Regional Processes
Melting and Crystallisation

Key Ideas

Magma and lava (molten rock) crystallise to form igneous rocks.

Intended Student Learning

Describe the differences between magma and lava.

Explain how the rate of cooling determines the grain size of igneous rocks.

State that the minerals commonly found in igneous rocks are quartz, orthoclase, and plagioclase feldspars, biotite and muscovite micas, amphibole, pyroxene, and olivine.

State, with the aid of a diagram, the order in which the minerals listed above crystallise from a melt, and relate this order to the mineral composition of rocks.

Explain how metallic ores are concentrated by gravity-settling and hydrothermal processes.

Explain how igneous rocks are classified according to texture (grain size and arrangement) and mineral composition.

Identify the following igneous rocks, and explain how each is formed:
- Granite
- Rhyolite
- Pegmatite
- Basalt
- Andesite
- Gabbro
- Dolerite

Describe the textures of the igneous rocks listed above.

State the mineralogies of the igneous rocks listed above.

Explain the formation of:
- batholiths
- dykes
- sills.

Explain the effect of temperature, silica content, and volatiles on the viscosity of a magma, and hence on the:
- nature of volcanic eruptions;
- shapes and sizes of the resulting volcanic land-forms.

Explain the formation of the following extrusive igneous land-forms:
- Shield cones
- Composite cones
- Cinder cones
- Flood basalts.

The sections of the Intended Student Learning that are italicised must form part of the fieldwork or practical materials submitted for moderation. They will not be examined in the public examination.
1.3 – Regional Processes
1.3.1 – Melting and Crystallisation

BASIC IDEAS

**Magma** is molten rock material containing dissolved gases. It is formed by (usually partial) melting of rock deep beneath Earth's surface; and it rises towards the surface because it is less dense than the surrounding rock. When this molten material runs onto Earth's surface, it is called **lava**.

When magma or lava cool, they crystallise to form **igneous rocks**.

**Viscosity of Magma**

The **viscosity** of a liquid is a measure of how freely it flows. Water is non-viscous (runny), whereas honey is viscous. Some types of magma are viscous - other are runny.

**Grain Size or Texture**

The **texture** of an igneous rock is defined as the **size** and **arrangement** of the crystalline **grains** in the rock. This can range from coarse (up to 1 cm) as in some granites, to very fine — too small to distinguish with the naked eye, as in basalt.

As summarised in the table below, the rate of cooling of magma or lava determines the grain size of igneous rocks.

<table>
<thead>
<tr>
<th>Rate of cooling</th>
<th>Grain size of rock formed</th>
<th>Syllabus examples</th>
<th>Location of cooling magma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very slow</td>
<td>Large (coarse) - up to 1 cm</td>
<td>Granite, Gabbro</td>
<td>Large body of magma deep under the ground.</td>
</tr>
<tr>
<td>Fairly slow</td>
<td>Medium - ~1 mm</td>
<td>Dolerite</td>
<td>Small body of magma just below the Earth's surface</td>
</tr>
<tr>
<td>Fast</td>
<td>Small (fine) &lt; 1 mm</td>
<td>Basalt, Rhyolite, Andesite</td>
<td>Above Earth's surface - lava from a volcano or lava flow.</td>
</tr>
</tbody>
</table>
**Composition of Igneous Rocks**

The minerals commonly found in igneous rocks are quartz, orthoclase and plagioclase feldspars, biotite and muscovite micas, hornblende, augite (a pyroxene) and olivine. You should be familiar with all the above minerals; except augite which is a greenish black mineral similar to hornblende (an amphibole).

In the **minerals** topic, the **feldspar family** of minerals was introduced, but individual feldspar minerals were not discussed. Two members of this family are very important constituents of igneous rocks.

**Orthoclase** feldspar contains potassium. This mineral can be pink, but it can also be white or grey. It is found in granites.

