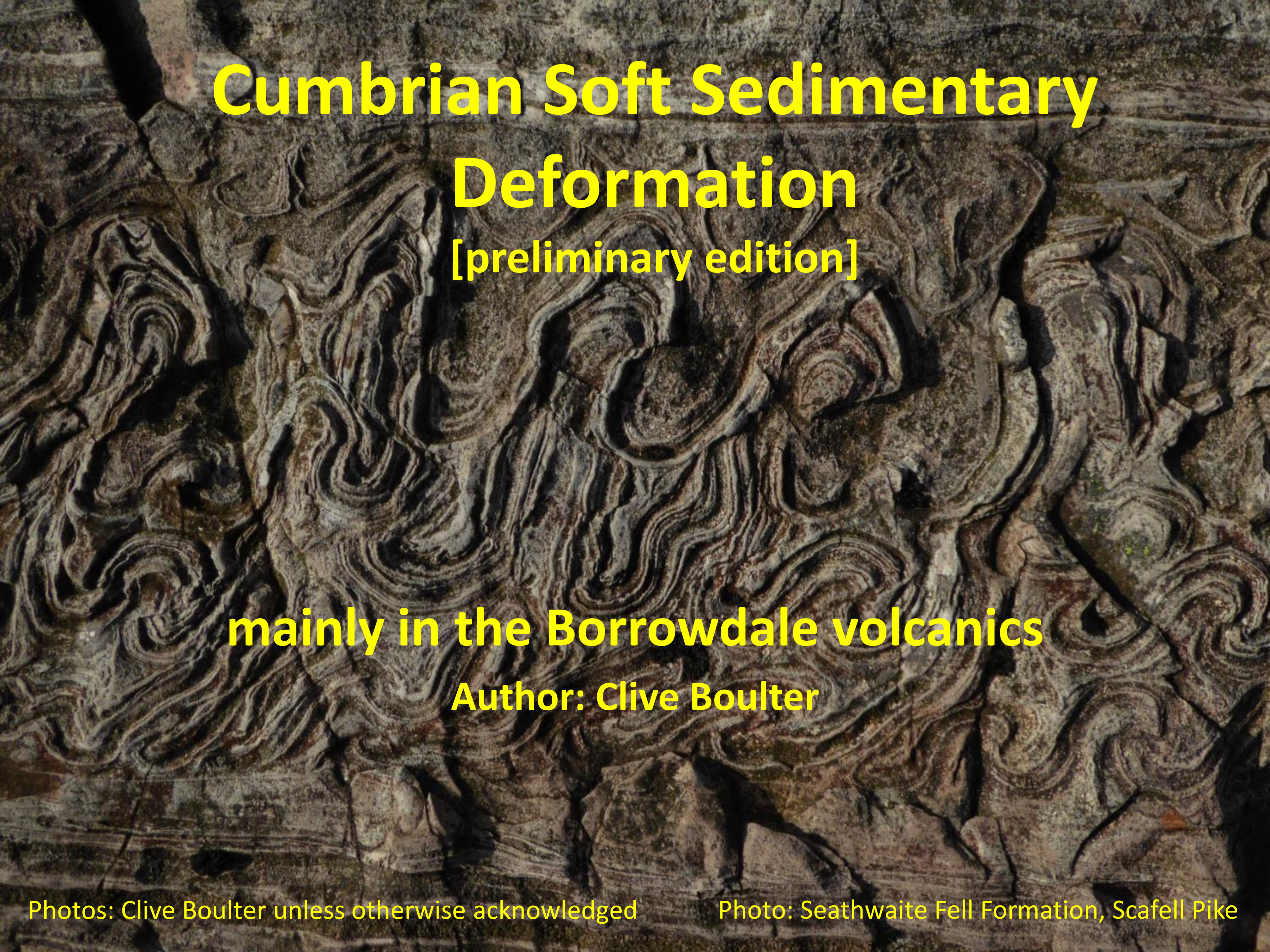
Cumbrian Soft Sedimentary Deformation

[preliminary edition]



mainly in the Borrowdale volcanics

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Photos: Clive Boulter unless otherwise acknowledged

Photo: Seathwaite Fell Formation, Scafell Pike

Soft-sedimentary Deformation.

