

# Unsuitability of the Eskdale Granite as a host rock for high- and intermediate-level nuclear waste

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## 1. Introduction

The Eskdale granite crops out east of the Lake District Boundary Fault. Despite never having been considered by the BGS in its national search during the late 1980s, it has now been suggested by Dr. J. Dearman of FWS Consultants Ltd. as a “*potentially suitable repository host rock*” for a nuclear waste repository in West Cumbria [1]. The purpose of this paper is to demonstrate that this suggestion is unfounded, and that this rock mass is unsuitable.

## 2. Footprint required and volume of rock spoil

Before considering the detailed structure of the granite, it is necessary to have an idea of the underground area required for a potential HLW/ILW repository. DECC estimates that around 4 km<sup>2</sup> of subsurface area is required, comprising 1 km<sup>2</sup> for ILW and LLW, plus 3 km<sup>2</sup> for HLW and spent fuel. The department states:

*“The underground area of host rock required (i.e. the 'footprint') for an ILW/LLW disposal facility would be of the order of 1km<sup>2</sup>, and for a HLW and spent fuel disposal facility (assuming that the latter were treated as a waste) would be of the order of 3km<sup>2</sup>. In practice it may be possible to build a geological disposal facility over a smaller area, by building deposition tunnels or vaults on different levels. This would however depend on the geology of the site.”*

This figure does not take account of any new build waste.

The DECC diagram reproduced as Figure 1 shows a schematic repository of 4 km by 1 km.

The Nirex review of the site selection process of the late 1980s [2] states that the size of underground site envisaged then was 400 Ha. This was the criterion used at the third stage of site sieving. But at that epoch only ILW/LLW disposal was envisaged. 400 Ha corresponds to 4 km<sup>2</sup>. The area required for this category of waste seems to have been reduced by a factor of 4.

Some of the maps herein show an outline square of 10 km<sup>2</sup>, to give a notion of the footprint required.

Comparison with well-developed concepts for radioactive waste disposal also suggest that the DECC figure is unrealistically small. For example, the Bure disposal site in NE France will undertake a seismic survey with a subsurface coverage of about 31 km<sup>2</sup> [3], to identify a final repository layout (Fig. 2) of 15 km<sup>2</sup> in area [4].

The volume of rock waste spoil to be removed (and not replaced as backfill) is of the order of 7x10<sup>6</sup> m<sup>3</sup>, assuming that the repository is excavated in ‘higher strength’ rock, the category into which granite obviously falls [5]. As an illustration, this would make a berm 7 m high over 100 Ha (1 sq km), or 35 m high over an area of 20 Ha (e.g. 1000 m by 200 m). This figure excludes the 4x10<sup>6</sup> m<sup>3</sup> of spoil which is to be stored on site for around 50 years, and then used for backfill.

These figures contradict the assurances in the more recent letter [6] from the Nuclear Decommissioning Authority (NDA) to Cumbria County Council (CCC), which states:

### ***“Rock spoil***

*For our reference conceptual design we have assumed that all of the excavated rock spoil could be stored on the surface and then either re-used in construction and backfilling, or for landscaping and site restoration. Under this scenario there would be no requirement to transport rock spoil off-site. Under different scenarios (e.g. different inventories for disposal; different host geologies; different disposal system concepts) then there may be surplus rock spoil to be taken off-site. In such cases it is likely that bulk spoil transport would be by rail.”*

There are three different ‘scenarios’ for a repository: in higher strength rock, in lower strength sedimentary rock, or in evaporites [5]. All result in considerable volumes of spoil. I have quoted the figures above for higher strength rock, appropriate to granite. The letter to CCC is therefore misleading.

The NDA environmental and sustainability report [5] states:

*“For all of the host rock types, surplus excavated rock is assumed to be transported off-site via rail and therefore no significant effects on the road network are anticipated.”*

Presumably then, if a repository in the Eskdale granite were to be excavated, a new railway line would have to be built from Ravenglass, or its vicinity, running into Eskdale. It is difficult to envisage this new railway line being sited anywhere else, due to the mountainous terrain. So unless the line went straight to the drift entry for the underground works, there will be considerable road transport disturbance within the national park.

### **3. Age, shallow structure and relief**

The Eskdale granite is  $450 \pm 3$  Ma, that is, of Ordovician (Caradoc) age. It predates the the regional cleavage, which is early Devonian (Acadian) in age; the dating and field relationships of the Skiddaw and Shap granites indicate that these bodies are broadly synchronous with this tectonic event. These latter granites are dated at around 390-399 Ma. Overall, the various Lake District granites make up the buried Lake District batholith (Fig. 3, from ref. 7), but the individual granites are distinct.

The crucial point is that the Eskdale granite pre-dates the Acadian orogeny. It has therefore been fractured and faulted, unlike, for example the Shap granite (Fig. 3). Figure 4 shows a geological cross-section [8] running north-south through southern West Cumbria, to show the present-day configuration (top) compared to the restored (reconstructed) geological cross-section (bottom) inferred for mid-Silurian time, that is, after the intrusion of the granite, but before the orogeny.

Figure 5 shows a detail of the BGS solid geology map in the vicinity of Ravenglass and Eskdale, 1:50,000 scale (the printed versions are Sheet 37 *Gosforth* and Sheet 38 *Ambleside*, both Solid edition). This and other BGS geology map extracts shown herein come from the BGS online version of the 1:50,000 series of maps, and are © NERC. The map extract has been chosen so that the area of granite displayed is about 10 km<sup>2</sup>.

The more regional solid geology map of Figure 6, showing all the granite outcrop, gives a misleading impression of homogeneity and simplicity. In fact the exposure of the granite is very poor, as is shown by the superficial geology map of Figure 7. On average about 80% of the granite outcrop is hidden. This means that many more small faults, fractures and dykes will be present than are depicted on the solid geology version. However, it is clear that the granite is heavily faulted, unlike most other granites in the UK.

On Figure 7 I have labelled three main blocks of granite between major faults east of the Lake District Boundary Fault (LDBF) A, B and C. The northern block A has about 50% granite exposure, the central block B about 30%, and the large southern block C only about 10%. These relative

exposures of solid rock (or, inversely, the coverage of superficial deposits) correlate with the topography - the steeper the topography, the better exposed is the granite. The topography in shaded relief form underlies the geology map in Figure 8, in which it can be seen that block A to the north of Eskdale has the steepest relief, and block C the most gentle.

Note also the extent of mapped faults cutting the folded volcanics and sediments east of the Eskdale granite in Figure 5, indicated by the dotted ellipse. The same density of faulting is expected to be present within the pink areas to the west, marked as Eskdale granite, but cannot be mapped due to the combination of poor exposure and the homogeneity of the rock type. In other words, it is the varieties of rock layering that make it possible to identify the faults by geological field-mapping within the area of the ellipse in Figure 6.

The present day topographic relief of the Eskdale granite is considerable. Figure 8 shows the shaded relief with the solid geology map draped over. Spot heights are indicated. Eskdale has probably been gouged out by glacial action along the major Eskdale Fault.

The Eskdale granite is not a simple homogeneous volume. It includes six sub-types, of which the principal two are granite and granodiorite [9]. Its deeper structure near the western margin adjacent to the LDBF has been mapped by the BGS using Nirex seismic reflection data and other geophysical methods. The deeper structure is a 'cedar tree' interfingering [10], or laccolith, of leaves of granite alternating with country rock (Figs. 9, 10). There are also rafts of country rock within the main granite body. The vertical scale of this layering is of the order of 200-500 m, and the lenses and shapes are 1-3 km in horizontal extent. Incidentally, this exceptional wealth of data, very rare over granitic outcrops, is an illustration of how well West Cumbria is understood geologically, thanks largely to the Nirex-funded research of the 1980s and 1990s.

In conclusion, the Eskdale granite, being pre-orogeny (mountain-building), will be as heavily faulted as the more easily mapped areas of sediments to the east, i.e. it will be cut up by significant faults and fractures at a spacing of a few hundred metres. Vertically, it is interfingered with country rock (the pre-existing metamorphic rocks which the granite has penetrated). This is not a suitable environment for finding homogeneous unfaulted volumes of rock.

#### **4. Mineralisation and heat flow**

Veins of haematite are common in the Eskdale granite. They frequently occupy large faults of NNW-SSE trends (Fig. 11). Indeed, the haematite mineralisation was important enough for a railway to have been constructed in Eskdale in the nineteenth century to carry ore from the mines to Ravenglass. Despite its former importance, and continued existence of mineralization deeper than past mining, the presence of this economic deposit has not led to the area being screened out [11].

Comparison of the southern granodiorite block of granite on Figure 11 with the superficial geology map of Figure 7 shows that the reason for the apparent relative lack of documented faulting and mineralisation here (block C in Figure 7) is evidently due to the lack of solid rock exposure.

The age of the haematite mineralisation is mid to late Triassic (248-225 Ma), with multiple superficial modifications by subsequent flow events including the present day. But the important point is that this implies multiple water flow events through geological time, and a consistent history of *oxidising groundwater*. The Borrowdale Volcanic Group (BVG) host rock at Longlands Farm exhibited the same problem, which is fundamental for the safety case. Nirex undertook detailed investigation of fracture minerals in their site investigation boreholes, and these records show that haematite or calcite, deposited from oxidising groundwater, coats practically all fracture surfaces within 1 km of the present land surface [12]. This means that this part of the UK holds a record of unusually and persistently oxidising groundwaters – the opposite of what is needed for long term retention of uranium wastes.

Oxidising groundwater implies high uranium solubility. The BGS memoir on the Ambleside district [9] discusses anomalously high uranium concentrations within stream sediments over the outcrop of the Eskdale granite, despite the fact that the granite has an unusually low uranium content compared to other granites of northern England. Since no uranium mineralisation source has been discovered, the BGS concludes that “*scavenging of this element is still considered the most likely explanation for these relatively high values*” [9]. In other words, present-day oxidising groundwater is leaching out uranium from the granite.

The BGS screening report [11] has not properly considered the possibility of geothermal energy resources in West Cumbria, with reference to the Eskdale granite. It states (Table 3), on the exclusion criterion of low grade heat extraction from deep rocks:

“*Not an a priori general exclusion - value for development is currently speculative*”

and concludes that such resources are not to be considered further in the screening report. But this granite is regarded as a geothermal heat prospect, so should be excluded as a future resource on that basis [13]. The granite is within one of the three principal granitic batholiths of the UK having exceptionally high heat flow values [14].