The term **plagioclase** covers a group of feldspars that may contain calcium, sodium or a mixture of these two metals. They may be white, cream or grey. Almost all igneous rocks contain some plagioclase feldspars.

NB: You do not have to be able to distinguish between hand specimens of orthoclase and plagioclase. However, a **pink** specimen of feldspar must be **orthoclase**.

**CRYSTALLISATION OF MAGMA**

Magma is a mixture of many minerals, each one having a different melting point. As a body of magma begins to cool, the minerals with the highest melting point crystallise first, followed in turn by minerals with lower and lower melting points.

**Bowen's Reaction Series:**

![Bowen's Reaction Series Diagram]

**Bowen's Reaction Series is a diagram showing the order in which the constituent minerals crystallise from magma as it cools.**

Olivine and calcium-rich (Ca) plagioclase have the highest melting points and therefore crystallise first. Quartz has the lowest melting point and is therefore the last mineral to remain in the molten state. Therefore quartz veins (and pegmatite) are formed within joints in rocks.
In general, minerals that crystallise at similar temperatures are likely to be found in the same igneous rocks. Basalt therefore contains olivine, Ca-plagioclase and augite. Andesite is an igneous rock containing augite, hornblende, and a plagioclase feldspar containing both calcium and sodium. Granites may contain hornblende, biotite, orthoclase and sodium (Na) plagioclase, muscovite and quartz.

**FORMATTION OF METALLIC ORES**

**Gravity Settling**

Because magma contains a variety of minerals with different melting points, when a body of magma cools slowly, a process known as **gravity settling** may occur. The stages in this process are outlined below.

1. As a body of magma cools, the mineral with the highest melting points begins to solidify and crystals of this mineral (called early-formed crystals) are formed.

2. These early-formed crystals may sink to the bottom of the magma chamber, where they are concentrated to form a layer of a single mineral.

If the early-formed crystals are those of an ore mineral, one or more layers of a useful mineral may be formed – e.g. nickel, chromium, platinum. These may constitute an **ore** deposit.

**Hydrothermal (hot water) Deposits**

Heat from a cooling body of magma will cause temperature of the surrounding rocks to rise, and also heat the groundwater contained in those rocks. Hot water travelling through the rocks may cause chemical reactions that may **break down silicate minerals and dissolve normally insoluble substances**. Solutions enriched by breakdown and dissolving of useful minerals penetrate fissures in the rocks and deposit minerals as they cool.
Some ores that may be found in hydrothermal deposits are chalcopyrite, galena, sphalerite and gold. Gold is always found as an element because it does not react to form other minerals.

The adjacent diagram shows that minerals in a hydrothermal vein build up from the outside of the cavity, as layers of minerals are deposited on the cavity walls.

The diagram also shows that the ore minerals occupy only a very small proportion of the vein. The majority consists of useless minerals known as gangue minerals.

### CLASSIFICATION OF IGNEOUS ROCKS

Igneous rocks are classified according to:
- Mineral composition
- Texture (grain size and arrangement).

### Mineral Composition

Since igneous rocks are formed by crystallisation of magma, they consist of intergrown grains of silicate minerals. The **mineral composition** of igneous rocks determines their colour and the viscosity of the magma or lava from which they formed. Three major groups are recognised, and their essential properties are summarised in the table below. LEARN THIS TABLE.
<table>
<thead>
<tr>
<th>FEATURE</th>
<th>NAME OF GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>FELSIC (acid)</td>
<td>INTERMEDIATE</td>
</tr>
<tr>
<td>Colour</td>
<td>Light</td>
</tr>
<tr>
<td>Major minerals</td>
<td>Quartz</td>
</tr>
<tr>
<td>Viscosity of magma</td>
<td>Very Viscous (thick)</td>
</tr>
<tr>
<td>Examples in your syllabus</td>
<td>Rhyolite, Granite</td>
</tr>
<tr>
<td></td>
<td>Darker</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
</tr>
<tr>
<td></td>
<td>Less Viscous</td>
</tr>
<tr>
<td></td>
<td>Andesite</td>
</tr>
<tr>
<td></td>
<td>Black</td>
</tr>
<tr>
<td></td>
<td>Olivine, Augite</td>
</tr>
<tr>
<td></td>
<td>Non-Viscous (runny)</td>
</tr>
</tbody>
</table>

**Texture**

The texture of an igneous rock is described in terms of the size and arrangement of its constituent grains.

