The Ennerdale granite: Implications of a nuclear waste repository development

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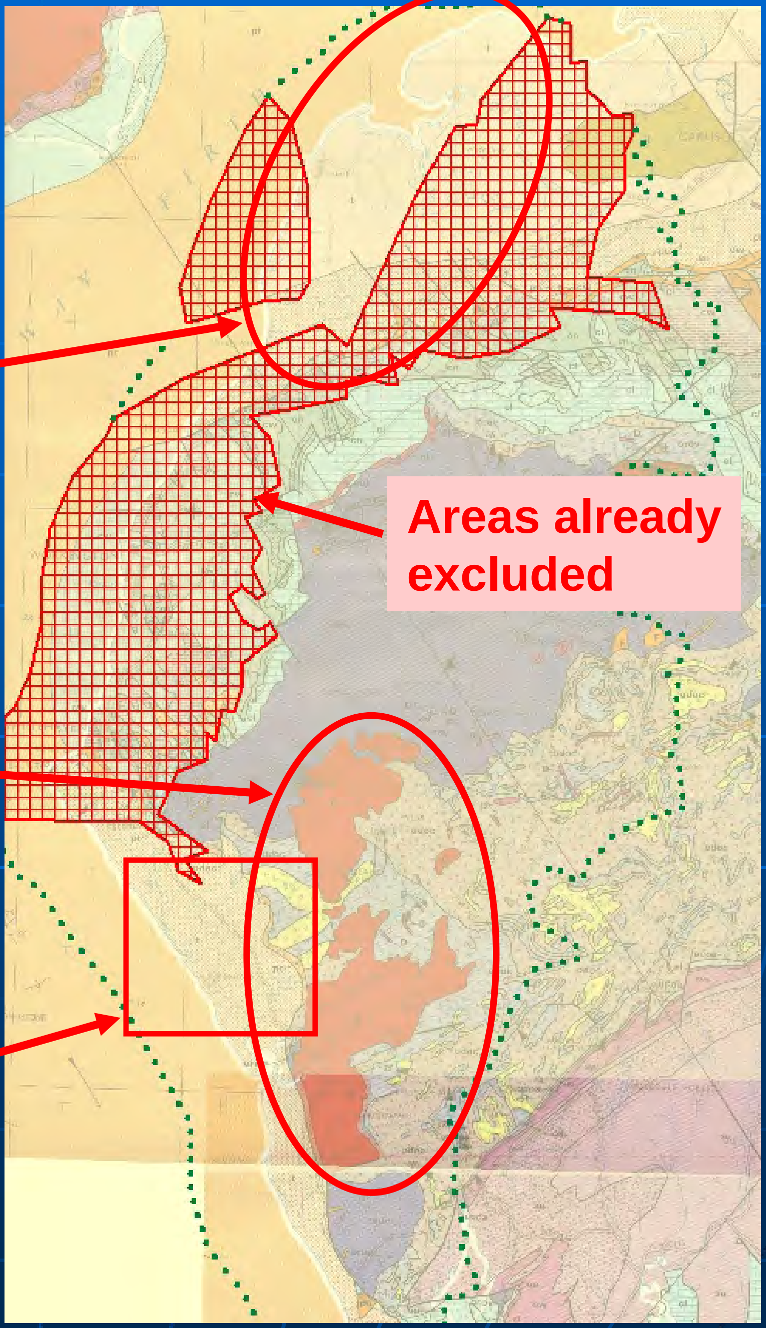
[updated from October 2012]

Geology of the areas left in play (autumn 2012)

Northern Allerdale – the Mercia Mudstone Group

Eskdale and Ennerdale granites (red areas)

Sellafield / Longlands Farm (effectively now ruled out)



The Ennerdale granite is shown in salmon pink within the red ellipse

The Ennerdale granite has been suggested as one of three possible locations left in play for a high- and intermediate-level nuclear waste repository (a Geological Disposal Facility, or GDF).

It is suggested that emplacement of waste could be achieved directly from Sellafield via a 10 km-long tunnel – the implication being that the surface of the National Park would be unaffected.

This slideshow demonstrates why such a development would be deleterious to the environment, and unsafe.

Irrespective of the geological problems, Ennerdale is clearly an area of extreme relief. This should be enough to rule it out of consideration, based on international guidelines and practice.

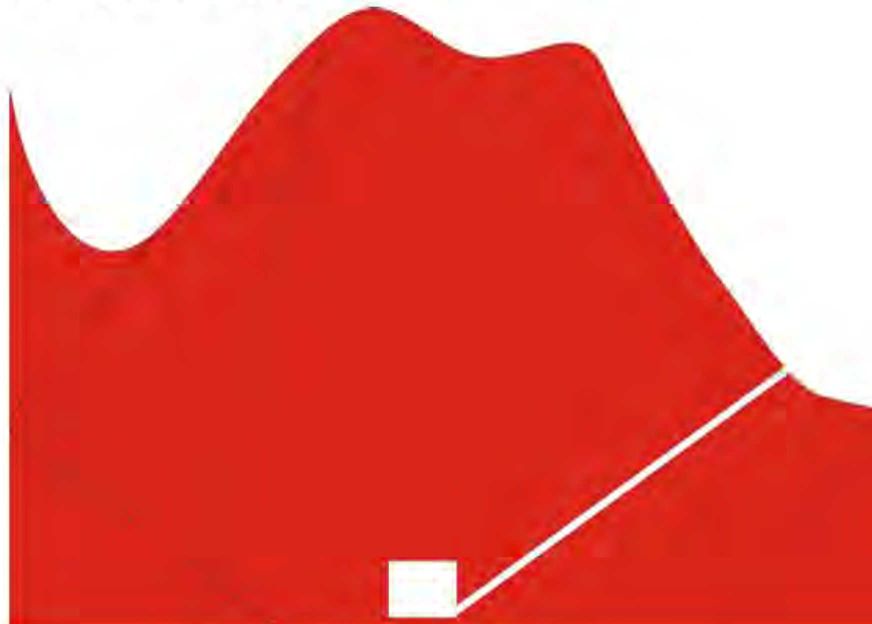
But the BGS has tried to come to the rescue here, with a novel concept illustrated by a cartoon slide …

Favourable Geological Situations

Low permeability basement ('hard') rocks

Rocks with low bulk rock permeability rocks at surface, regardless of surface relief

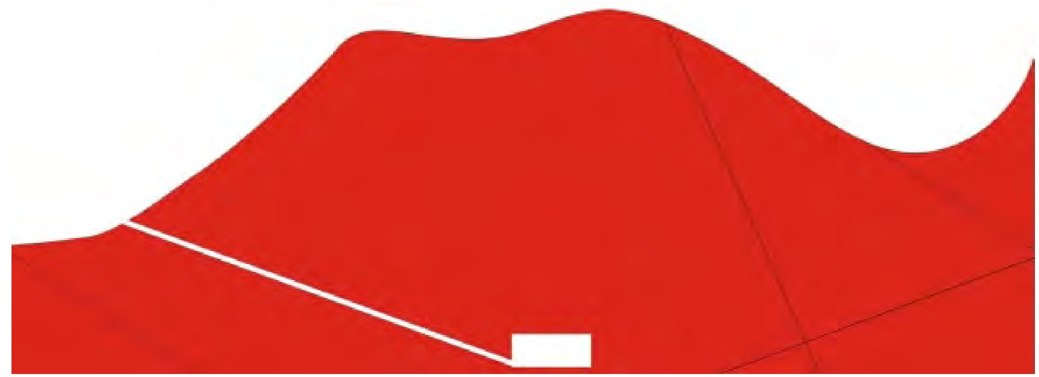
Potential problems of complex geology (sometimes) and short return pathways