## **5. Stress regime**

A variety of different types of data show that West Cumbria is under a compressional stress regime [15], with the maximum principal stress horizontal, aligned NNW-SSE, and the minimum principal compressive stress also horizontal (below 150-200 m) and aligned at right-angles to the maximum [16]. At shallower depths the minimum principal compressive stress is vertical.

An analysis of primary tension joints in the NE part of the Eskdale granite confirms this stress orientation [17]. Joints of this orientation (Fig. 12) will open easily under the current stress regime.

## **6. Comparisons with other UK granites**

Since ‘granite’ is being considered as a suitable host rock, let us briefly examine some other granites, by way of comparison with Eskdale.

Firstly, the Western and Eastern Red Hills granites of the Isle of Skye have excellent exposure – probably 95%. The solid geology and the solid plus superficial geology maps are shown in Figures 13 and 14, respectively. The Northern Granite of the Isle of Arran is similarly depicted in Figures 15 and 16. In this example the exposure of the granite is probably about 70%.

The maps of Skye and Arran are shown at the same scale as the corresponding pair of maps for Eskdale (Figs. 6 and 7). The Skye and Arran granites are ‘normal’ examples, in that there is *not a single fault* mapped within these granite volumes. Either of these bodies would in principle make a promising host repository rock, if the topography were subdued in the region (which it is not).

In contrast, the Eskdale granite is abnormal in its large intensity of faulting and fracturing. As stated above, the actual intensity of faulting is probably much greater than mapped, because the great extent of superficial cover greatly limits the opportunity for observations.

The buried Weardale granite is the largest component of the North Pennine batholith, emplaced at around 399 Ma. It is nowhere exposed at outcrop. It has been tested by the Rookhope borehole and two Eastgate boreholes (Fig. 17). In the Eastgate no. 1 borehole, which was drilled to investigate the granite as a source of geothermal energy, a zone of extremely high permeability was found within the granite. It is probably related to an ancient sub-vertical hydrothermal vein [18]. Permeability was three orders of magnitude greater than the value for normal granite. Based on this surprising

discovery, the authors caution against assuming ‘conventional’ values for fluid transmissivity in granite-type rocks in the context of nuclear waste disposal, stating:

*“As similar veins ... and similar buried weathered zones are probably widespread in many ancient granitic terrains, it would be imprudent to summarily dismiss the Eastgate findings as unique. Indeed, given the general lack of other motivations to drill to such depths in granites, the lack of prior records of such high transmissivity might well be an artefact of low sample density. Discretion therefore favours the amendment of risk assessment protocols for possible future radionuclide migration in granitic terrains ... to take account of far higher upper-bound estimates of fracture transmissivity at depth than have hitherto been considered.”*

A recent discussion by Dr F.W. Smith, and presentation of more detailed investigations, suggests that the permeable flowing fractures are a consequence of the present-day stress field [19]. Dr. Smith is a colleague of Dr. Dearlove in FWS Consultants Ltd.

However, in West Cumbria there is no evidence that the granitic batholith was actually unroofed (and therefore weathered) in late Palaeozoic or Triassic time, even though it may have been buried by as little as 500 m of BVG.

## **7. Comparisons with Sweden and Finland**

Any attempt to compare a granitic hard rock site in West Cumbria, such as the Eskdale granite, with any of the sites already investigated and/or selected in Sweden and Finland is misleading. Firstly and most importantly, the hydraulic head in West Cumbria will be about 20 times higher than in Scandinavia, where the sites studied all come into the category of ‘hard rock in low relief terrain’.

Relief maps showing the extreme contrast in topography are illustrated in the slideshow which I put on my website in November 2010 and communicated to MRWS:Cumbria, *Geology: Why the whole of West Cumbria is unsuitable for a nuclear waste repository* [20].

Secondly, the Scandinavian rocks are not ‘granite’ as such, but ancient supracrustal highly metamorphosed sediments termed *gneiss*, which has a bulk geochemical composition termed ‘granitic’, but is otherwise rather different.

Thirdly, it is worth mentioning that the preferred Swedish site at Forsmark may have trouble satisfying the safety criteria, because of the fractured nature of the rocks and the upward-directed groundwater flow at the coast. Furthermore, the Swedish 'SKB-3V' multi-barrier concept (copper flasks encased in bentonite clay), is proving less secure than anticipated on account of potentially rapid copper corrosion. The NDA wishes to apply this concept in the UK, but it will not work anywhere in West Cumbria, because it relies absolutely on the groundwater being reducing, not oxidising.

## **8. Conclusions**

There are many reasons which jointly and severally rule out the Eskdale granite from consideration as a potential host rock. In summary, these are:

- Extreme relief and hence high hydraulic gradient.
- It was never previously considered by BGS – so why now?
- The granite is prospective as a geothermal heat resource – so should be excluded.
- There is a complex geometry, interfingering structure of granite and country rock.
- It is extensively faulted and fractured, in contrast to ‘normal’ granite bodies.
- There is strong evidence for oxidising groundwater flow, both in the past and today.
- It lies in proximity to a major fault zone, the LDBF.

- The contemporary stress regime is unfavourable.
- There exists the possibility of ultra-high-permeability zones.
- Comparisons with ‘granite’ host rocks of Sweden and Finland are invalid.

In addition, there appear to be grave uncertainties, inconsistencies and underestimates concerning:

- The footprint of the repository.
- The amount of spoil to be dealt with.
- The transport system for removal of the spoil.

In conclusion, the Eskdale granite is unsuitable for consideration as a host rock for a deep HLW/ILW waste repository.

### References

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- [3] Andra 2011a. *Map of 3D seismic acquisition at Bure*. <http://www.andra.fr/download/andra-meuse-fr/document/actualites/dplasmg10-0001b.pdf>
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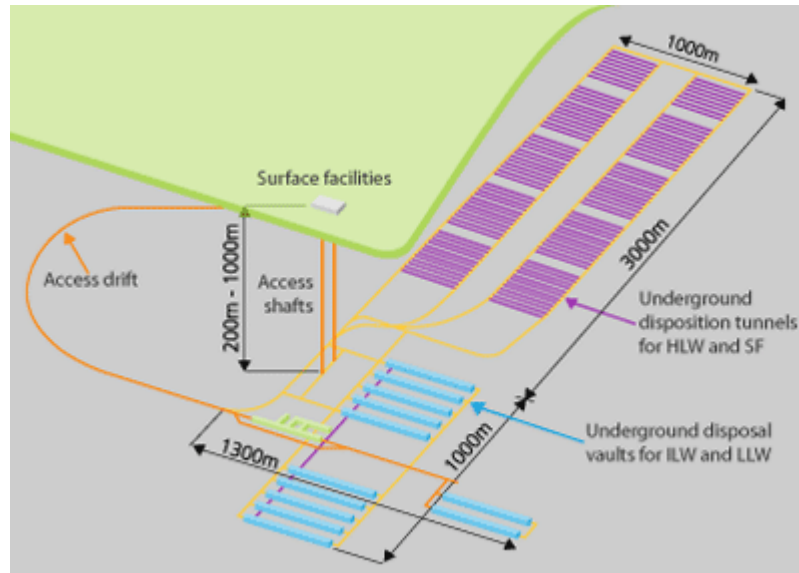


Fig. 1. DECC diagram illustrating indicative dimensions of a waste repository

The “*underground area of host rock required (i.e. the 'footprint') for an ILW/LLW disposal facility would be of the order of 1 km<sup>2</sup>, and for a HLW and spent fuel disposal facility (assuming that the latter were treated as a waste) would be of the order of 3 km<sup>2</sup>. In practice it may be possible to build a geological disposal facility over a smaller area, by building deposition tunnels or vaults on different levels. This would however depend on the geology of the site.*”