When describing igneous rock textures, the terms coarse-, medium- and fine-grained may be used. Alternatively the grain size, or range of sizes in mm can be estimated.

Arrangement of grains refers to the presence or absence of layers in the pattern of the grains. Irrespective of the size of their crystals (grain size), all igneous rocks are comprised of randomly-oriented interlocking crystals.

Different rocks can have the same mineral composition, but different grain sizes if they formed from the same type of magma but solidified under different conditions.

**Felsic Igneous Rocks**

**Granite** and **rhyolite** are the two felsic igneous rocks in your syllabus. The above table indicates that they both have the same mineral composition. They are both light coloured igneous rocks, which solidified from viscous magma. However:

- **Granite** is a coarse-grained igneous rock since it solidified deep within the Earth's.
- **Rhyolite** is fine-grained because it solidified above Earth's surface from lava extruded by a volcano.

Granite and rhyolite are found only on the continents, never in ocean basins. They are associated with boundaries of continental plates, where granitic magma is formed by melting of rocks deep within the continental crust.

**Intermediate Igneous Rocks**

**Andesite**, the only intermediate igneous rock you need to recognise, is a fine-grained igneous rock that solidified from fairly viscous lava. Andesitic volcanoes are found around the edges of continents and in island arcs, such as the Japanese Island Arc. They are associated with boundaries of converging plates (plate tectonics will be studied later in the year).

**Mafic Igneous Rocks**
**Basalt, dolerite** and **gabbro** are the three mafic igneous rocks in your syllabus. They are all dark coloured, and their mineral composition is the same. However, the textures of the three rocks are different.

**Gabbro** is coarse-grained, **dolerite** is medium-grained and **basalt** is fine-grained. The different grain sizes are, as usual, due to the different rates of cooling which depends on the different situations under which the rocks cooled.

Basalt is the most common of these mafic rocks. It is extruded from volcanoes and from long fissures (slits) at Earth’s surface. Basalt is produced at boundaries of converging plates. However, some basaltic volcanoes are not associated with any plate boundaries (e.g. Mt Gambier). The oceanic crust consists of basalt, but it is also found on the continents (e.g. Tertiary basalts of western Victoria and the SE of South Australia). Basaltic magma is formed and extruded from Earth’s **mantle** — the zone below the crust.

A simple classification scheme, based on grain size and the colour of the rock (which depends on mineral composition) is shown below. The seven rocks shown in this table are the ones in the SSABSA syllabus - the ones you must **recognise**.

<table>
<thead>
<tr>
<th>Grain Size</th>
<th>Light coloured</th>
<th>Medium coloured</th>
<th>Dark coloured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine-grained (extrusive)</td>
<td>Rhyolite</td>
<td>Andesite</td>
<td>Basalt</td>
</tr>
<tr>
<td>Medium-grained (hypabyssal)</td>
<td></td>
<td>Dolerite</td>
<td></td>
</tr>
<tr>
<td>Coarse-grained (plutonic)</td>
<td>Granite</td>
<td>Intermediate</td>
<td>Mafic</td>
</tr>
</tbody>
</table>

**Composition:**
- Felsic
- Intermediate
- Mafic

**INTRUSIONS**

Igneous **intrusions** are formed when magma solidifies before it reaches Earth's surface.

**Batholiths**

A **batholith** is an example of a **plutonic** intrusion. Batholiths are formed when magma solidifies a long way (i.e. many km) below Earth's surface. They may extend over a wide area, up to hundreds of square kilometres. Batholiths usually consist of **granite**. Batholiths are frequently formed at the boundaries between pairs of continental plates.

