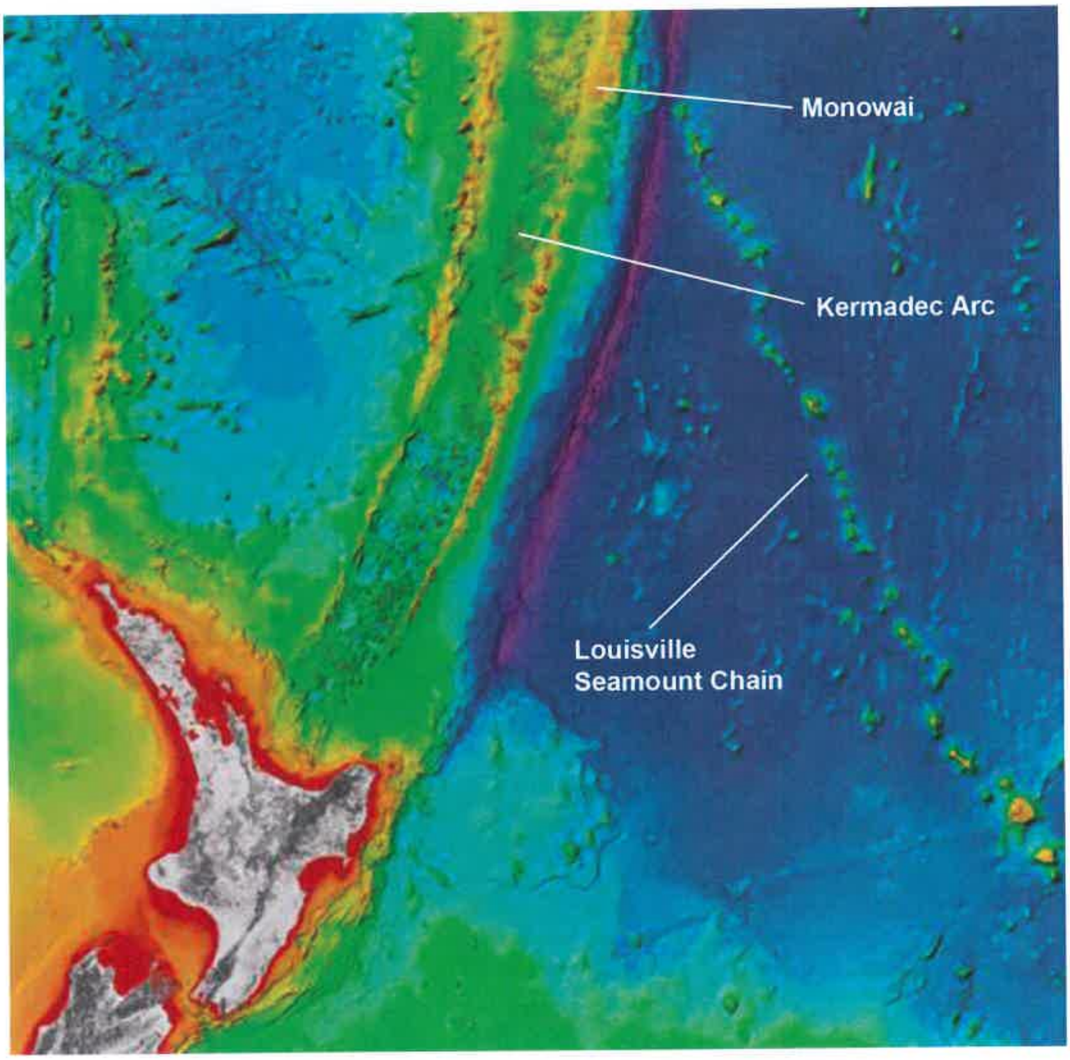
*Use this information to help you answer Question Three on page 10 of your Exam Booklet.*

**The Kermadec Arc and the Louisville Seamount Chain**

North-east of New Zealand are two lines of volcanoes that differ dramatically in their formation.

- The Louisville Seamount Chain has about 80 extinct volcanoes extending for 4300 km that have been formed as a result of hotspot volcanism over about 80 million years. It is thought that the hotspot has decreased in activity over time.
- The Kermadec Arc extends for 2500 km and contains about 80 active volcanoes formed by subduction.

The two lines of volcanoes meet near Monowai, a volcano in the Kermadec Arc.




**The Louisville Seamount Chain meeting the Kermadec Arc.**

http://kapitifishing.co.nz/wp-content/uploads/2012/12/niwa-underwater-map.jpg

Many of the Kermadec Arc volcanoes have high-temperature hydrothermal vents called "black smokers". Emissions from the black smokers result in the formation of "sea-floor massive sulfides", which are major sources of metals such as copper, lead, iron, zinc, silver and gold, as well as many rare earth metals.

**How black smokers and sea-floor massive sulfides are formed**

Cold sea water sinks to depths of several kilometres under the sea floor along cracks and fissures until it reaches the magma source. The sea water is heated to temperatures over 400°C, and this is hot enough to dissolve metals and sulphur from the rock that it flows through. This heated water with dissolved minerals has a lower density than the cold water, so rises very quickly to the sea bed, and erupts at high pressure out of vents shaped like chimneys. When the hot water, metal- and sulfur-enriched solution meets the cold sea water at the bottom of the ocean, the dissolved metals precipitate as metal sulfide compounds, and are deposited on and under the sea bed as formations called "sea-floor massive sulfides".

Metal sulfides also coat the chimneys, increasing their size. Some black smokers can grow several centimetres in just a few days.

**A black smoker showing the chimney-like structure.**

http://www.weirdwarp.com/wp-content/uploads/2010/07/Black-Smoker-Hydrothermal-Vents-570x855.jpg