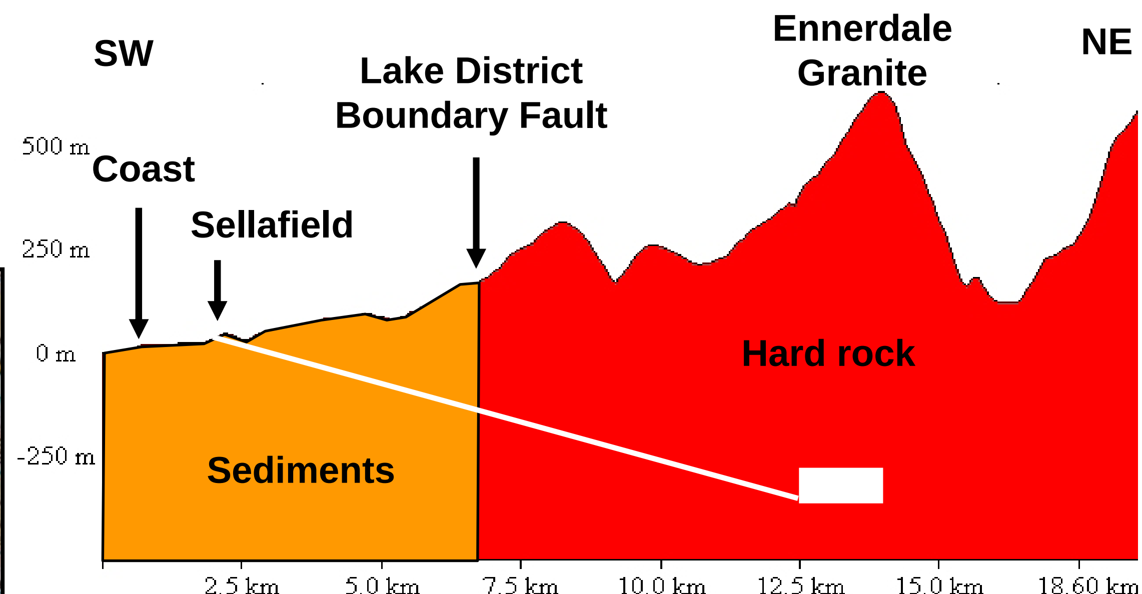


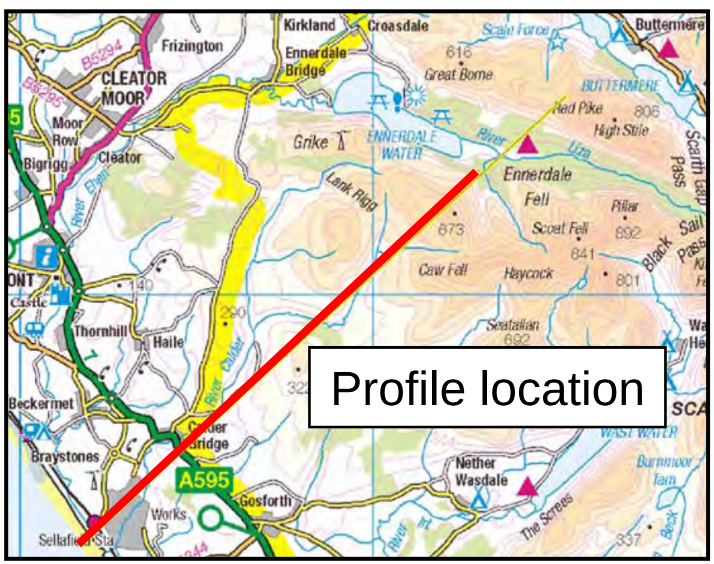
Published BGS cartoon (Shaw 2006 and 2010).
This purports to show high-relief mountains as 'favourable'.
But no GDF search guidance supports this concept.

Comparison of the BGS '*favourable geological situation*' of high-relief hard rock with a repository in the Ennerdale granite, linked directly by a 10 km tunnel to Sellafield. The repository (white rectangle, schematic) would be about 400 m below the level of Ennerdale Water.

BGS hard rock cartoon, reversed







Actual topographic profile from the coast to the head of Ennerdale Water (vertical exaggeration x7.5).

Comments on the BGS cartoon

The BGS cartoon was first published by Dr Richard Shaw in 2006.
It conforms to no national or international guidelines, nor to overseas practice.

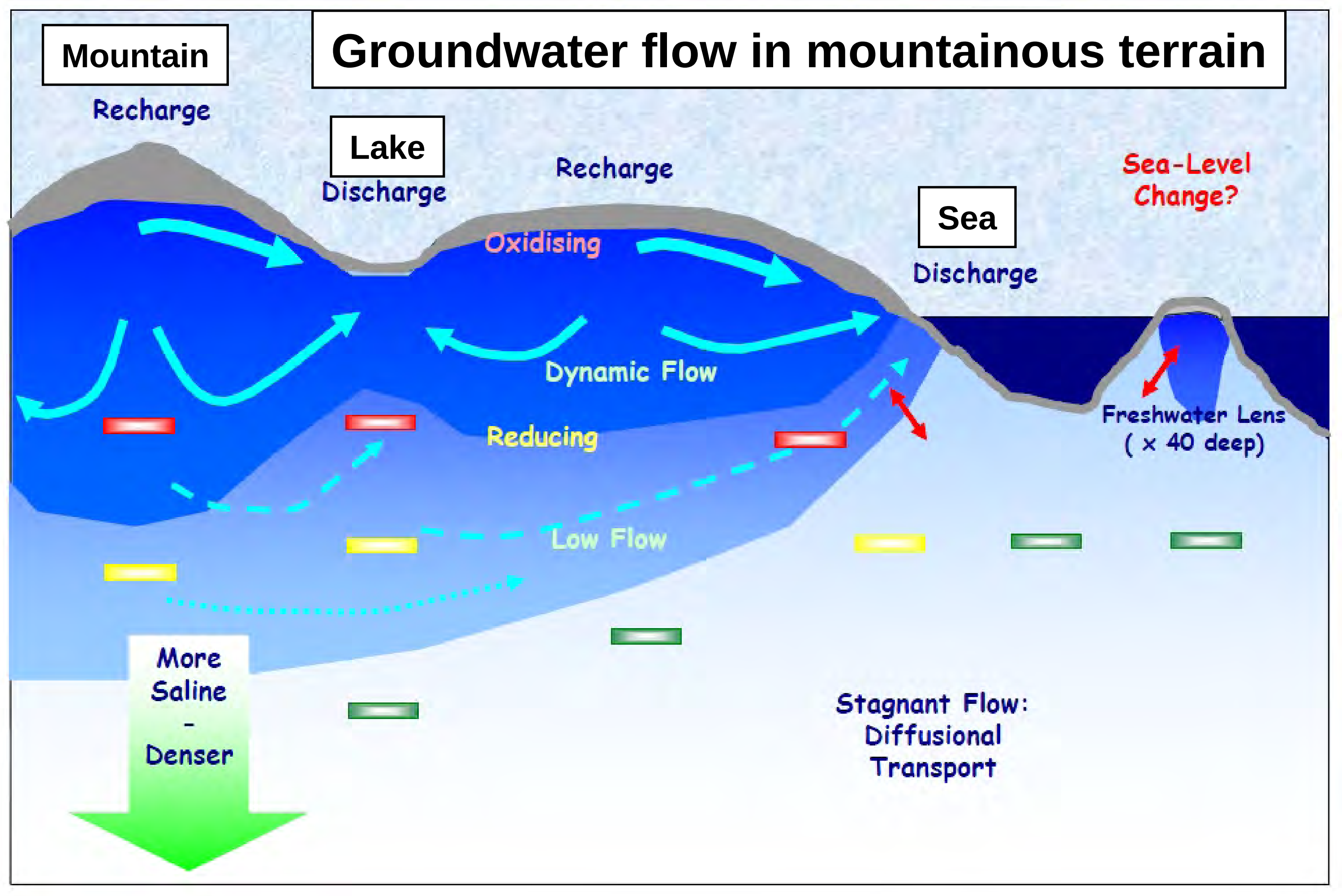
NERC (of which the BGS is a component body) has tried to explain that it conforms to a 2009 Environment Agency “key” document.

