The view from above: living tectonism
What was it like to be there – on top of a mountain-building collision?

Take your pupils to an area of folded rocks like these and ask them '*What was it like to be there – on the ground above where these rocks were being folded*?'

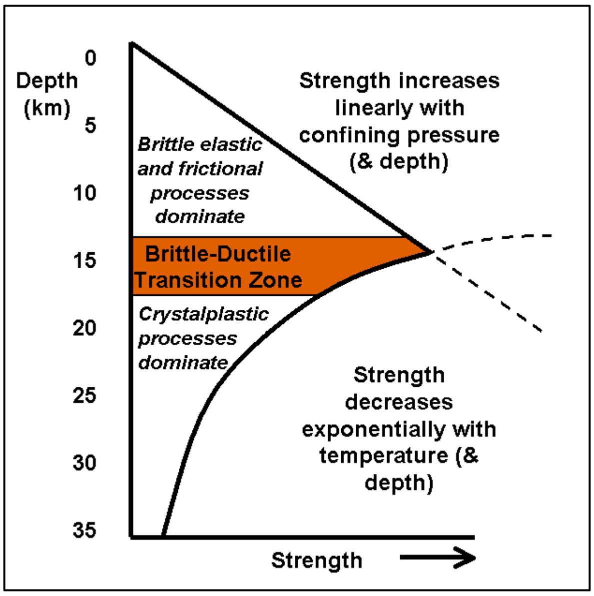
Devonian rock folded by near-horizontal compression, St Annes Head, Pembrokeshire, Wales.

As the rocks were squeezed by pressure from the sides, reducing the width of the area (and so causing crustal shortening) ask them where the squeezed material must have gone. Squeeze a soft ball to give them a clue. The answer is that the squeezed material must have gone up and down.

Squeezed soft ball. (*Chris King*).

Ask how far up they think the material above was squeezed to. Help them to answer this question, by showing the graph modelling how rocks deform under pressure.

The graph shows that when rocks are compressed, the ductile behaviour which results in folding occurs either within or beneath the 'Brittle-Ductile Transition Zone' and so must have occurred at a depth of more than 13 km. This means that there must have been at least 13 km of material above the folded rocks – or that they must have been pushed up into mountains.



A simplified graph of the strength of quartz-rich rock and the type of deformation.

From:https://en.wikipedia.org/wiki/Brittle%E2%80%93ductile_transition_zone

Now you can ask again '*What was it like to be there? – What would the view be like on the ground above where these rocks were being folded?*' They should answer that they would have been on top of a mountain range.

Aerial view of the Mount Everest range.

Finally ask, what would have been going on under their feet as the rocks deep underground were compressed into folds in the roots of the mountains. The answer is that the upper rocks in the crust would not have folded, but would have fractured into faults. Each fault movement would have caused an earthquake. This might have been a '*shivering mountain chain'* with lots of small earthquakes or subjected to very large earthquakes from time to time. As the new mountains were forming, weathering and erosion would have been very active, with frequent landslides and fast-flowing rivers carrying sediment away – a very dynamic environment on top of a mountain-building collision zone.

They would experience 'living tectonism' – being in an environment where plate tectonic collision was forming new mountain chains.

The back up

Title: The view from above: living tectonism

Subtitle: What was it like to be there – on top of a mountain-building collision?

Topic: A thought experiment asking pupils to imagine what it would have been like on top of a mountain range as it was being formed.

Age range of pupils: 8 years upwards

Time needed to complete activity: 10 minutes

Pupil learning outcomes: Pupils can:
- explain how rocks are folded by compressional forces in the roots of mountains;
- explain how this results in crustal shortening;
- describe how the compression must have caused the rocks above and below to have been squeezed up and down respectively;
- describe the likely conditions on top of a newly-forming mountain chain, subjected to earthquakes and extremes of weathering and erosion.

Context:
This activity helps pupils to visualise the intensity of the Earth processes that cause folding and uplift, and of the intense surface processes that are likely to result – on the high exposed surfaces so formed.