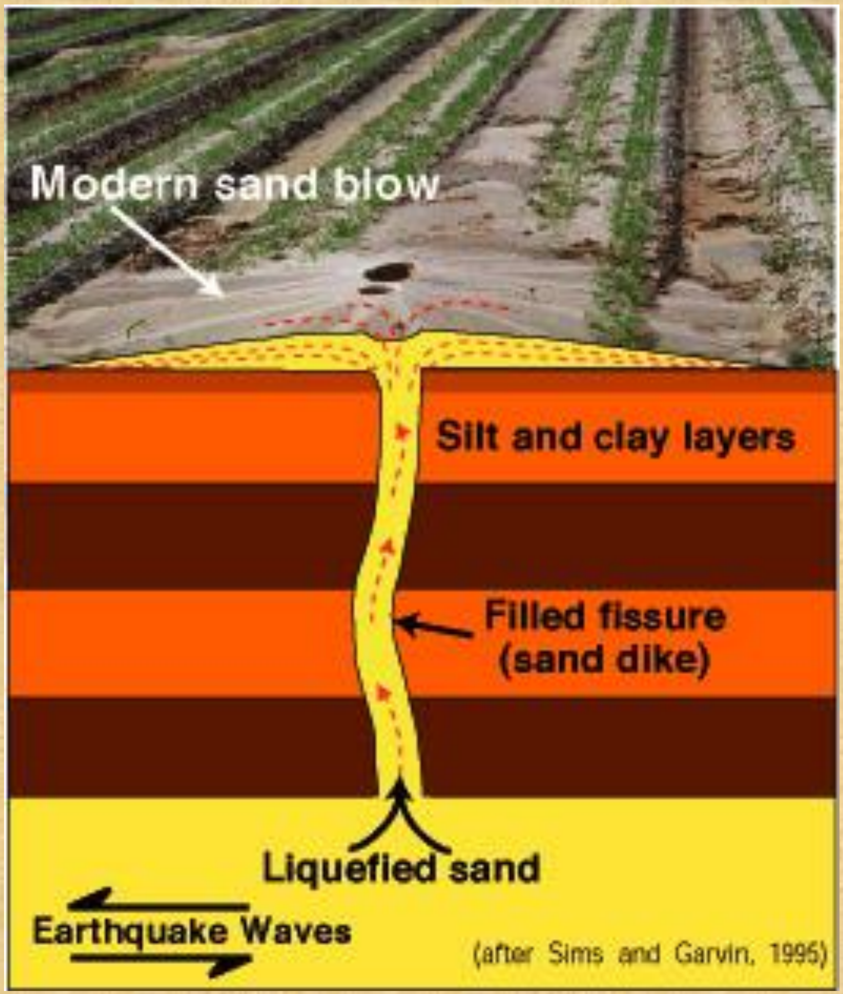
"Christchurch quake, 2011-02-22" by Tim - Christchurch quake, 2011-02-22. Licensed under CC BY-SA 2.0 via Wikimedia Commons http://commons.wikimedia.org/wiki/File:Christchurch_quake,_2011-02-22.jpg#mediaviewer/File:Christchurch_quake,_2011-02-22.jpg