This suggests that either:

- Dr Shaw has remarkable powers of precognition, or
- It is evidence for predetermination.

‘Predetermination’ means that the NDA and/or the BGS had already selected Ennerdale as a possible site by 2006 (because there is nowhere else in England that fits the essentials of the BGS cartoon), and have subsequently engaged in an exercise to manipulate quasi-scientific opinion in favour of such a site.

Vertical scale of the recharge / discharge circuits is typically 2-3 times the topographic relief.



This is from Chapman & Curtis (2006): "*Cartoon showing some general relationships between groundwater flow and chemical composition. Hydraulic pressure gradients, caused by topography in this cartoon, cause more dynamic flow at shallower depth but die out at greater depths. Surface waters recharging the deeper groundwater system rapidly become reducing with depth as they react with the rock and then progressively denser*."

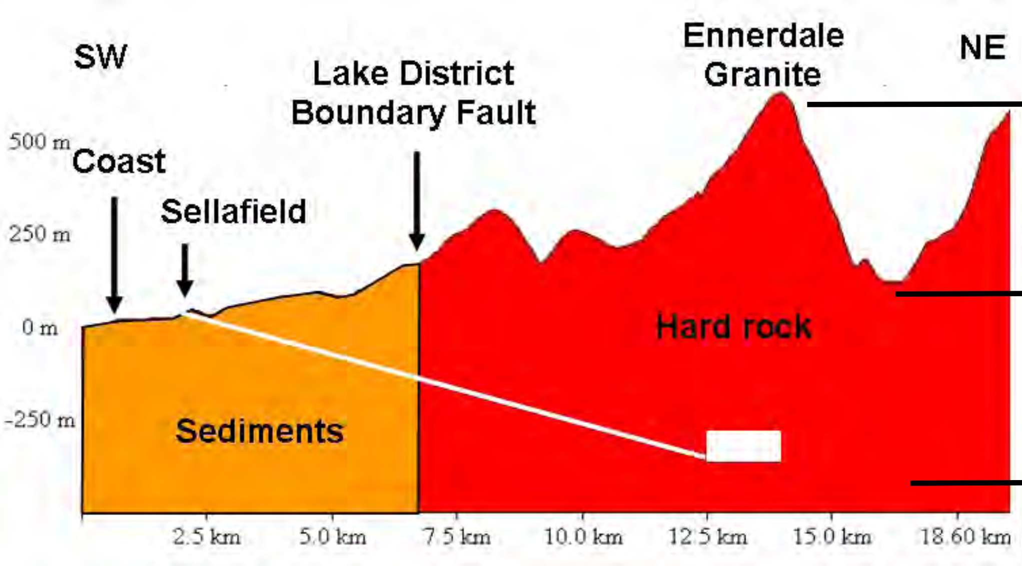
Note: the horizontal 'slots' in the cartoon represent various possible locations for a repository.

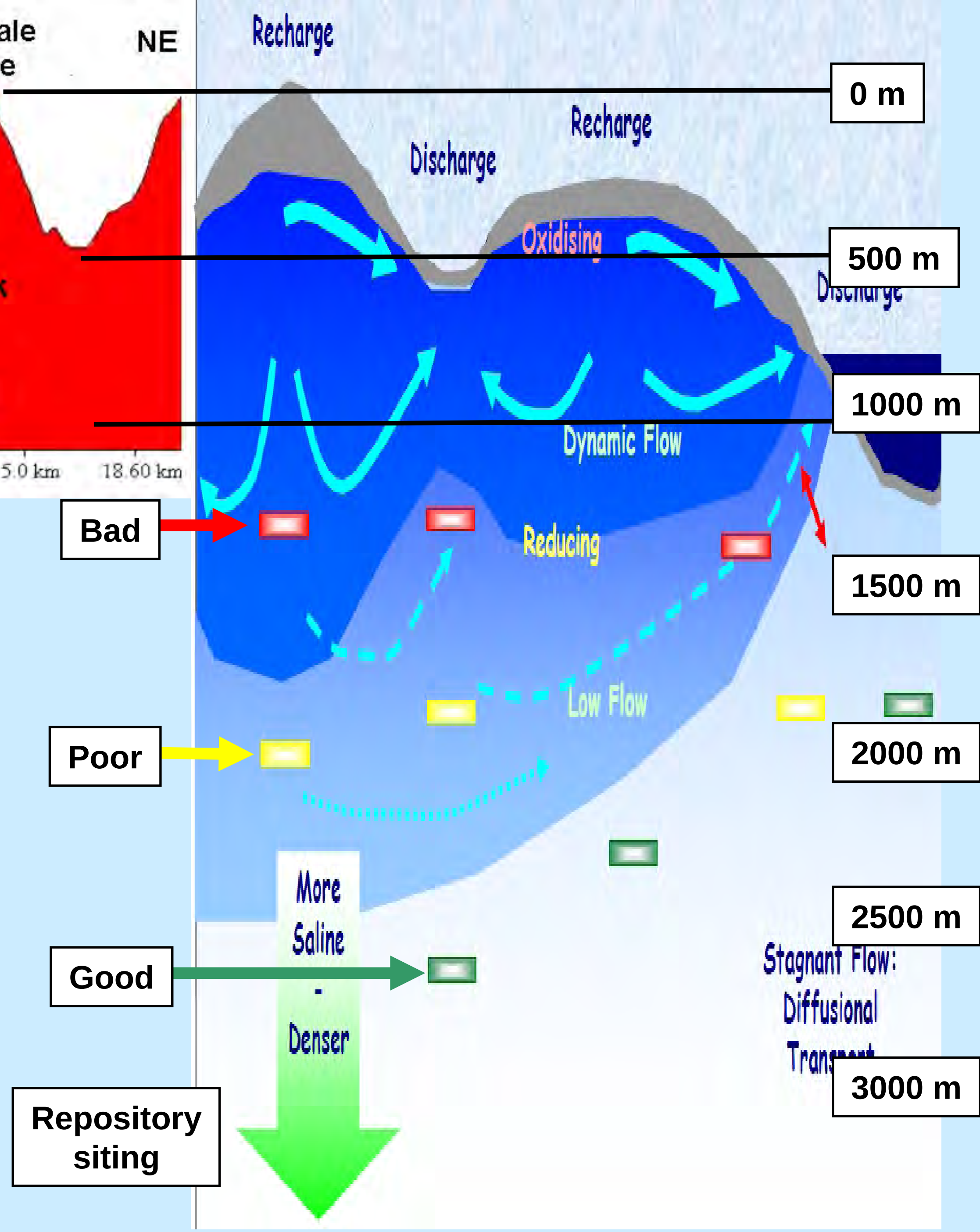
The traffic-light colour coding is presumably intended to indicate:

Red – bad location, due to strong upward return flow

Yellow – poor location, with slow upward flow and longer pathways

Green – good location, in the zone of stagnant and saline groundwater.





Possible repository location cartoon on the right (Chapman & Curtis), scaled to the topography of West Cumbria (left) by matching the 500 m elevation from mountain top to lake. Scale added at right (datum at top of Ennerdale Fell).

The vertical scale of the recharge / discharge cycles, dominated by the topography, shows that in the case of the Ennerdale granite (500 m topographic amplitude) the repository would have to be sited deeper than 2000 m (minimum) below the mountain tops, or about 1500 m below sea level.