Some of the compression in a mountain-building collision is accommodated by:
- reduction in the porosity of the original sedimentary rocks to zero;
- the formation of new denser minerals during metamorphism, for example, kaolinite is a clay mineral typical of sedimentary rocks, with a relative density (RD) of 2.6; biotite, a typical mineral of metamorphic rocks, has an RD of 2.7-3.1, whilst garnet, typical of higher grade metamorphic rocks, has an RD of 3.9-4.2.

However, most of the compression results in the formation of uplifted mountain chains with mountain roots beneath, as the material was forced up and down.

On the graph, rock fracture (e.g. faulting), dominates in the 'brittle, elastic and frictional processes' zone whereas folding occurs in the 'crystalplastic processes' area. Crystalplastic deformation is the main process by which foliation develops in metamorphic rocks. The graph assumes a geothermal gradient (increase of temperature with depth), of 20^{o}C km^{-1}; this is because, although 'normal' geothermal gradients can vary between 15 and 30^{o}C km^{-1}, in plate collision zones where cold rocks are being subducted, low geothermal gradients are normal.

It is important to realise that the mountain chain formed above the folded rocks did not necessarily have an altitude of more than 13 km. The rocks would have been folded deep in the crust, and the mountain chain is unlikely to have been much higher than mountain chains on today's Earth – approaching 9km at Mount Everest. As new mountains are formed, their roots develop at the same time, keeping them in isostatic equilibrium. See the Earthlearningidea, *Isostasy – 1: Modelling the state of "balance" of the Earth's outer layers* for an explanatory activity for this process.

This activity highlights the fact that when you are looking at an exposure of folded rocks, you are standing in the roots of the mountains that once would have loomed high above you.

Following up the activity:
Ask where the rock overlying the folded area must have gone. A thickness of at least 13 km of material must have been eroded and transported away from the area of folded rocks, to have been deposited elsewhere.

Try the '*From folds to crustal shortening: visualising past processes by calculation'* Earthlearningidea to carry out an approximate calculation of how much crustal shortening must have taken place.

Help pupils to visualise what an earthquake actually feels like, by showing them Charles Darwin's account of an earthquake he felt in Chile in 1835:
"The day has been memorable in the annals of Valdivia, for the most severe earthquake experienced by the oldest inhabitant. I happened to be on shore, and was lying down in the wood to rest myself. It came on suddenly, and lasted two minutes; but the time appeared much longer. The rocking of the ground was most sensible. The undulations appeared to my companion and myself to come from due east; whilst others thought they proceeded from south-west; which shows how difficult it is in all cases to perceive the direction of these vibrations. There was no difficulty in standing upright, but the motion made me almost giddy. It was something like the movement of a vessel in a little cross ripple, or still more like that felt by a person skating over thin ice, which bends under the weight of his body.
A bad earthquake at once destroys the oldest associations: the world, the very emblem of all that is solid, has moved beneath our feet like a crust over a fluid; one second of time has conveyed to the mind a strange idea of insecurity, which hours of reflection would never have created. In the forest, as a breeze moves the trees, I only felt the earth tremble, but saw no consequences from it".
Charles Darwin, February 20th 1835, Valdivia, Chile. From: *Voyage of the Beagle*, Penguin Books, 1989: 228.

Underlying principles:
- Rocks are folded by compression, resulting in crustal shortening.
- Large-scale crustal shortening produces mountain chains with roots.
- The newly-forming mountains would be subjected to earthquakes and extremes of weathering and erosion.

Thinking skill development:
Pupils have to construct a picture of mountain-building from visible folding. Cognitive conflict might be caused in considering what happened to the 'missing' materials. Creative imagination is necessary to visualise the conditions on newly-formed mountain chain tops.

Resource list:
- a vivid imagination

Useful links:
Try putting '*mountain-building animation'* into a search engine like Google™, to find animations to help pupils to visualise mountain-building processes.
Try the '*From folds to crustal shortening: visualising past processes by calculation'* Earthlearningidea.

Source:
Devised by Chris King of the Earthlearningidea Team.