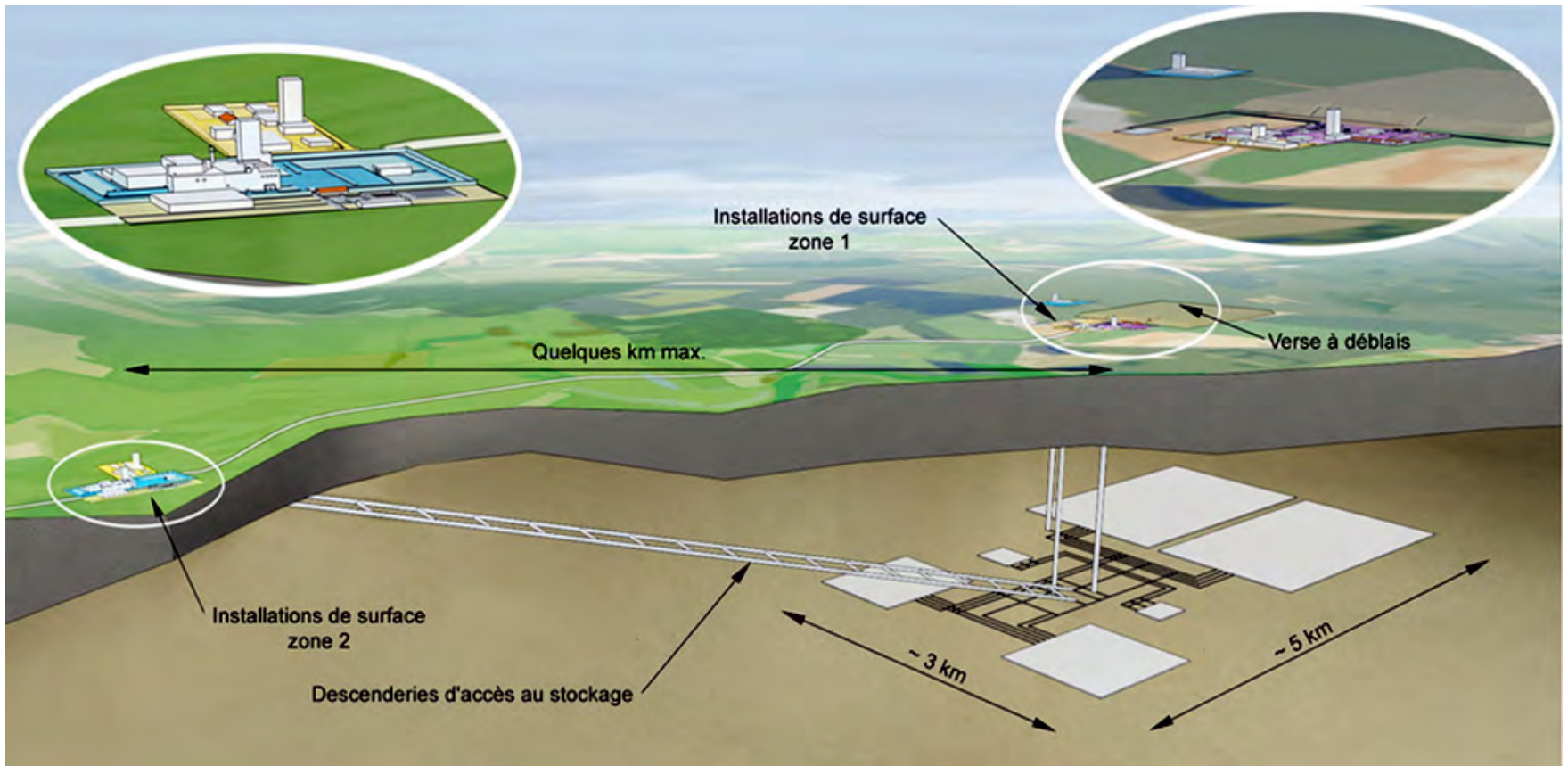


Fig. 2. Diagram from Andra, the French agency for nuclear waste disposal, illustrating the dimensions envisaged for their waste repository in clay at Bure. Note that the underground area of around 15 km<sup>2</sup> is about four times as large as DECC envisages for UK waste (Fig. 1 above).

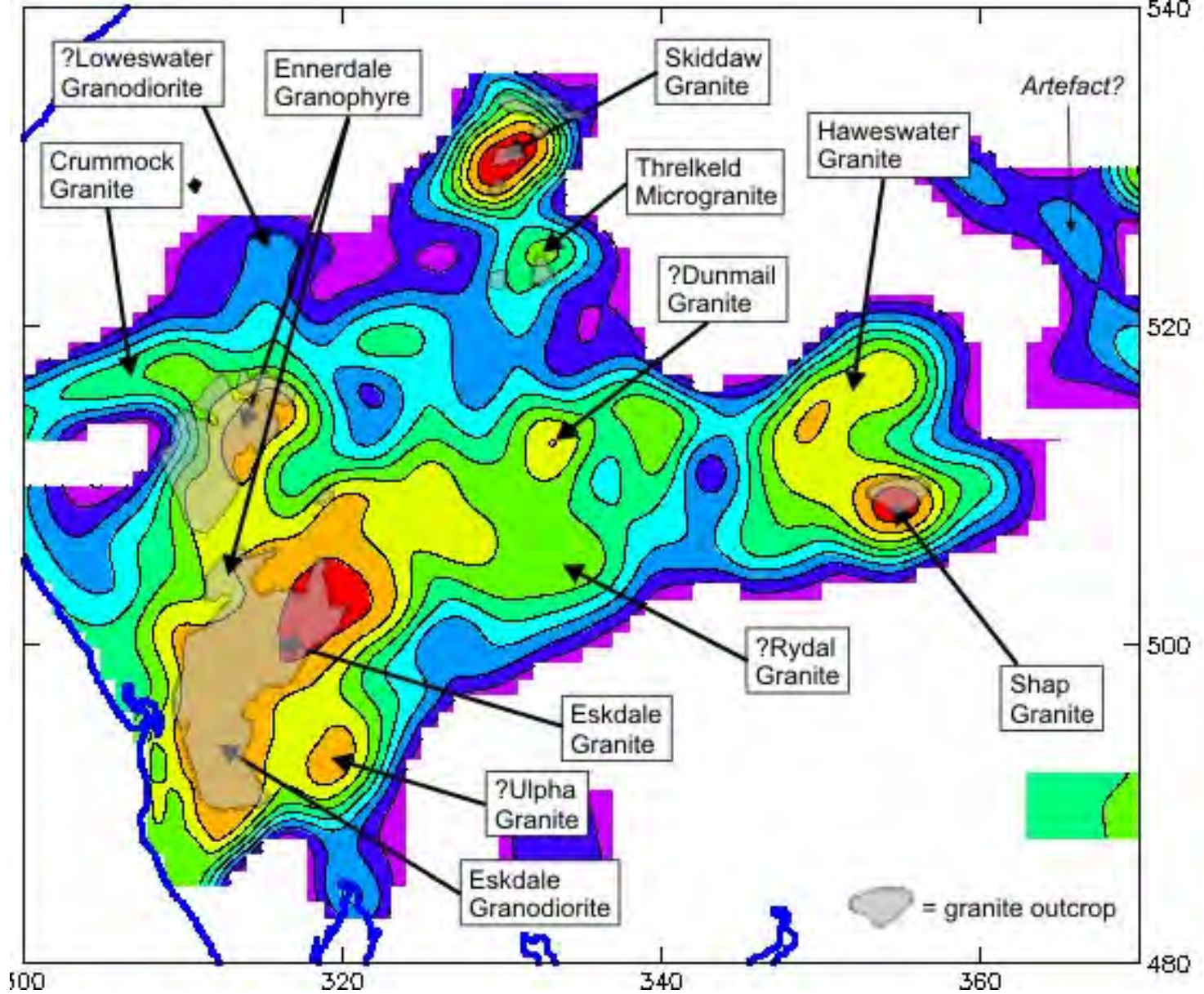


Fig. 3. Lake District: modelled depth of top of granite (relative to OD). From ref. 7.

Fig. 4. North-south cross section of the geology of West Cumbria:

- (a) Present-day  
(b) Before the Acadian orogeny

The Eskdale granite is shown in pink.

From ref. 8.

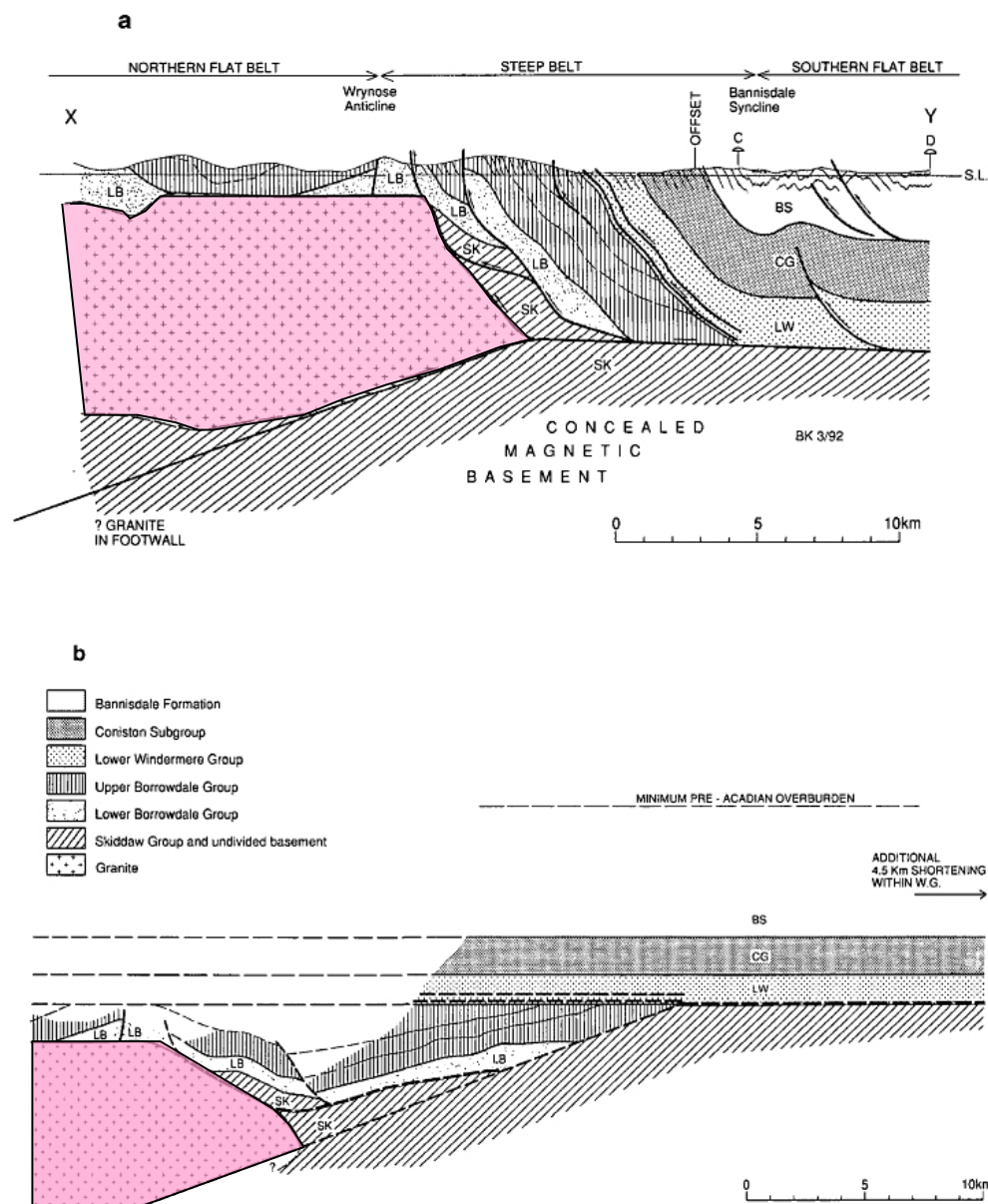
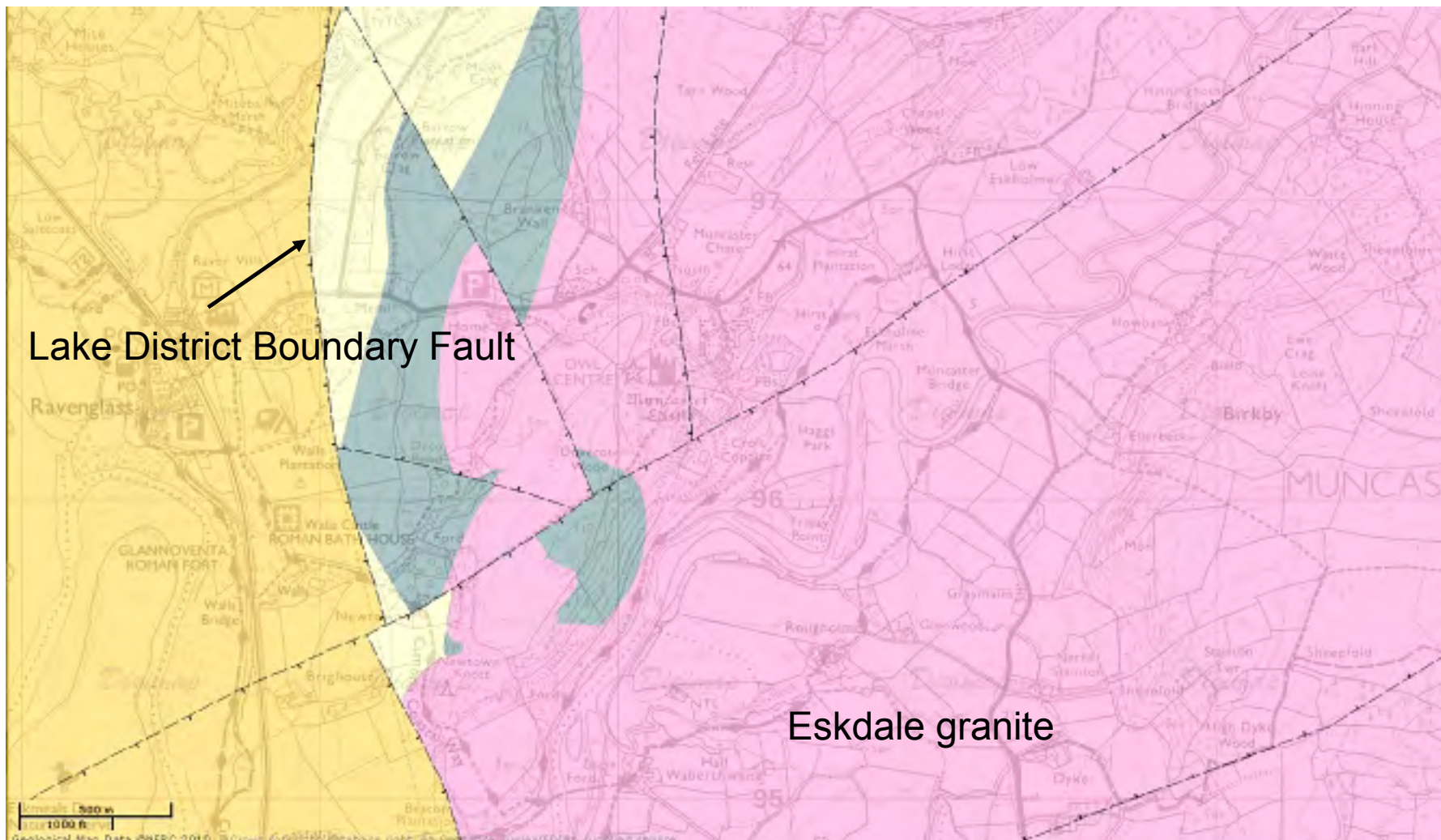