Comments on the flow line cartoon

Neil Chapman (of the Chapman & Curtis 2006 paper) is the same Chapman who was the lead author of the seminal 1986 BGS/Nirex paper that classified hydrogeological environments, and then applied the results to the whole of the UK. He is also chair of the NDA's Radioactive Waste Management Technical Advisory Panel Directorate.

Although the cartoon is not scaled, it accurately illustrates the essential fact that the flow lines in the subsurface are a bit like a mirror-image of the topography, but on a somewhat larger vertical scale. Oxidising surface fresh water excavates down to a depth of 1000-1500 m below the high peaks of the area, and returns to the surface. If a repository is sited within this zone (the red option), radionuclides will be fast-tracked back to the surface along short pathways.

This scenario does not quantify the travel time, which will also depend upon the hydraulic conductivities of the rock formations. The assumption is also made that the rock is homogeneous. But if there is layering and interfingering of different rock types, and/or faults and fractures, the picture will be much more complex. These complicating factors will make the problem worse. The 'hyperpermeable' zone found in the Weardale granite serves as a warning.

The red, yellow and green 'slots' illustrate different repository positions. But in the Ennerdale granite case the repository will be two to three times wider than shown above, thus exacerbating the flow problem.

What if the vertical scale of the cartoon is considered to be non-linear, in that the depths from red to green repository locations have been stretched out for purposes of clarity, relative to the upper section? Even if that were the case, it is geometrically impossible for there to be a 'good' repository location shallower than about 2000 m below the top of Ennerdale Fell, in other words about 1500 m below sea level.

Implications for the Ennerdale area of the National Park

If the Ennerdale granite were selected for Stage 5 investigations, this would involve a great deal of industrial activity in an around the area of the granite, for the following approximate periods:

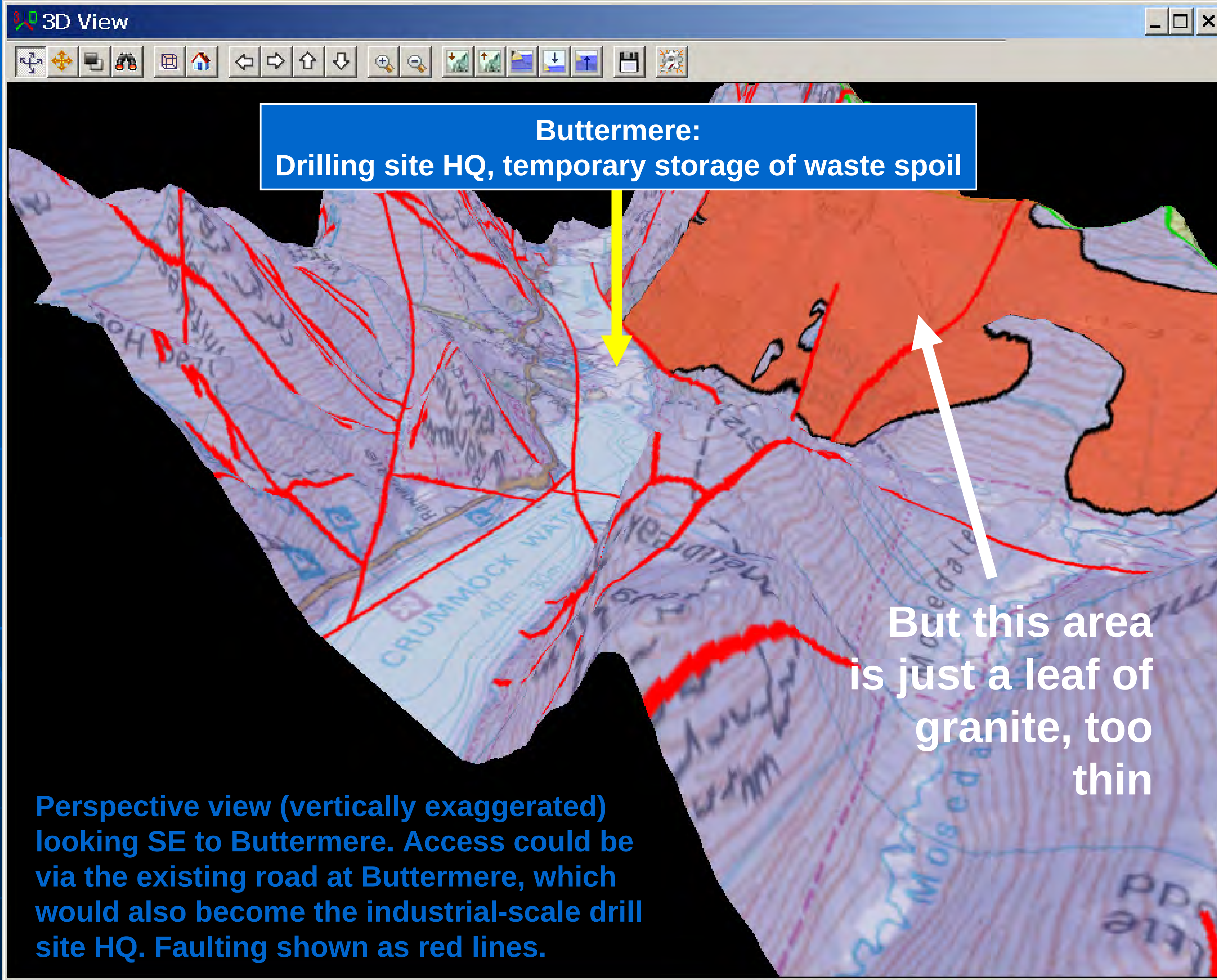
- Opening up of several roadways onto the mountain - permanent
- Surface seismic reflection survey – 1-2 years
- Drilling of the granite for investigation – 10 years

Stage 5 would then move to construction:

- Excavation of 3 vertical shafts above the selected GDF location
- Building of surface works – permanent
- Drilling of 2-3 access tunnels from Sellafield to the GDF

By ‘permanent’ is meant for a period of 200 years or more that the GDF would be in operation. Only after the GDF is closed could the surface works above be removed.

Details of possible locations are shown next.