![Batholith Diagram](image)

The granites at Victor Harbor and Port Elliot form part of a batholith which solidified at about 490 Ma beneath approximately 10 kilometres of rock.
Sills and Dykes

Hypabyssal igneous intrusions are formed when magma solidifies closer to the Earth’s surface. This is usually non-viscous basaltic magma, which flows into joints (or cracks), in the surrounding rock (known as country rock).

Sills are formed when magma flows between the layers (beds) of the sedimentary country rock. A sill is likely to consist of dolerite.

A sill is not always horizontal because the layers of country rock may tilt either before or after intrusion of the magma. Because dolerite is harder than most sedimentary rocks, erosion may result in the sill forming a ridge-like escarpment.

Dykes are formed when magma cuts across the layers of country rock. Like a sill, a dyke is usually composed of dolerite.

VISCOSITY AND LANDFORMS

Lava (i.e. molten rock which is extruded above Earth’s surface) solidifies to produce a range of landforms; the most easily recognised being volcanic cones. The nature of both a volcanic eruption and the resulting landform depend largely on the viscosity of the lava.

The viscosity of magma or lava is determined by three factors:

- **Temperature**: The hotter the lava, the less viscous it will be.
- **Silica content**: Silica (SiO₂) is the chemical name for quartz. Lava that contains a high proportion of silica is more viscous than one containing little silica.
- **Volatiles**: Lava contains dissolved gases in the same way as 'Coke' contains dissolved CO₂. Gases dissolved in magma are called volatiles, of which the largest percentage is water steam (H₂O) — hence large quantities of steam are emitted during volcanic eruptions. Other gases present are carbon dioxide (CO₂), nitrogen...
(N₂), sulphur dioxide (SO₂) and hydrogen sulphide (H₂S) — hence the 'sulphur' (rotten egg) smell associated with volcanoes.

Lava containing a high proportion of volatiles is less viscous than one containing few volatiles.

**Effect of Viscosity on Nature of Volcanic Eruptions**

**Basaltic** lava has a low viscosity, and basaltic volcanoes usually erupt comparatively quietly, as the non-viscous nature of the lava means that volatiles can escape easily. 'Fiery fountains' of lava are formed, but no explosions occur. Tourists flock to the island of Hawaii when a (basaltic) volcanic eruption occurs because they can see spectacular flowing lava in comparative safety.

**Andesitic** and **rhyolitic** lavas are viscous, and volatiles cannot escape so easily. Explosive eruptions occur, shattering the lava to fragments. Sizes of these fragments range from large 'bombs' to fine ash and dust. Ash and dust may cover a wide area, causing considerable destruction (e.g. Mount St Helens, USA).

In many eruptions of andesitic lava, initial gas pressure is high, and explosive activity occurs. As explosions release the pressure, activity becomes milder and lava begins to flow.

**Effect of Viscosity of Lava on Resulting Landforms**

Basaltic lava is not viscous and therefore it can travel long distances, forming **shield cones** that cover a wide area but are not very high. The Hawaiian volcanoes are excellent examples of shield cones.

Opposite: The last eruption of the shield volcano Mauna Loa (Hawaii) in 1984 (http://en.wikipedia.org/wiki/Image:Aa_channel_flow_from_Mauna_Loa.jpg)

Opposite: Oblique computer image of the volcano of Moana Loa (center) on the main island of Hawaii (Moana Loa centre).

Opposite: The largest volcano in the solar system is Olympus Mons (Mars) is approximately 300 000 km$^2$ in area, 25 km high, and its caldera is 500 km wide overlapped by six pit craters. The massive size of shield volcanoes on Mars is evidence that Earth-like plate tectonics is not, and has not happened within that planet (on Earth hotspot volcanoes eventually move away from sources of magma and therefore individual volcanoes are less massive than would otherwise be the case).