Figure 4. (a) Deep cross-section along the line shown on Figure 3. (b) Restored section. See text for discussion of construction and details of restoration. Upper Borrowdale Volcanic Group includes the Whorneyside Formation and above. Lower Windermere Group includes dominantly fine-grained late Caradoc (Longvillian) to early Ludlow (lower *nilssoni* zone). The Coniston Subgroup is a sand-dominated turbidite unit of late *nilssoni* to *scanicus* age. The Bannisdale Formation is a mudstone/siltstone-dominated turbidite unit, of late Ludlow age (late *scanicus* to *leintwardinensis* zone). Horizontal and vertical scales are the same.



Lake District Boundary Fault

Eskdale granite

Fig. 5. Detail of the BGS solid geology map (1:50,000 scale) showing the outcrop of the Eskdale granite (pink). Faults are marked by dashed lines, with the tick-mark on the downthrow side.

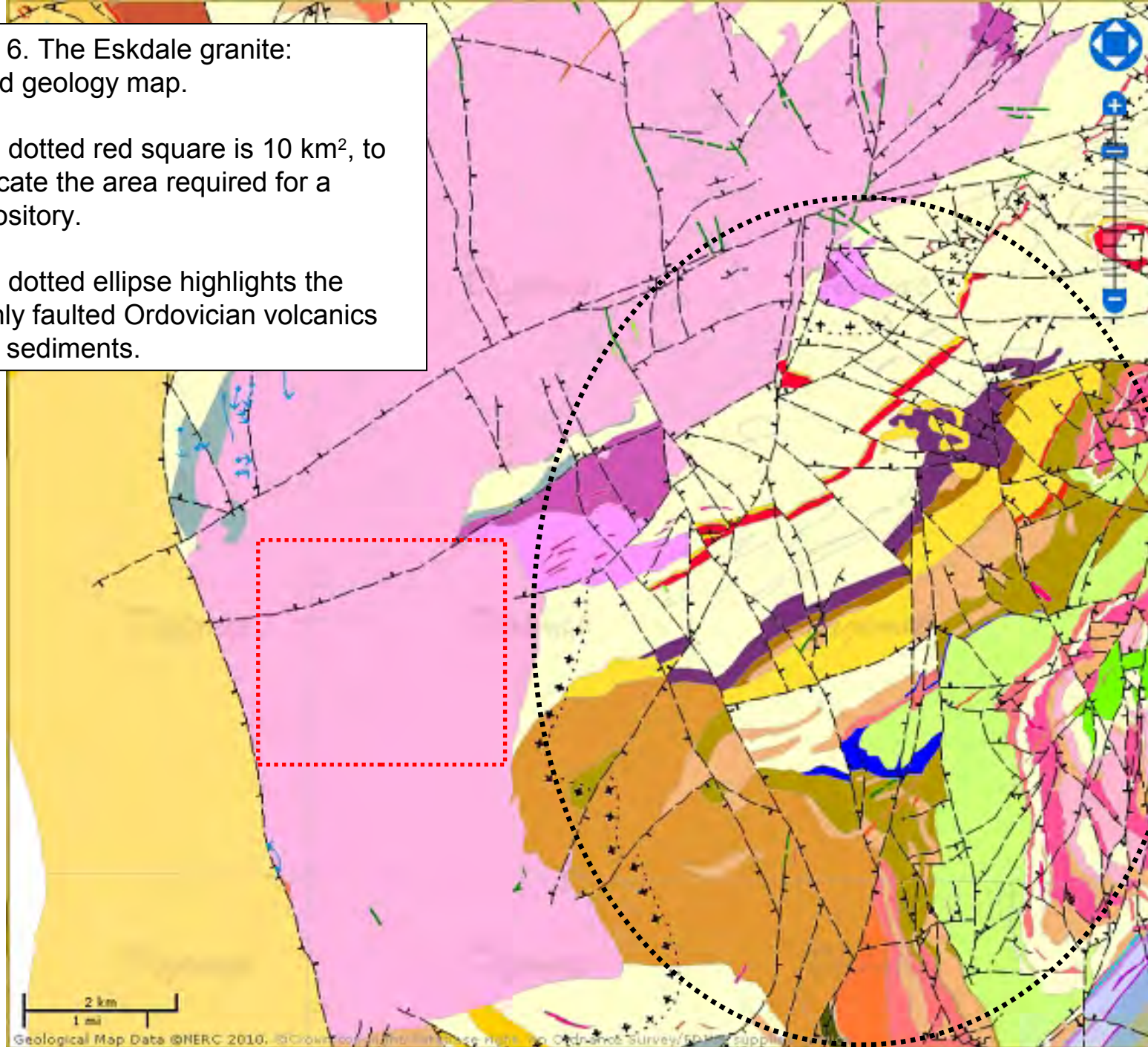
‘Solid’ geology means the rocks that are seen at the surface or inferred below the superficial deposits.

The area of granite shown here is 10 km<sup>2</sup>, the subsurface area required for a repository.

Fig. 6. The Eskdale granite:  
Solid geology map.

The dotted red square is 10 km<sup>2</sup>, to  
indicate the area required for a  
repository.

The dotted ellipse highlights the  
highly faulted Ordovician volcanics  
and sediments.