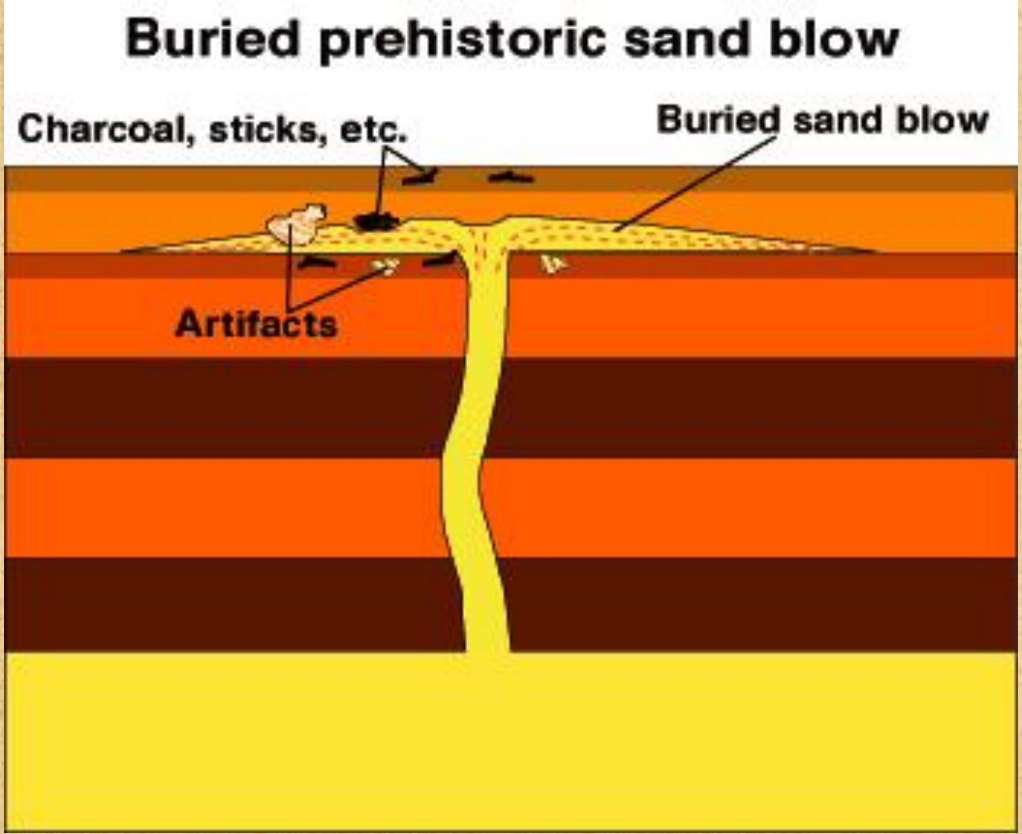
If a sedimentary deposit is disturbed soon after deposition, the structures created during its deposition can be modified in shape. The key to understanding what happens is the fluid between the sedimentary grains. It is also important to appreciate that initially there are no chemical precipitates binding the grains together so they can move independently. Earthquakes, or sediment piled on top of a layer, can increase the pressure on the fluid between the grains until the grains are forced apart, allowing them to become mobile.

In this example pore-fluid pressure exceeded the weight of the grains in the sediment layers resulting in liquefaction; the slurry of pore fluid and grains found [or created] weaknesses in the overlying sediment leading to an eruption of slurry at the surface. The volcano-like forms are very susceptible to erosion and their preservation potential is very low.