Buttermere:
Drilling site HQ, temporary storage of waste spoil

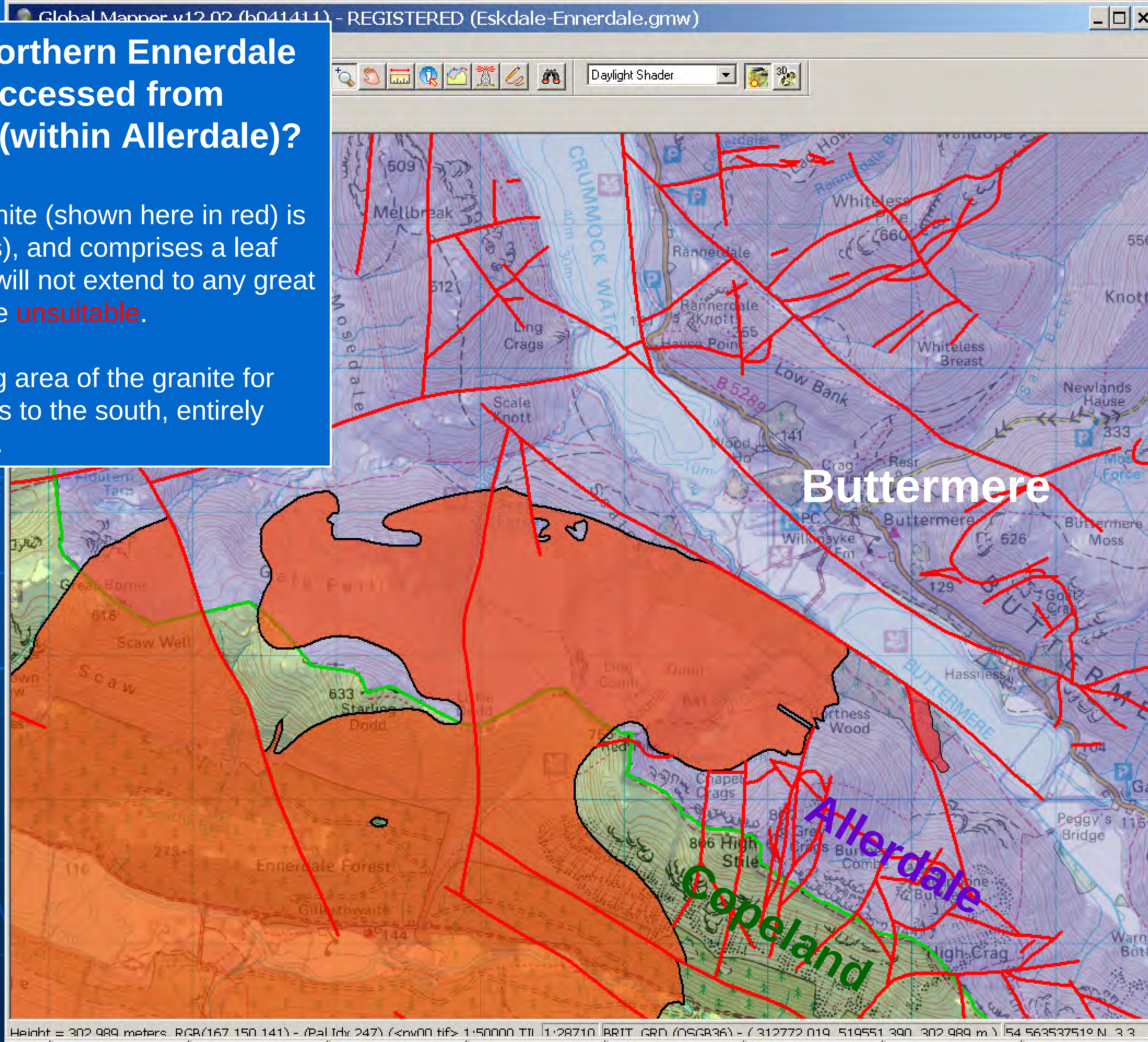
But this area is just a leaf of granite, too thin

Perspective view (vertically exaggerated) looking SE to Buttermere. Access could be via the existing road at Buttermere, which would also become the industrial-scale drill site HQ. Faulting shown as red lines.

Could the northern Ennerdale granite be accessed from Buttermere (within Allerdale)?

Yes, but the granite (shown here in red) is faulted (red lines), and comprises a leaf structure which will not extend to any great depth – therefore unsuitable.

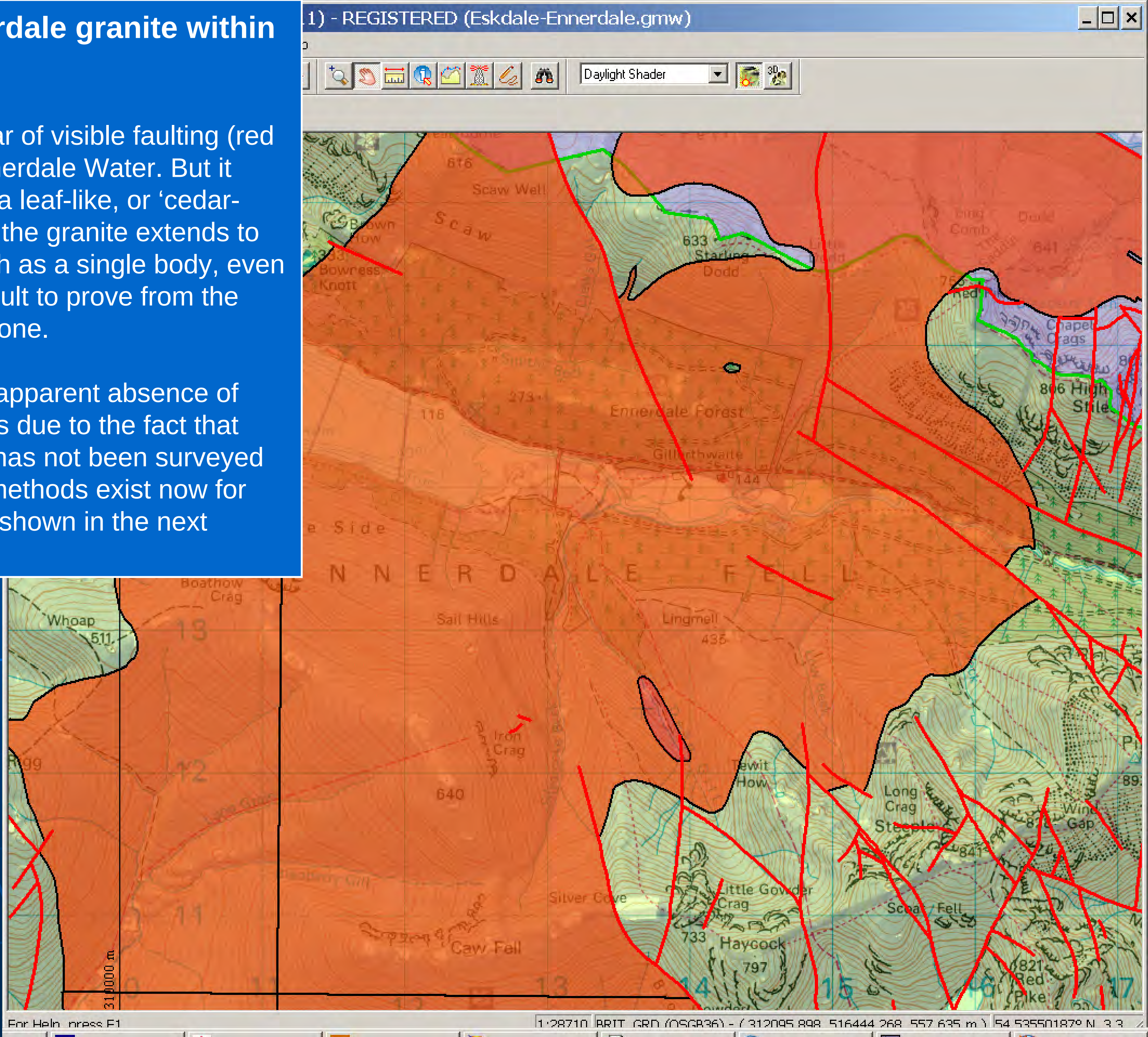
So the remaining area of the granite for consideration lies to the south, entirely within Copeland.



Northern Ennerdale granite within Copeland:

It seems to be clear of visible faulting (red lines) south of Ennerdale Water. But it probably also has a leaf-like, or ‘cedar-tree’ structure, i.e. the granite extends to no significant depth as a single body, even though this is difficult to prove from the surface geology alone.

It may be that the apparent absence of faults in this area is due to the fact that some of this area has not been surveyed since 1924. New methods exist now for inferring faults, as shown in the next slides.