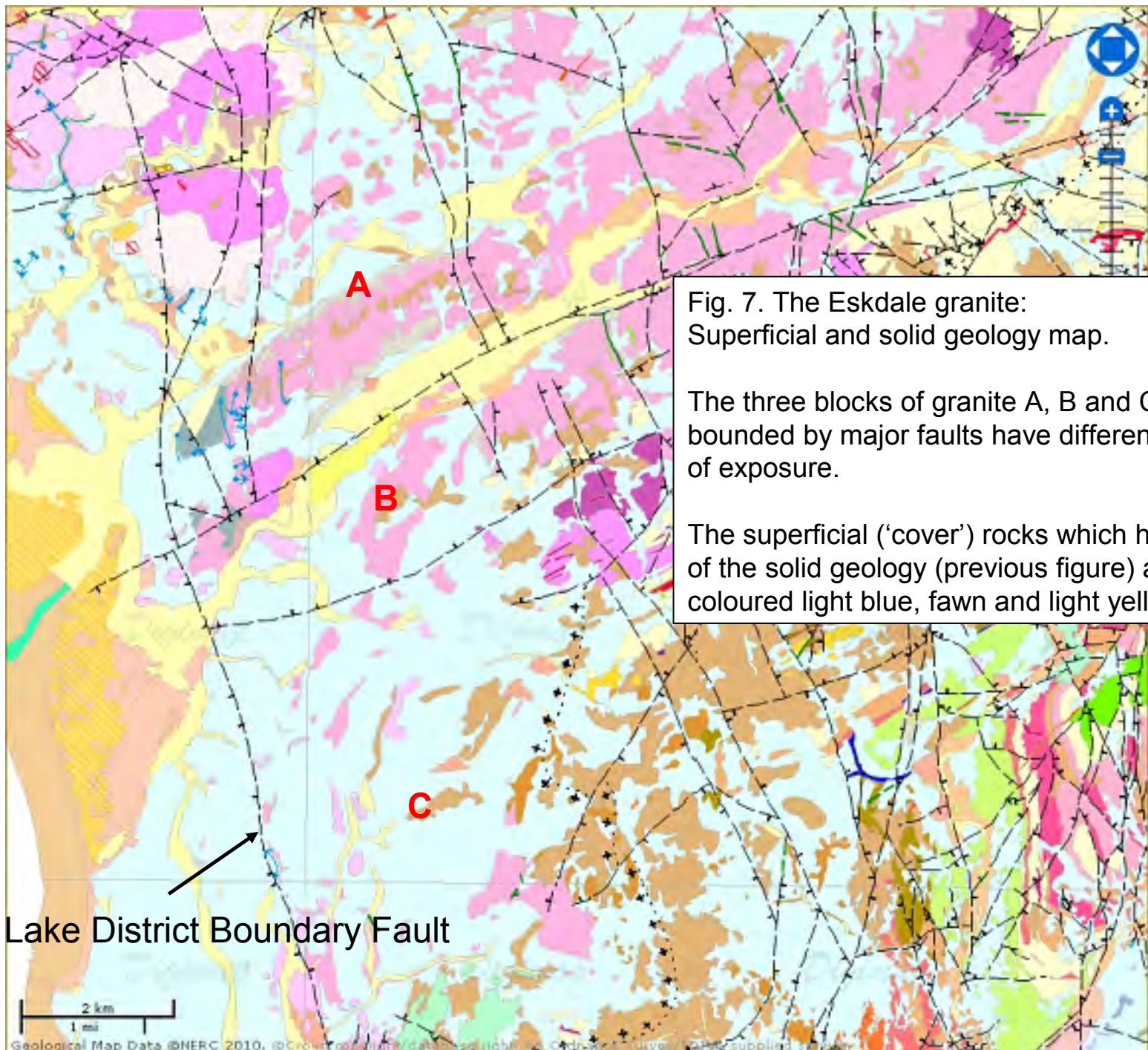


Fig. 7. The Eskdale granite:  
Superficial and solid geology map.

The three blocks of granite A, B and C, bounded by major faults have different degrees of exposure.

The superficial ('cover') rocks which hide most of the solid geology (previous figure) are coloured light blue, fawn and light yellow.

Lake District Boundary Fault

2 km  
1 mi

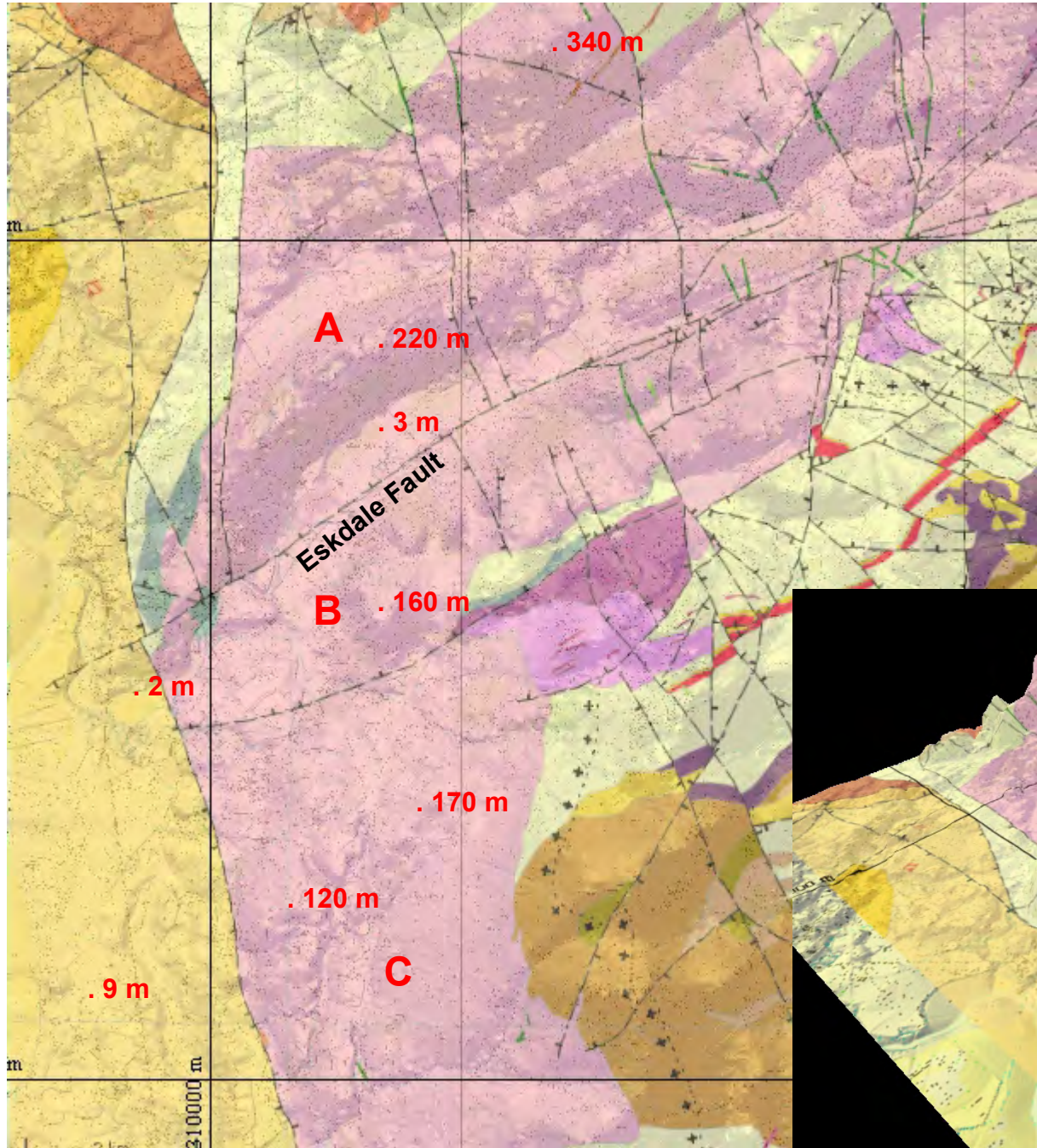
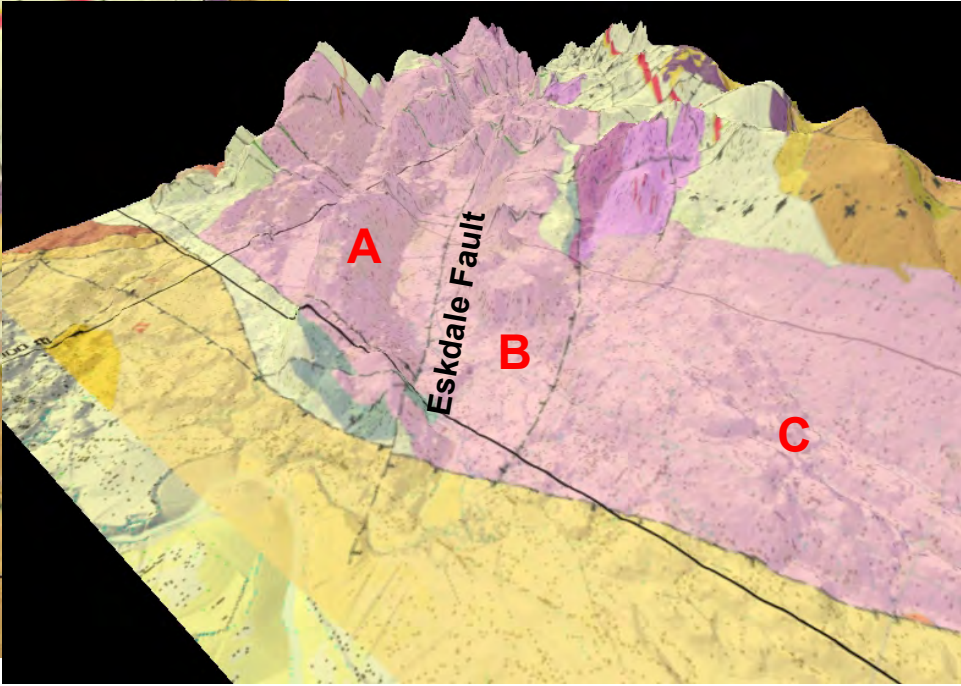


Fig. 8. Shaded relief of the Eskdale granite (solid geology), with spot heights in meters.

Inset: 3D view looking NE.