http://www.showme.net/~fkeller/quake/liquefaction.htm

Mechanism of Sand Volcano Formation

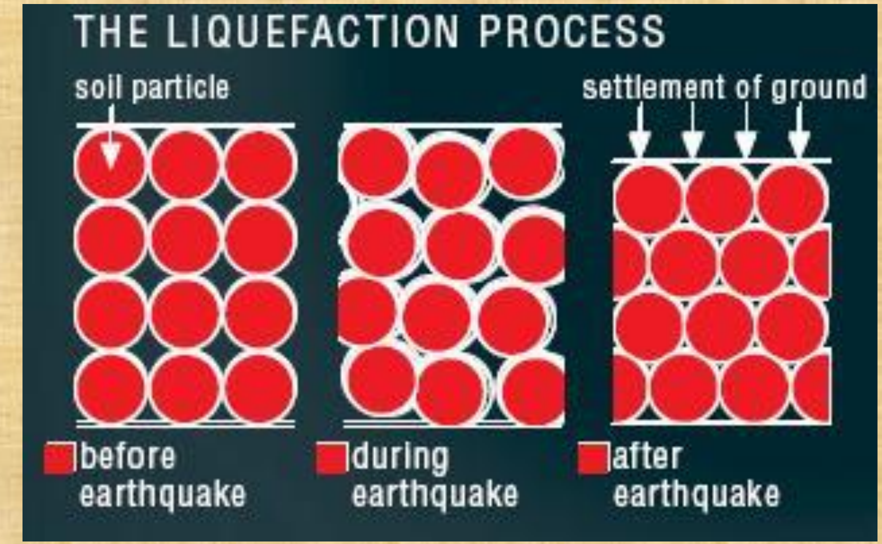


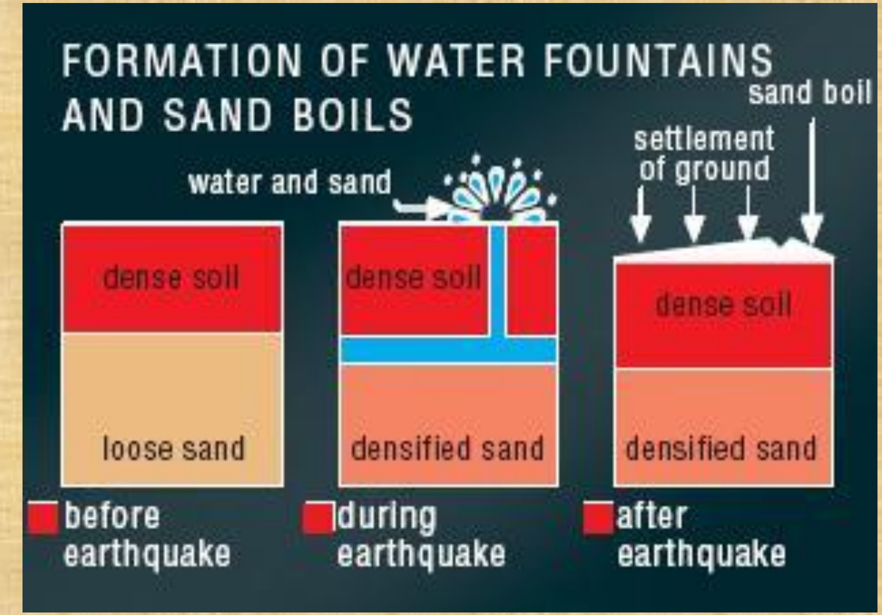


http://pubs.usgs.gov/fs/fs-131-02/fs-131-02-p3.html

Shaken not Stirred:

grain-scale processes during liquefaction.





A tiny sand volcano, about the size of a 20p coin, in the Windermere Supergroup.

http://img.scoop.co.nz/media/pdfs/1009/Ecan_Brochure_Title__The_Q_files___the_solid_facts_on_Christchurch_liquefaction.PDF

SCALE OF SOFT SEDIMENTARY DEFORMATION

Illustrated is a reasonably large example pre-lithification deformation – students for scale. It is an open-cast soft sedimentary fold in Miocene deposits of the Carboneras Basin – a case of very rapid basin filling in a strike-slip releasing bend. At the upper end of the scale range thousands of cubic kilometres of material can be involved in slope failure as happened with the Storegga Slide on the continental margin of Norway about 8,000 tears ago. Here the slide mass has a volume of 3,000 km^3 and covers an area of 95,000 km^2. In the Lake District the upper end of the spectrum is the Buttermere Formation olistostrome which is a 1,500 m thick deposit with blocks up to one kilometre. Folding in this unit has left sections hundreds of metres in vertical extent with inverted beds. The Skiddaw Group chapter gives more details.

Causes of Soft-Sedimentary Deformation

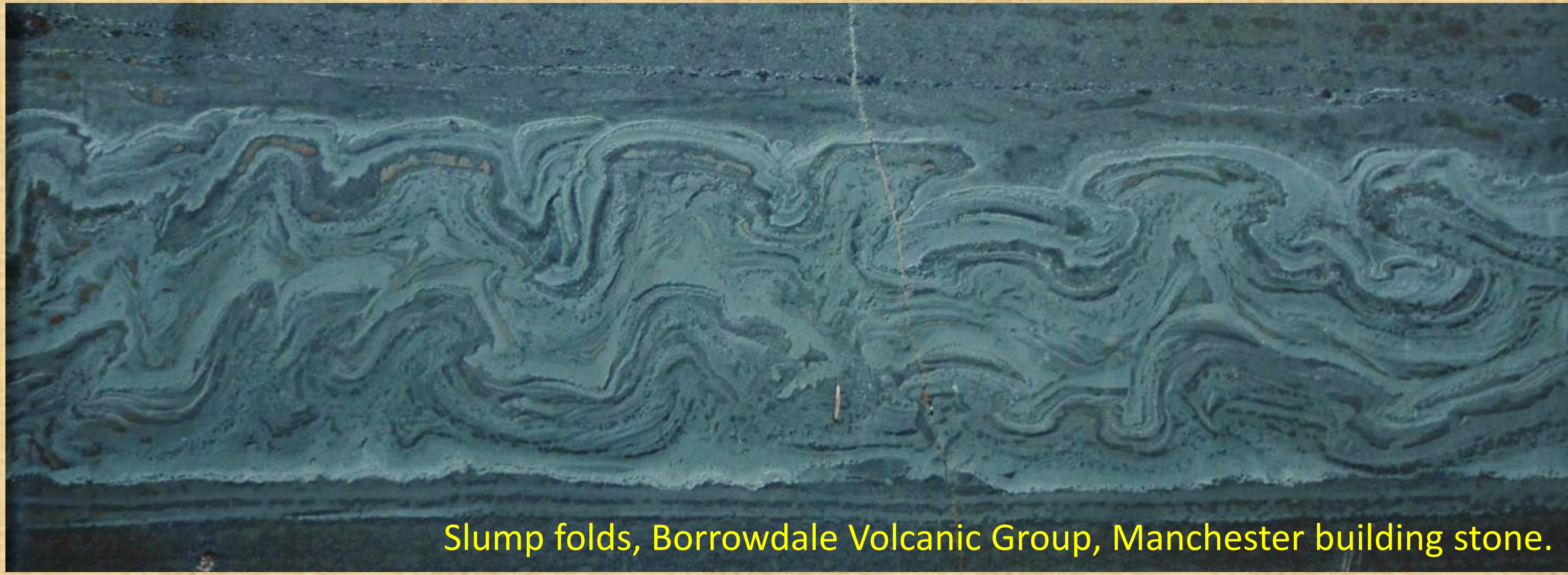
We have a ready mechanism to explain the soft-sedimentary deformation in the Whorneyside Bedded Tuff. Early in the piecemeal collapse of the Scafell Caldera blocks rotated. In doing so slabs of the bedded tuffs slipped independently and at their headwalls created extensional faults [upper photo] whereas the slump toes were in compression creating thrusts [lower photo].