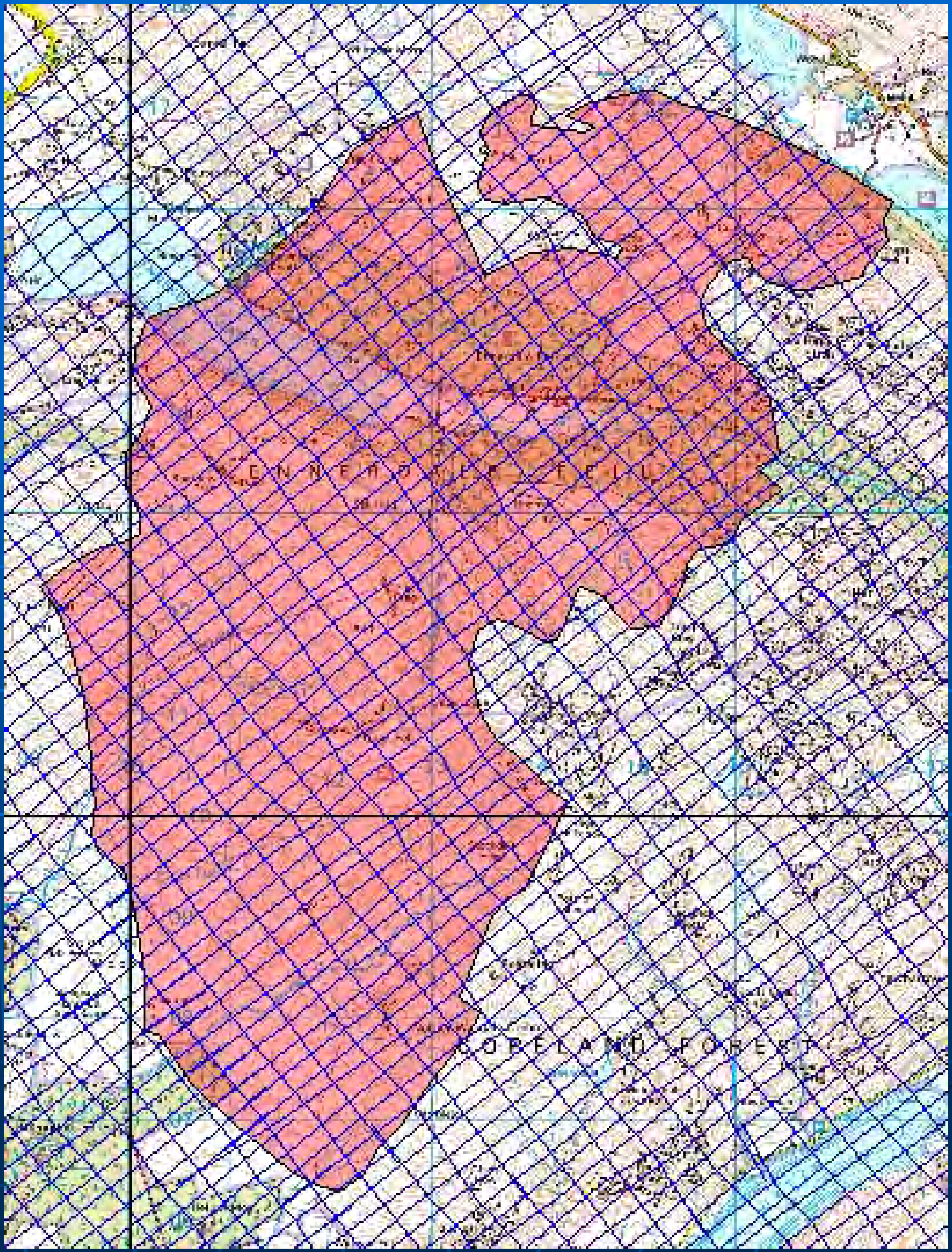
Flight line coverage of low-level (100 m elevation) airborne geophysical survey over the Ennerdale granite (pink) in 1991.

This was obtained and interpreted by the BGS under contract to Nirex, and published in 1993. The NE-SW lines are spaced at 200 m, and the NW-SE lines at 400 m.

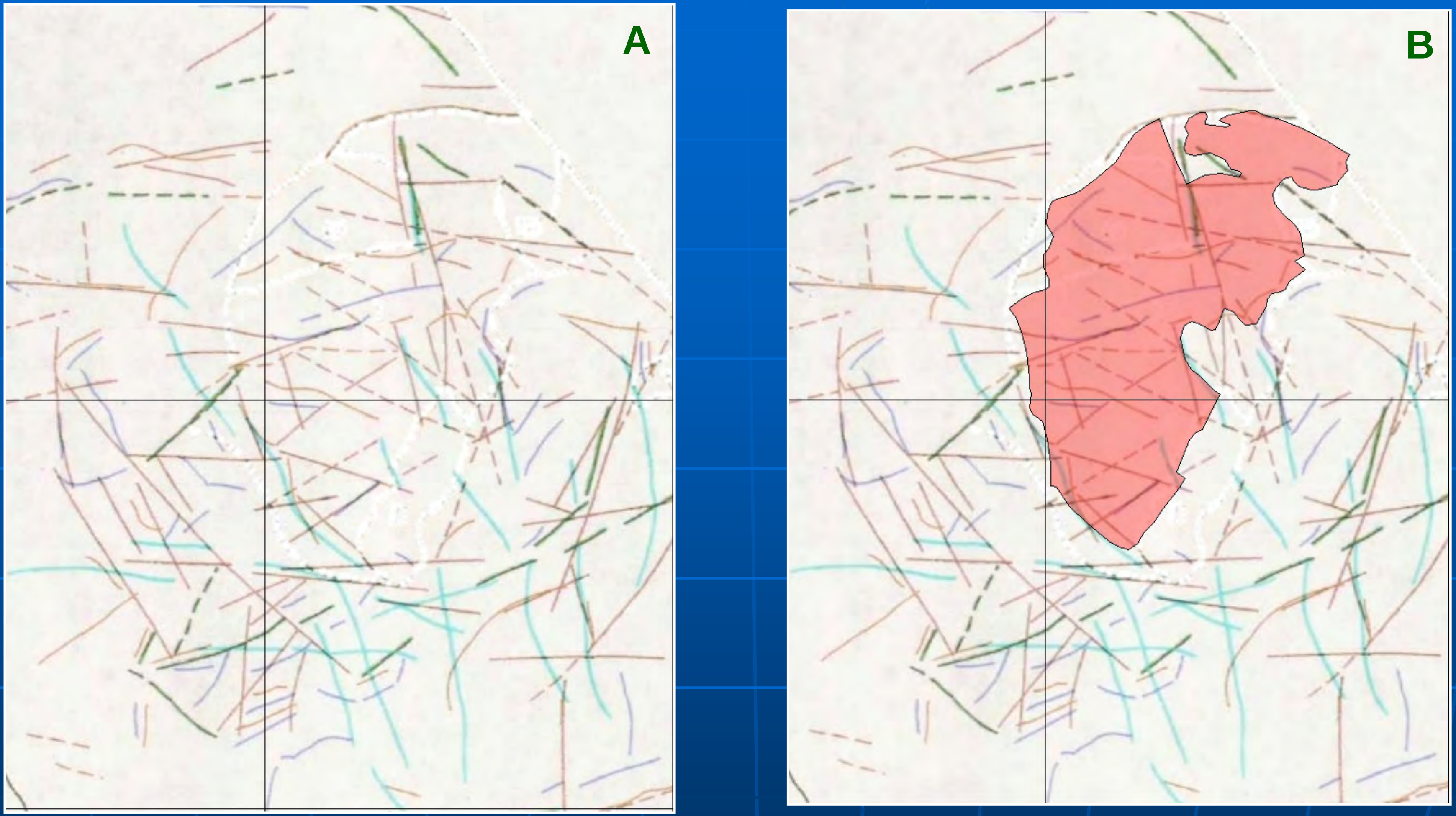
The three methods used were:

- Total field magnetic
- Radiometric
- Electromagnetic.

No quantitative modelling was carried out, but linear features were mapped.



BGS interpretation (1993) of three non-seismic low-level (100 m) airborne surveys



A. Linear features identified; B same, but with outline of Ennerdale granite added. The triangular area in the north-east is blank because the survey did not cover it.