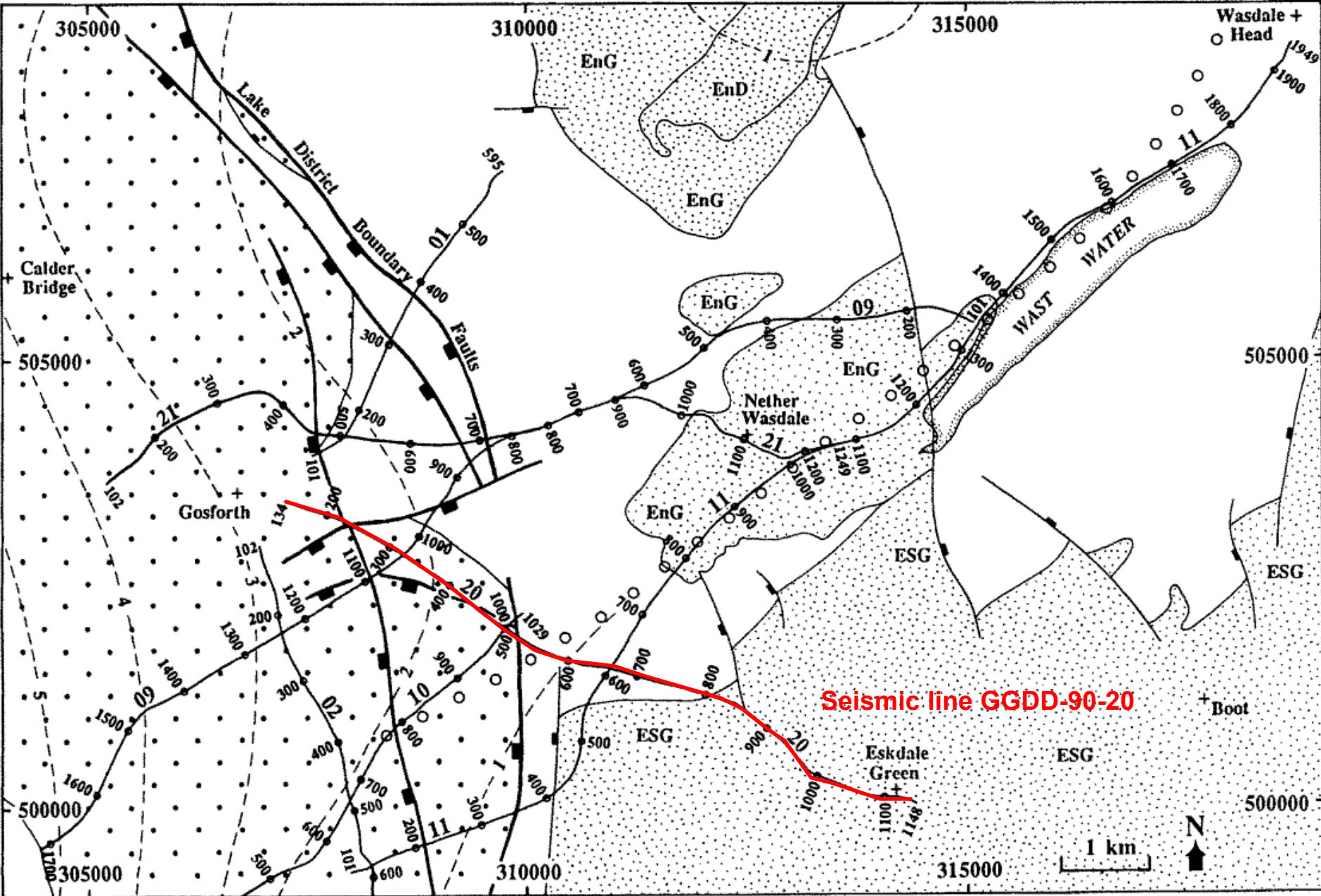


Fig. 9. Location of seismic reflection line GGDD-90-20 shown in the next figure.

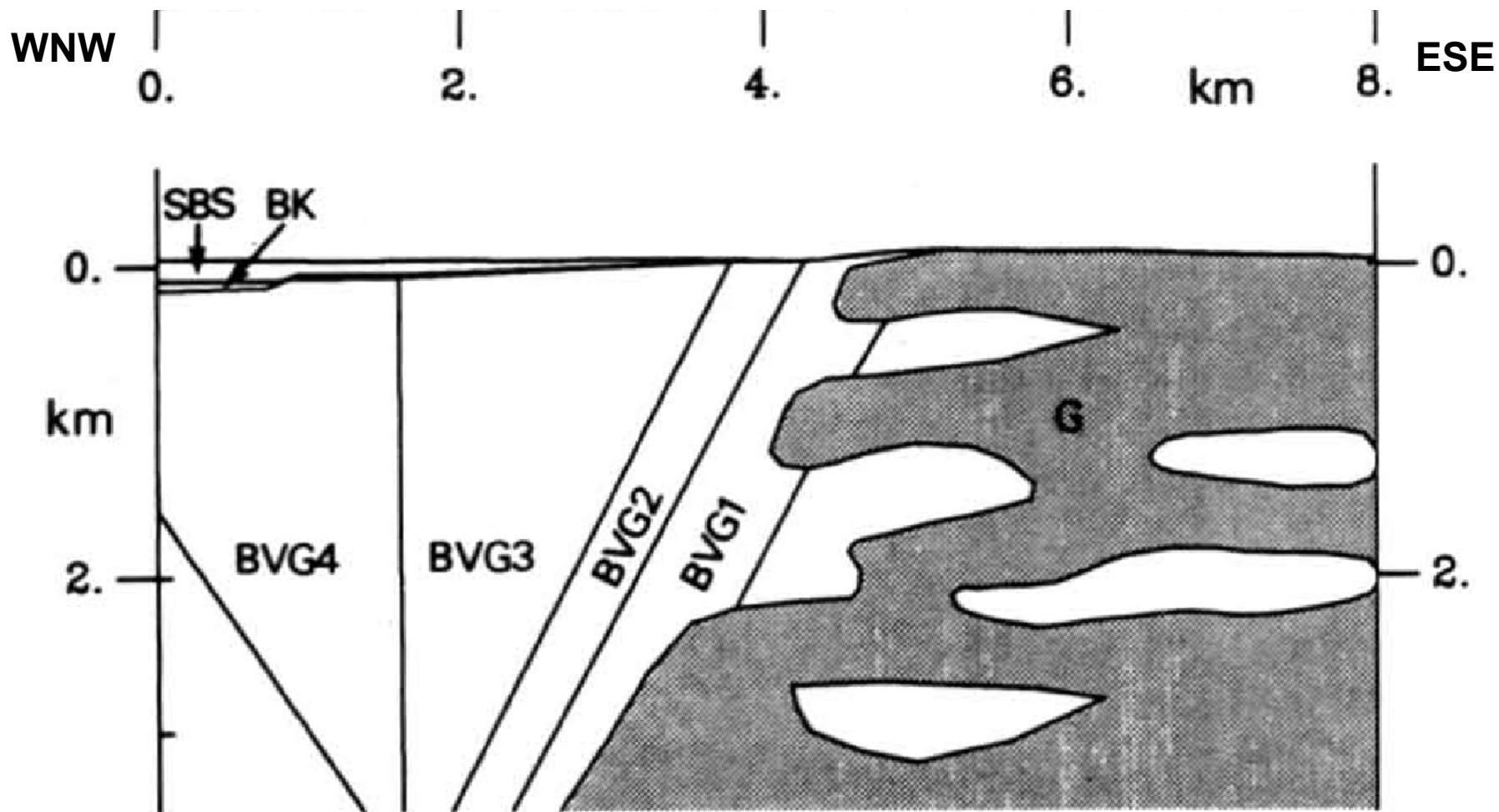
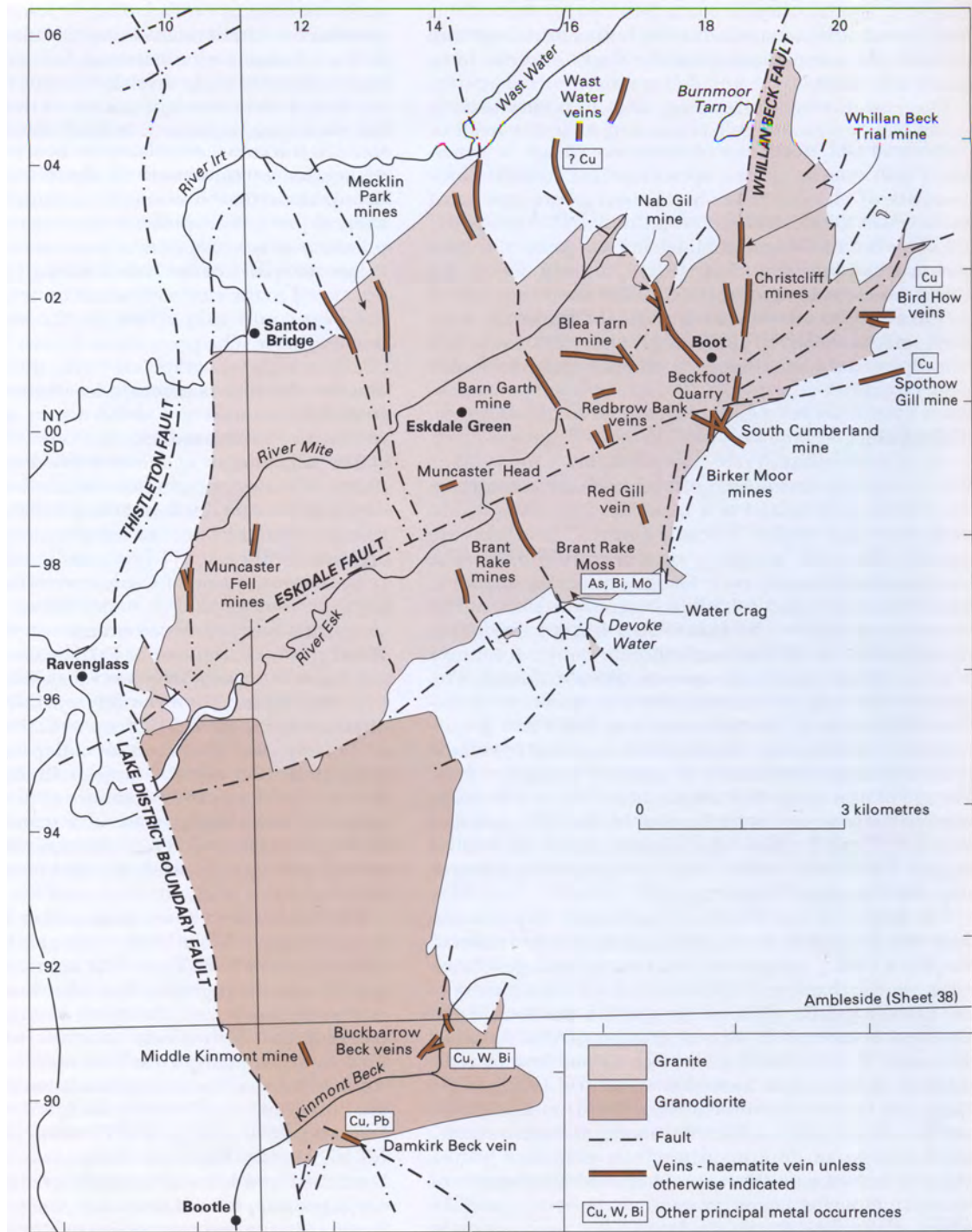


Fig. 10. Interpreted cross-section from Evans *et al.* 1994, fig. 14, along seismic line GDGG-90-20, showing the preferred model of the western edge of the Eskdale granite (G, shaded). BVG1-4 are Borrowdale Volcanic Group volumes with slightly different densities.

Fig. 11. Haematite veins of the Eskdale granite (BGS memoir, *Geology of the Ambleside District*, fig. 66).