Andesitic eruptions produce composite cones formed by alternate eruptions of ash and lava. Below are two photographs of Mount Fuji (Japan), a composite (stratiform) volcano of andesitic composition.


Rhyolitic volcanic cones are (by contrast) steep-sided and comparatively high, as the lava solidifies before it can flow very far. However, rhyolitic lava is very rare because viscous magma usually solidifies before reaching Earth’s surface.

**A detailed look at Extrusive Igneous Landforms**

*Shield Cones (usually basaltic)*

When basaltic magma erupts from a single vent (rather than a long fissure), it may form a gently sloping shield cone. Because the lava is non-viscous, it can travel long distances, so the cone may extend for many kilometres, but is not very high in proportion to its diameter. The Hawaiian volcanoes are excellent examples of shield cones.
Composite Cones (usually andesitic)

The 'classic' volcanic cone (e.g. Mt Fuji, Mt Vesuvius) is a composite cone, consisting of alternating layers of cinders and other fragments and solidified lava. An eruption may begin with fragmented material; but this may be followed by a flow of lava. Alternatively, an eruption consisting almost entirely of fragmented material may be followed many years later by an eruption of lava.

Cinder Cones (usually rhyolitic)

Sometimes the material erupting from a volcano is not lava, but an explosive eruption occurs and the volcano ejects rock fragments, which may range in size from fine volcanic ash to large boulders. This material may be formed when rising pressure inside a magma chamber 'unblocks' a vent which was blocked by solidification of lava from an earlier eruption. Alternatively, the presence of large quantities of dissolved gases, especially in a rhyolitic magma, may cause the magma to fragment into pieces of volcanic rock or glass. These fragments may form a second type of cone — a cinder cone, which never grows very large. Mount Schank (near Mount Gambier) is an example of a cinder cone.

Flood Basalts

Flood basalts (or lava flows) result from outpouring of large quantities of basaltic magma from a long slit (or fissure) at Earth's surface. The lava 'floods' over the land, forming a flat area of basalt, rather than a volcanic cone. A lava flow may cover an area of many thousands of square kilometres. Successive lava flows form layers of basalt.

Flood basalt is an important geological feature of the Kimberley Block in Western Australia.
Krakatoa was a volcanic island in between Sumatra and Java, Indonesia. It has erupted often during recorded history. However, over 26-27 August 1883 a series of giant eruptions occurred. This volcanic event (see http://en.wikipedia.org/wiki/Krakatoa):

- generated 25 cubic km of rock ash and pumice were generated.
- produced the loudest sound ever recorded (heard 3100 km away in Perth and Mauritius 4800 km away).
- produced atmospheric shock waves that travelled seven times around the globe.
- destroyed 165 villages and towns, and seriously damaged 132 others.
- killed at least 40 000 people (and injured more) as a direct consequence of the explosions, and by the tsunami that followed.
- destroyed two-thirds of the island of Krakatoa (previously about 6 x 9 km).
- caused a tsunami that was recorded as far away as the English channel.
- was the equivalent of 13 000 Hiroshima atomic bombs.


Opposite is a NASA photograph of Krakatoa taken from space. It last erupted in 2001 and is growing at an average rate of about 13 cm per year (http://en.wikipedia.org/wiki/Image:Anak_krakatau_nasa.jpg).
EXERCISES

BASIC IDEAS

1. a. What is magma?

______________________________

b. How and where is magma formed?

______________________________

c. Explain why magma rises to Earth's surface.

______________________________

2. Explain the difference between magma and lava.

______________________________

3. On the diagram below, indicate the locations of magma and lava.

4. Explain the difference between the properties of viscous and non-viscous liquids.

______________________________

______________________________

5. How is the texture of an igneous rock defined?

______________________________

______________________________
6. Complete the table below, which summarises the relation between rate of cooling of magma or lava, location of cooling and the nature of the rock formed.