Comparison of the two versions shows that the granite has no masking effect on the features, and that only two features can be identified with the granite margin - one along the north edge and the other (blue) along part of the SW margin. This suggests either that there is considerable complexity within the granite, not mapped on the geological map, or that the granite is a very thin sheet, and that the features represent structure within the underlying Borrowdale Volcanic Group. In the latter case these features would be attenuated in amplitude and frequency if the granite were thick. This latter case suggests that the granite sheet is perhaps only 100-300 m thick.

MRWS Stage 5
"*Surface investigations on remaining candidates*"

Stage 5 will comprise surface seismic investigations (2D and 3D reflection seismic), and drilling of 20-30 deep boreholes into the granite, to a depth of 1000 m or so.

Various engineering, geological and geophysical tests will be carried out in the boreholes.

By analogy with the Nirex Longlands Farm investigations and practice abroad, this phase will take at least 10 years.

3D seismic reflection survey of Ennerdale

This survey is essential to try to image the granite body and faulting in three dimensions.

It would be preceded by 2D test surveys.

Terrain is extreme, ruling out the vibroseis energy source used in the Nirex trial 3D seismic survey at Longlands Farm in 1994 (photo).

Had that site not proved to be too complex and unpredictable, a full 3D survey covering 10-20 sq km would have been planned.

The only alternative energy source is dynamite placed in drilled shot-holes. This is what would be used over Ennerdale.

Four vibroseis trucks on duty at Longlands Farm. The survey, a world first, was planned and executed for Nirex by the University of Glasgow, with IMC Geophysics as lead subcontractor.

Lead scientist – Prof David Smythe, here talking to the lead ‘vib’ driver.

3D dynamite survey - alternative scenarios

There are two fundamental parameters:

- Density and resolution of data
- Depth of penetration

We need penetration to 2 km, and a horizontal resolution of 10 m or better in the x and y directions. In a high-resolution survey (which is the case here) we hope to resolve geological features vertically down to a few metres.

There are (at least) two feasible methods:

(1) Caterpillar truck-mounted drilling rig:

- Shot holes 10-20 m deep
- Good penetration
- Fewer holes required

(1) Hand-held ‘slim-hole’ drilling machine

- Energy penetration doubtful, but compensated for by
- More holes (each 1 m deep) into granite

3D dynamite survey - geometry

(indicative figures only)

Area to be surveyed:	25 sq km incl. border fringe
Shot and receiver line spacing	20 m
Receiver interval	20 m
Shot interval (truck)	40 m
Shot interval (hand-held)	20 m
Resulting horizontal resolution	10 m x 10 m

Basically, the shots and receivers lie at points on a 20 m square grid, but with the truck-mounted rig we only shoot every second position.

Modern recording equipment can deploy several thousand recording channels – for example 50 lines of 100 channels each (5000 channels), thus covering an area of 1 x 2 = 2 sq km.

3D dynamite survey – some logistics

NB: whole mountain out of bounds to public for > 1 year.

Caterpillar truck-mounted drilling rig:

- 25 x 25 holes = 625 per sq km, at 40 m spacing
- Total no. of holes = 15625 to min. 10 m depth
- Air percussion drilling to avoid need for water lubrication

OR

Hand-held 'slim-hole' drilling machine(s):

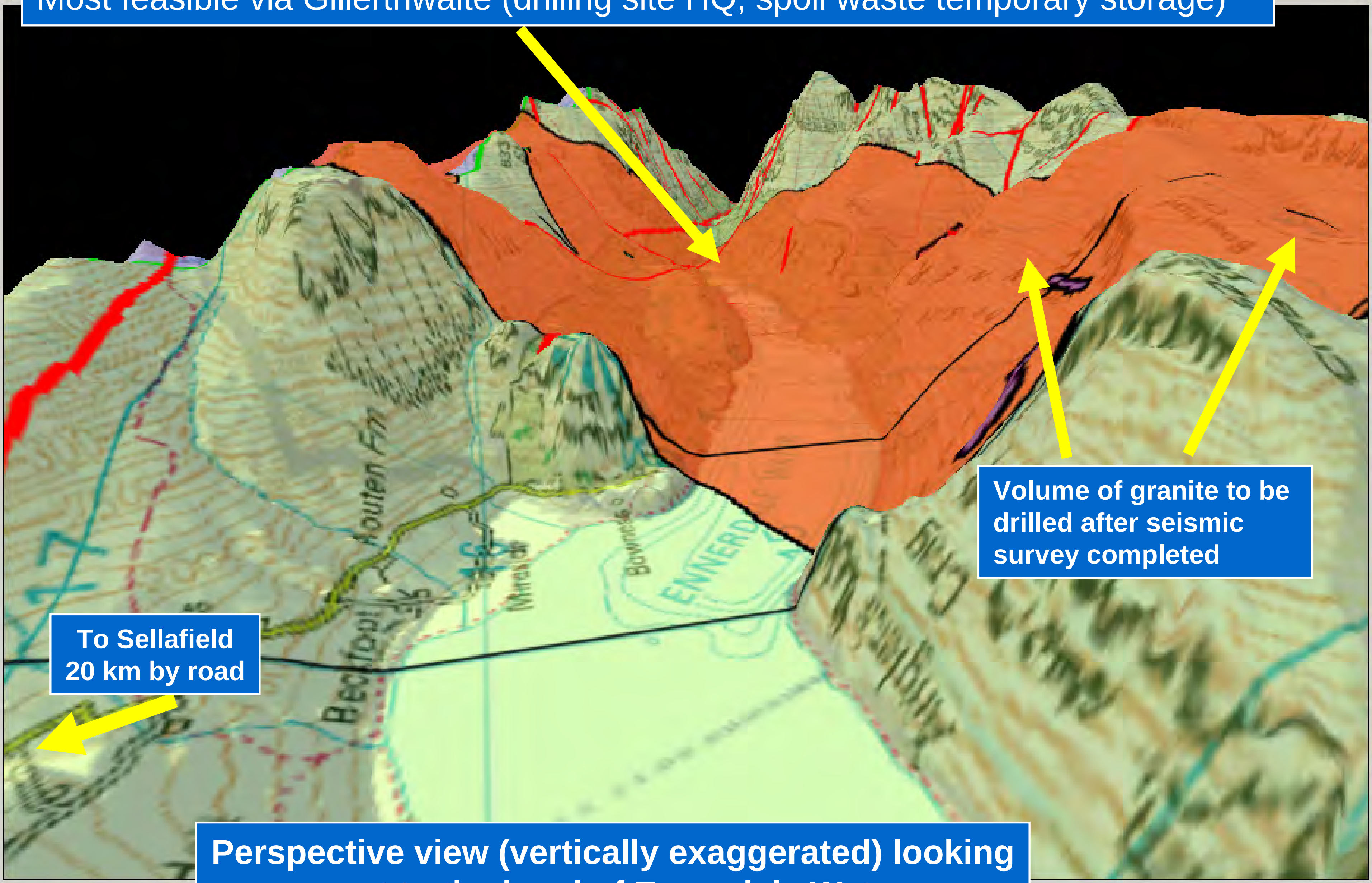
- 50 x 50 = 2500 holes per sq km, at 20 m spacing
- Total no. of holes = 62500 to 1 m depth

Holes can be drilled weeks or months in advance, and even charged with dynamite well in advance of the recording phase.