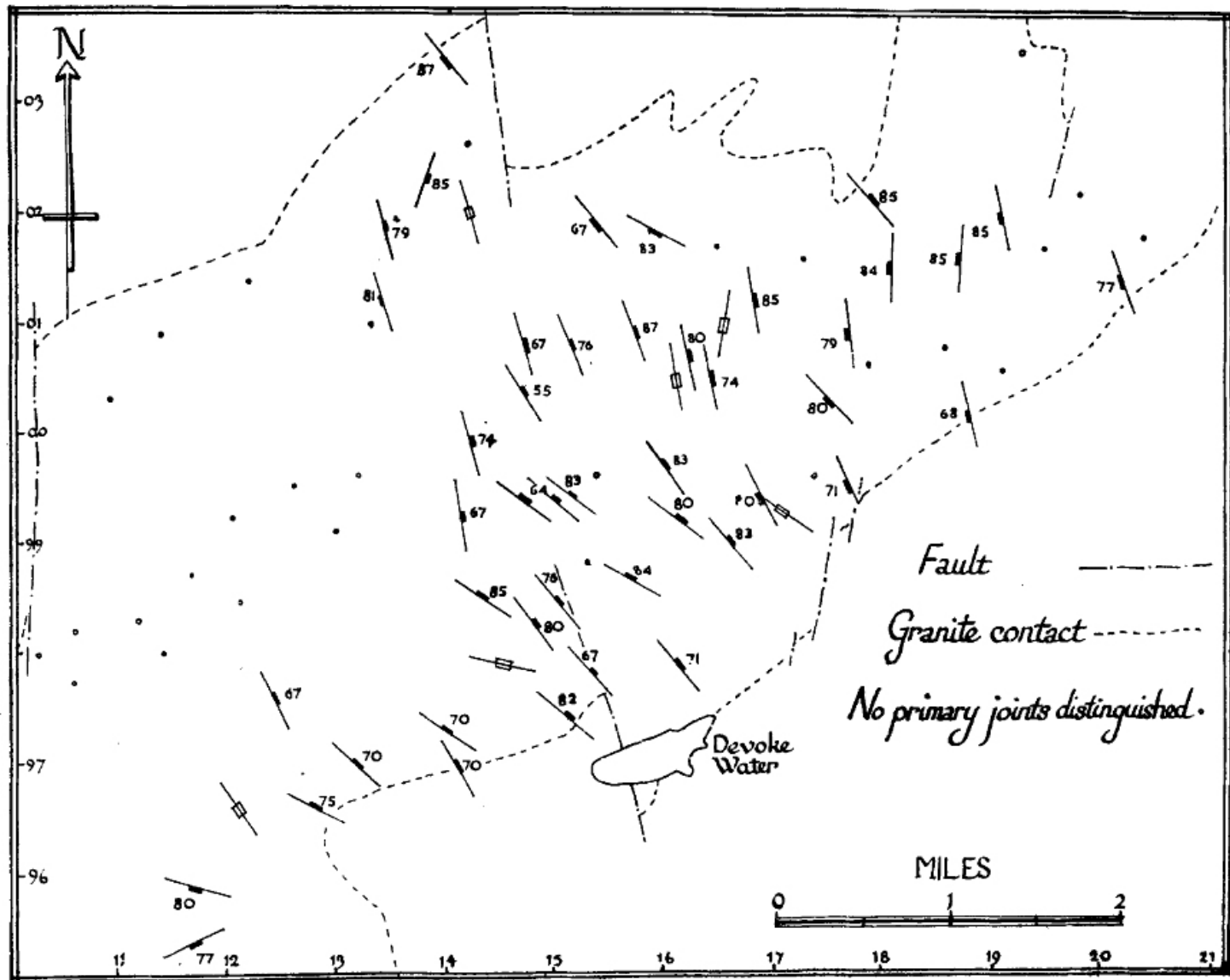


FIG. 3.—Possible primary granite joints.

Fig. 12. Primary tension joints mapped over the NE part of the Eskdale granite (Firman 1960).

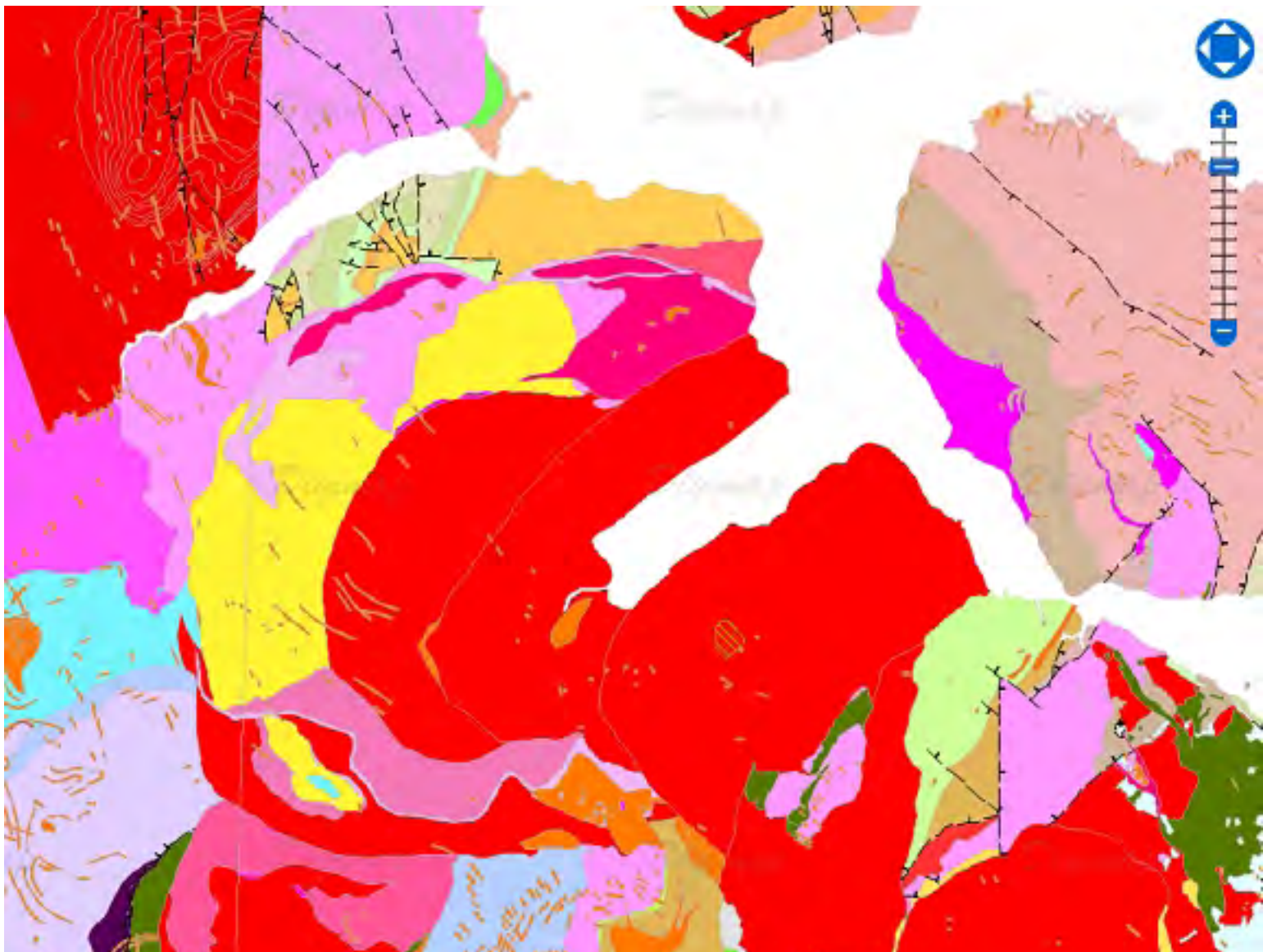


Fig. 13. The Red Hills granites of Skye: Solid geology map. The granites are shown in red. Note the complete lack of faulting of the granites.





Fig. 14. The Red Hills granites of Skye: Superficial and solid geology map. Comparison with the previous figure shows that only about 5% of the granite outcrop is hidden beneath superficial deposits

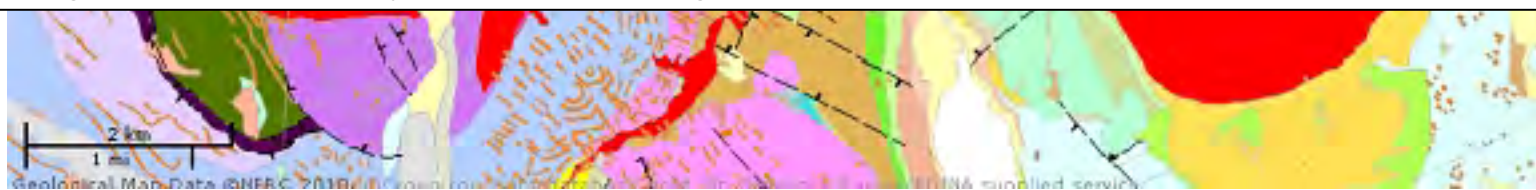


Fig. 15. The northern granite of Arran: Solid geology map.