<table>
<thead>
<tr>
<th>Rate of cooling</th>
<th>Grain size of rock formed</th>
<th>Syllabus examples</th>
<th>Location of cooling magma</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Name the 8 common rock-forming minerals that are major constituents of magma, and hence of igneous rocks.

8. a. Name two important members of the feldspar family which form very important constituents of igneous rocks.

b. Summarise the properties of these two feldspars in the table below.

<table>
<thead>
<tr>
<th>Name of mineral</th>
<th>Colours</th>
<th>Composition</th>
<th>Igneous rocks found in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CRYSTALLISATION OF MAGMA**

1. a. Is magma a pure substance? Explain your answer.

b. Explain what happens to its different constituents as magma begins to cool.
2. Name the diagram which shows the order in which the constituent minerals crystallise from a magma as it cools and solidifies.

3. Complete the above diagram, naming the minerals in their correct order and the igneous rocks formed in each temperature range.

4. Use the diagram to estimate the melting points of the following minerals:
   - Augite
   - Biotite
   - Orthoclase
   - Olivine
   - Na-plagioclase
   - Hornblende
   - Ca-plagioclase
   - Muscovite

5. State whether each of the mineral assemblages listed in the table below is likely to occur in an igneous rock, and name the rock - if appropriate.

<table>
<thead>
<tr>
<th>Mineral assemblage</th>
<th>Occur together?</th>
<th>Rock type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olivine, Ca-plagioclase, augite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Augite, hornblende, Ca/Na-plagioclase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olivine, muscovite, quartz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hornblende, Na-plagioclase, orthoclase, biotite</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FORMATION OF METALLIC ORES

1. The process which produces a layer of a single mineral as a body of magma cools is known as:

2. Describe, with the aid of a series of diagrams, how a layer of a single mineral may be formed.

3. Explain why the process you described above may provide economic benefits.

4. What is the meaning of the term **hydrothermal**?

5. What is the essential condition for the formation of a **hydrothermal** deposit?
6. Describe the formation of a hydrothermal minerals deposit.

7. Name some ores which may be found in hydrothermal deposits.

8. The adjacent diagram shows a typical hydrothermal vein containing ore minerals.
   a. Name the minerals which make up the majority of the vein.
   b. What is the name given to these useless minerals which are found with useful ore minerals?
   c. About what proportion of the vein is actually made of ore minerals?

CLASSIFICATION OF IGNEOUS ROCKS

1. Name the two properties which are used as a basis for classification of igneous rocks, and explain how each of these properties may be described.
2. Collect the numbered rock specimens 1, 2, 3, 4, 5 and 6. Divide them into three groups according to their rate of cooling.

- Cooled slowly:  
- Cooled faster:  
- Cooled fast:  

3. (a) In the first row of the table below, name the three groups into which igneous rocks may be divided according to their mineral composition.

(b) Use rock specimens numbered 1, 2 and 3, together with information on p.7 and 8 to complete the remainder of the table.

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>NAME OF GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td></td>
</tr>
<tr>
<td>Specimen number</td>
<td></td>
</tr>
<tr>
<td>Name of rock</td>
<td></td>
</tr>
<tr>
<td>Viscosity of magma</td>
<td></td>
</tr>
<tr>
<td>Major constituents</td>
<td>mineral</td>
</tr>
</tbody>
</table>

4. The diagram below shows the axes for a scheme for classifying igneous rocks according to composition and texture.

- Grain Size
  - Fine-grained (extrusive)
  - Medium-grained (hypabyssal)
  - Coarse-grained (plutonic)

- Felsic
  - Lighter colour

- Intermediate
  - →

- Mafic
  - Darker colour

In the above table, fill in the names of the rocks on the SSABSA list, in their correct positions.
5. The diagrams below show the textures and mineralogies of some igneous rocks. Use these diagrams to answer the questions in the table that follows them.