The extensional faults are from Teighton How and the contractional faults are from Stonesty Pike.

Upper photo:
Whorneyside Bedded Tuff, Seathwaite Slabs.

Lower Photo:
Gawthwaite Formation, Gawthwaite Moor.

Another common cause of soft-sedimentary deformation is water escape either immediately after deposition [elutriation channels plus dish & pillar] or at any time before significant lithification has taken place. Convolute lamination is the simplest expression of this process as illustrated here.


Slump folds, Borrowdale Volcanic Group, Manchester building stone.

Soft-sedimentary deformation in the Seathwaite Fell and Tilberthwaite formations cannot be directly related to block rotations during caldera collapse. Multiple mechanisms are candidates to explain the disturbance of these deposits. Perhaps the most common cause was seismicity either triggered by eruptions or magma moving in the subsurface. Syn-depositional faulting also generated seismic activity. Almost as common as a driver of early deformation was loading by subsequent sedimentation events as seen in the Tilberthwaite Formation example on the next slide. Folding is not always a result of compression and soft-sedimentary deformation can bring home this realisation.

Tilberthwaite
Formation
SD 2557 9509

In many cases we are left to speculate about the cause of soft-sedimentary deformation but in this example it was clearly the result of a debris flow many metres thick arriving over the top of this well-bedded sequence. The debris flow eroded down into the previous sediments no doubt aided by its weight fluidising the sub-strata but leaving a trail of angular fragments of the finer-grained materials.

Next is a series of slump folds in the Seathwaite Fell Formation mainly from around Scafell Pike.

Slumped horizon on the upper slopes of Bow Fell [NY 2484 0627] in the Seathwaite Fell Formation [possibly the Bowfell Links Member].

NY 21310 06969


At the summit of Pen is a remarkable exposure of soft-sedimentary deformation firstly shown in overview and then in closeup on the next slide. Seathwaite Fell Formation.

Breccia dyke, Seathwaite Fell Formation, Seathwaite Fell, Borrowdale. Fluidised sediment has burst through the bedded sequence and fractured more coherent materials.

Deformed elutriation channels in a turbidite block in a soft-sediment injectite, Seathwaite Fell, Borrowdale.

St Bees Sandstone, St Bees. Most of the soft-sedimentary deformation in this unit, and there is quite a lot, was caused by vertical or near-vertical water escape. Folds of the style shown above have been produced experimentally by the drag of a water current over a body of sand liquified on a shaking table.

Faulting during soft-sedimentary deformation can in many cases mimic tectonic deformation of lithified sediments and as such is can be a more readily accessible study case. What follows is a series of examples of faults associated with early deformation of the Seathwaite Fell Formation. Both extensional and contractional styles are illustrated.

Upper Photo: Lose slab in a slate quarry in the Kentmere Valley, Tilberthwaite Formation.

Lower photo: Seathwaite Fell Formation, Scafell Pike.

Load & flame structures require that either the lower bed or both beds lose strength by becoming fluidised. Where the flames are consistently overturned [in non-cleaved areas] the deformation was synchronous with deposition and gives the current flow direction.