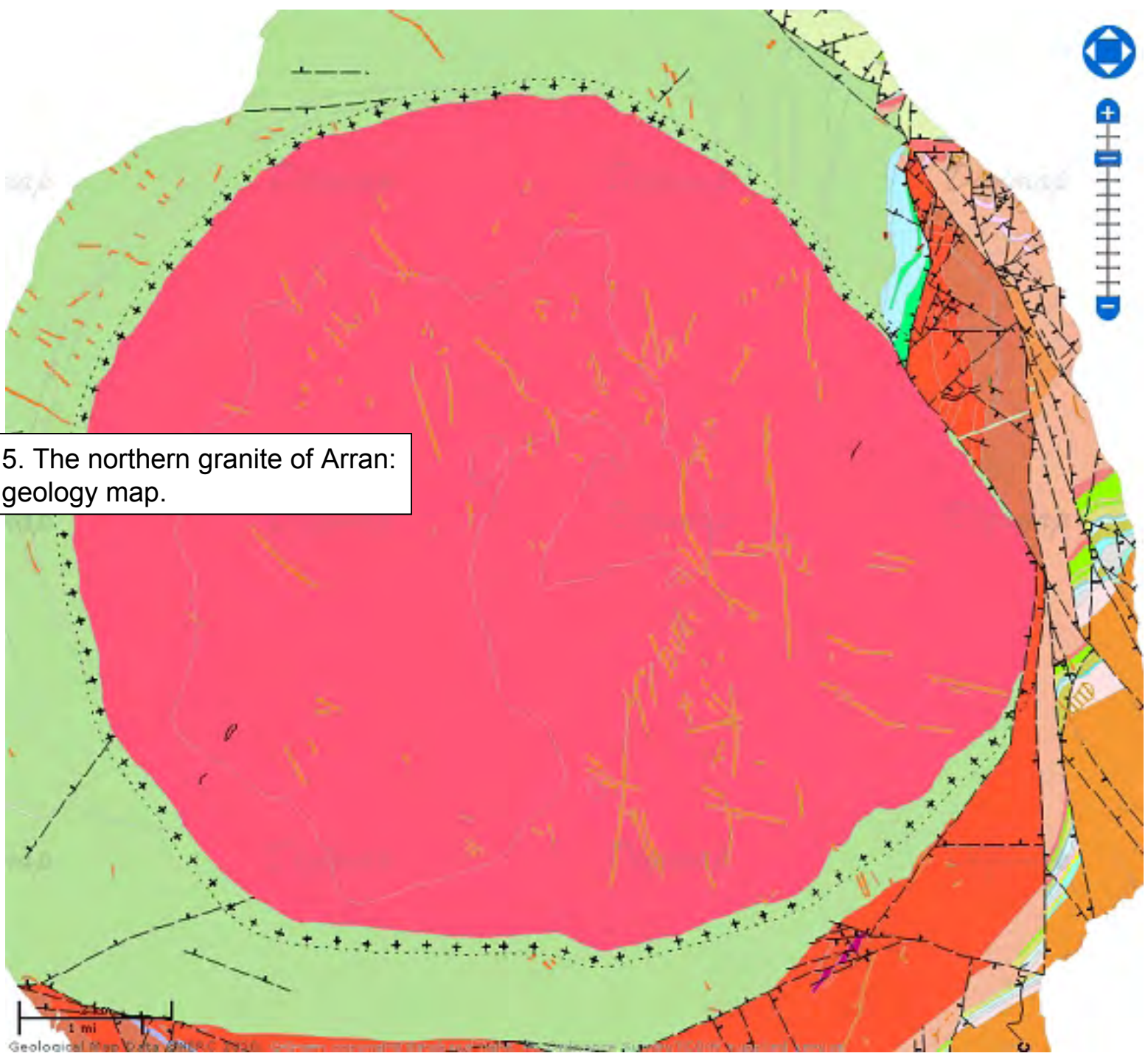
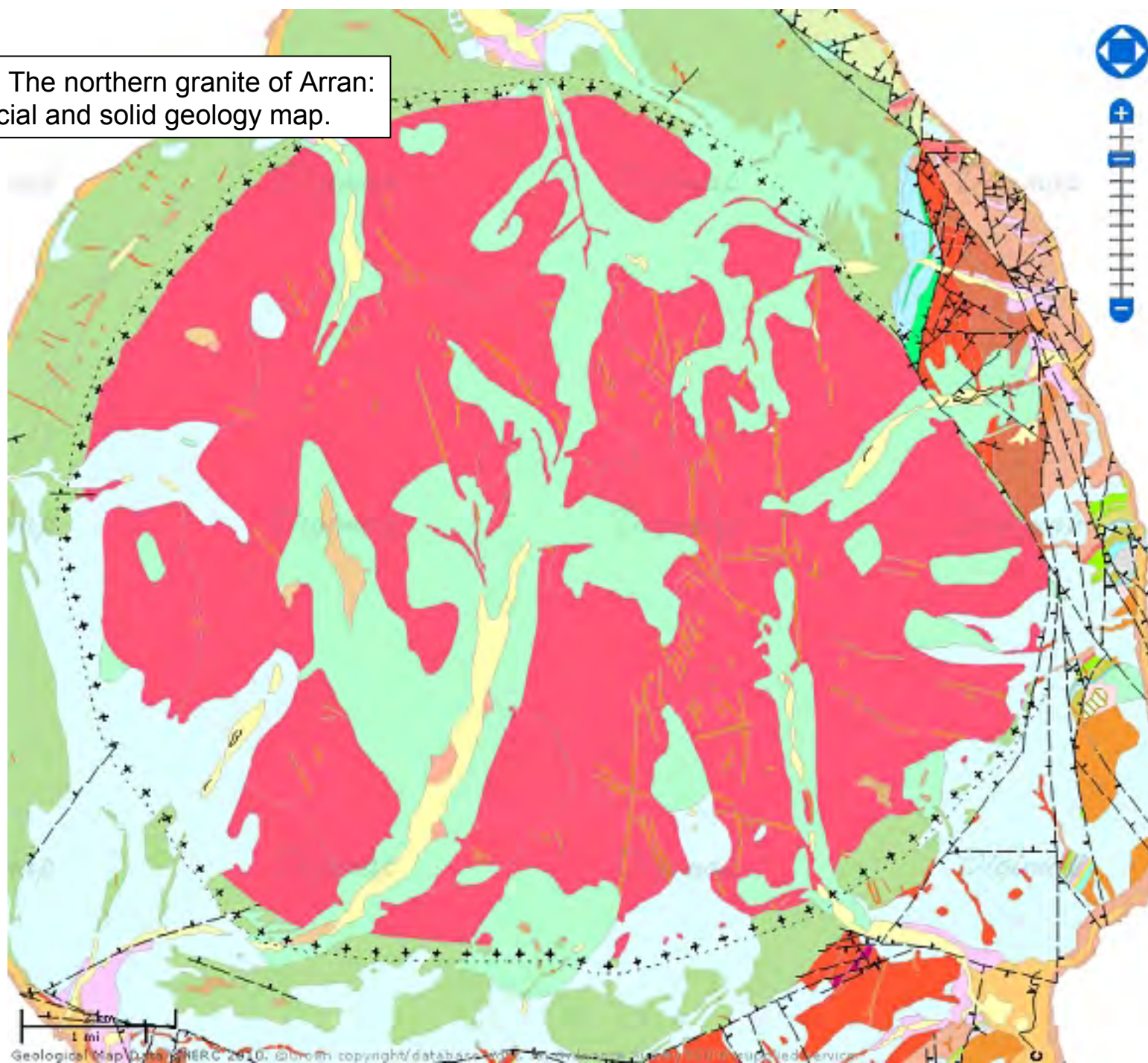


Fig. 16. The northern granite of Arran: Superficial and solid geology map.



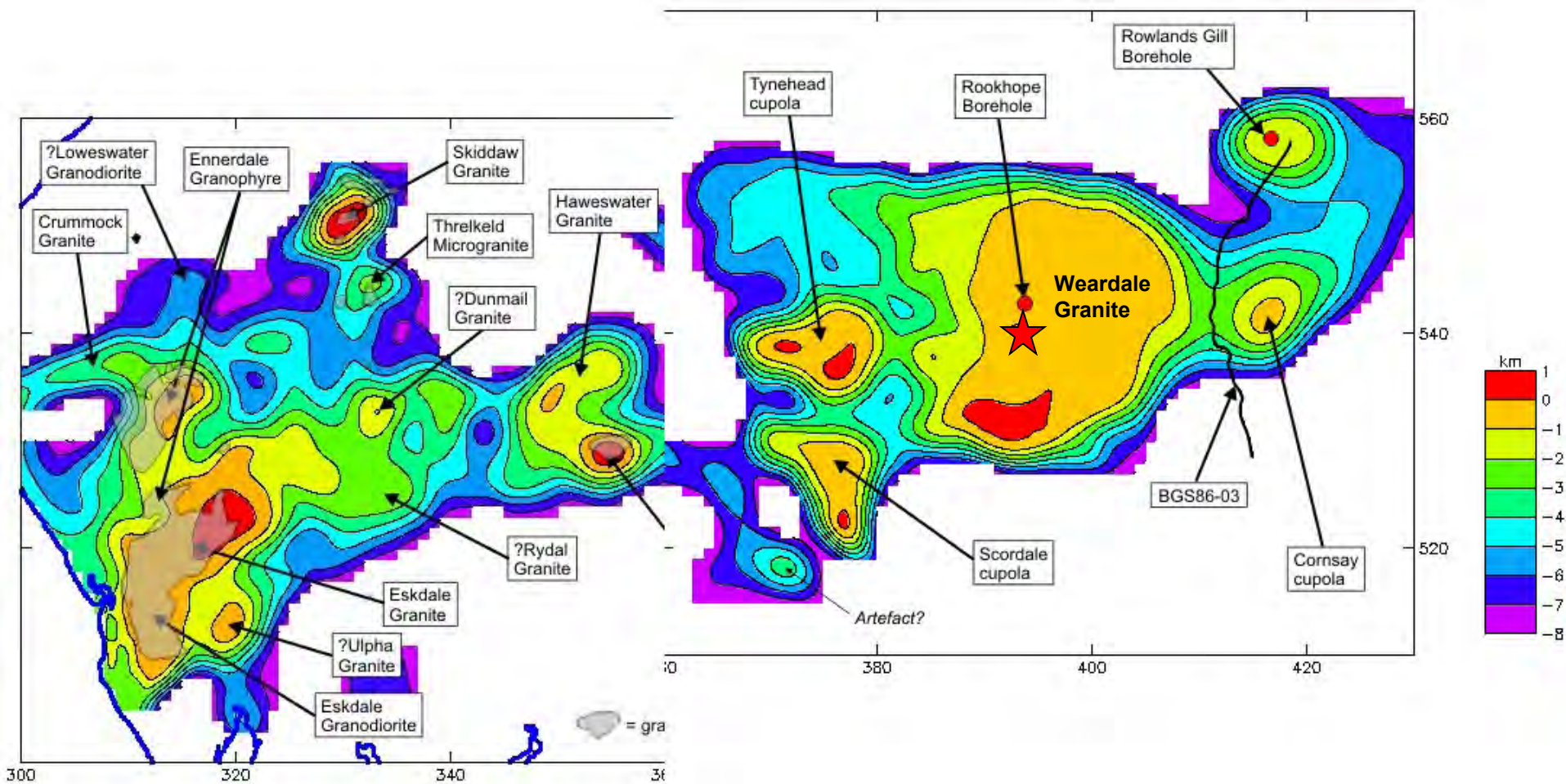


Fig. 17. Contour map of depths to the top of the Lake District and North Pennine granitic batholiths [7]. The star indicates the location of the Eastgate no. 1 borehole, which encountered a sub-vertical fracture zone of ultra-high permeability within the Weardale granite.