![Diagram of textures and mineralogies of igneous rocks]

**KEY TO SYMBOLS**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Mineral</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>Microcrystalline</td>
</tr>
<tr>
<td>O</td>
<td>Orthoclase</td>
</tr>
<tr>
<td>Q</td>
<td>Quartz</td>
</tr>
<tr>
<td>G</td>
<td>Glass</td>
</tr>
<tr>
<td>B</td>
<td>Biotite</td>
</tr>
<tr>
<td>A</td>
<td>Augite</td>
</tr>
<tr>
<td>P</td>
<td>Plagioclase</td>
</tr>
</tbody>
</table>

Answer each of the following questions by placing in the space provided on the right hand side of the page next to the question the number or numbers of boxes showing rocks which meet the descriptions given in the question.

**NB. SEVERAL BOX NUMBERS MAY BE REQUIRED FOR SOME ANSWERS**

<table>
<thead>
<tr>
<th>QUESTION</th>
<th>ANSWER/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Extrusive igneous rocks</td>
<td></td>
</tr>
<tr>
<td>2. Rocks which formed deep below the earth's surface</td>
<td></td>
</tr>
<tr>
<td>3. Acid (felsic)</td>
<td></td>
</tr>
<tr>
<td>4. Basic (mafic)</td>
<td></td>
</tr>
<tr>
<td>5. Shows layers</td>
<td></td>
</tr>
<tr>
<td>6. Wide range of grain sizes</td>
<td></td>
</tr>
<tr>
<td>7. Granite</td>
<td></td>
</tr>
<tr>
<td>8. Basalt</td>
<td></td>
</tr>
<tr>
<td>9. Dolerite</td>
<td></td>
</tr>
</tbody>
</table>
10. **Rhyolite**

**INTRUSIONS**

1. Explain, with the aid of a block diagram, how a granite **batholith** may be formed.

   __________________________________________
   __________________________________________
   __________________________________________

2. Draw a second block diagram showing how the situation in your first diagram would have changed over several hundred my, so that we can see the granite even though the magma solidified several kilometres under the ground.

3. Draw a block diagram of a **sill**.
   a. Explain how a sill is formed.

      __________________________________________

   b. Name one rock type which would probably be formed in a sill.

      __________________________________________

4. Draw a block diagram of a **dyke**.
   a. Explain how a dyke is formed.

      __________________________________________

   b. Name one rock type which would probably be formed in a dyke.

      __________________________________________
VISCOSITY & LANDFORMS

1. a. Explain the meaning of the term volatiles, as applied to magma or lava.

b. Name the gas which constitutes the highest percentage of any volatiles.

c. Name the gases which are responsible for the 'sulfur' smell associated with volcanic activity.

2. a. Name three factors which affect the viscosity of magma or lava.

b. Discuss the effect of each of the above factors.

3. Name three types of lava, and describe the viscosity of each.

4. a. Describe the essential features of an eruption of basaltic lava.

b. Explain why an eruption of andesitic or rhyolitic lava is much more dangerous than the type you described in part a.

5. Suggest reasons for the differences between the landforms produced by the different types of lava.
EXTRUSIVE IGNEOUS LANDFORMS

1. Name **three** types of volcanic cone.

2. Explain why a **cinder** cone will never grow very large.

3. Explain why a volcanic eruption may begin with ejection of rock fragments; but this may be followed by a flow of lava.

4. The diagrams below show the comparative sizes of three common types of volcanic cone. State the type of cone represented by each diagram, and name **one** example of each type.

   - **A**
     - [Diagram of shield cone]
     - 10 km
     - 200 km

   - **B**
     - [Diagram of cinder cone]
     - 5 km
     - 20 km

   - **C**
     - [Diagram of composite cone]
     - 1 km
     - 2 km

5. Draw labelled diagrams, including a scale, of a shield cone, a cinder cone and a composite cone.
6. Explain, with the aid of a diagram, how a **flood basalt** may be formed.