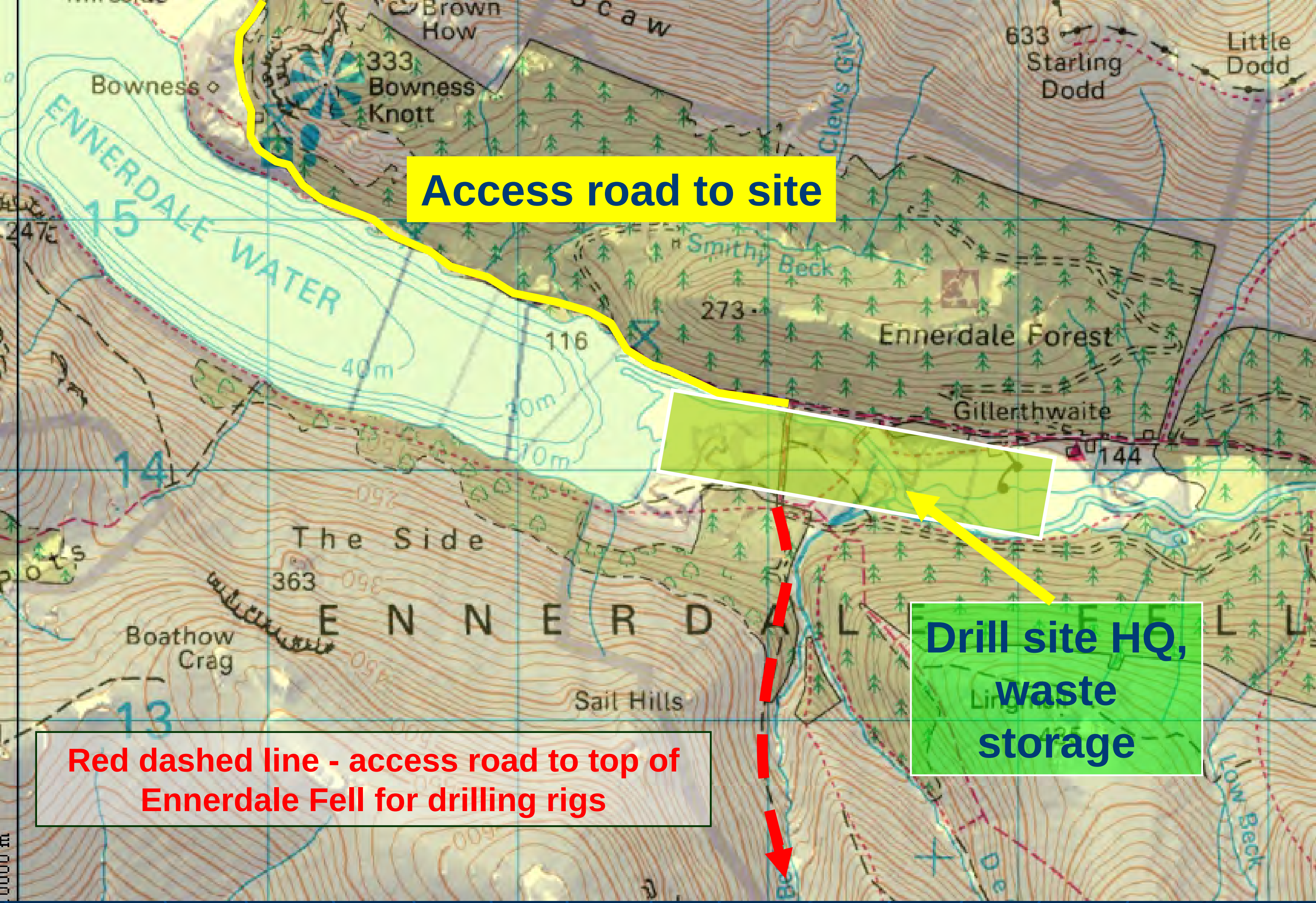
The above figures suggest that a truck-mounted drilling operation is too impracticable, even if the number of holes quoted above were halved or quartered.

Experiments on hard rock in Sweden suggest that a hand-held drill can achieve 20 holes per day. Assuming 10 hand machine crews operating simultaneously → 310 days work.

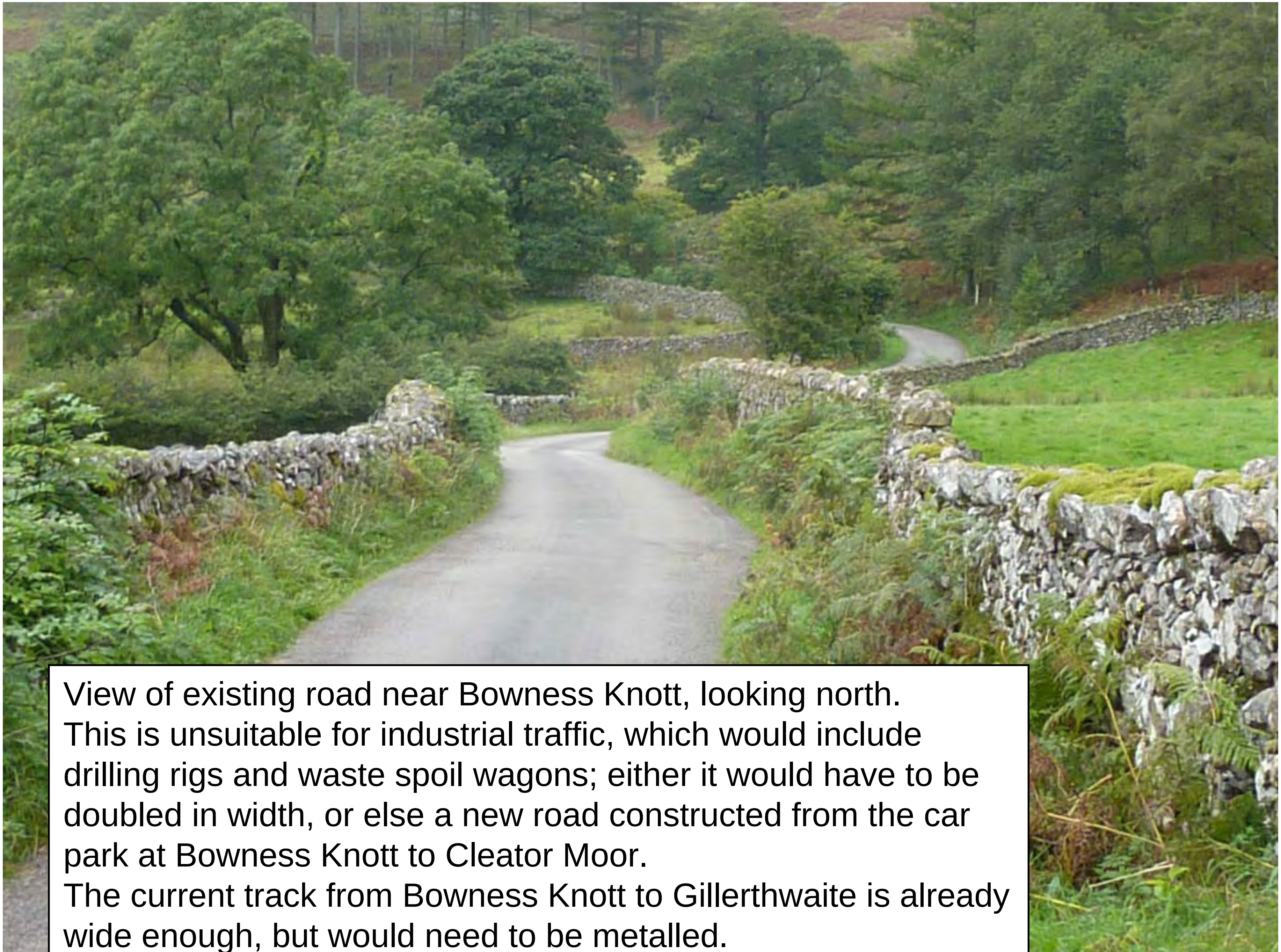
Access to the granite south of Ennerdale Water for drilling investigations:
Most feasible via Gillerthwaite (drilling site HQ, spoil waste temporary storage)



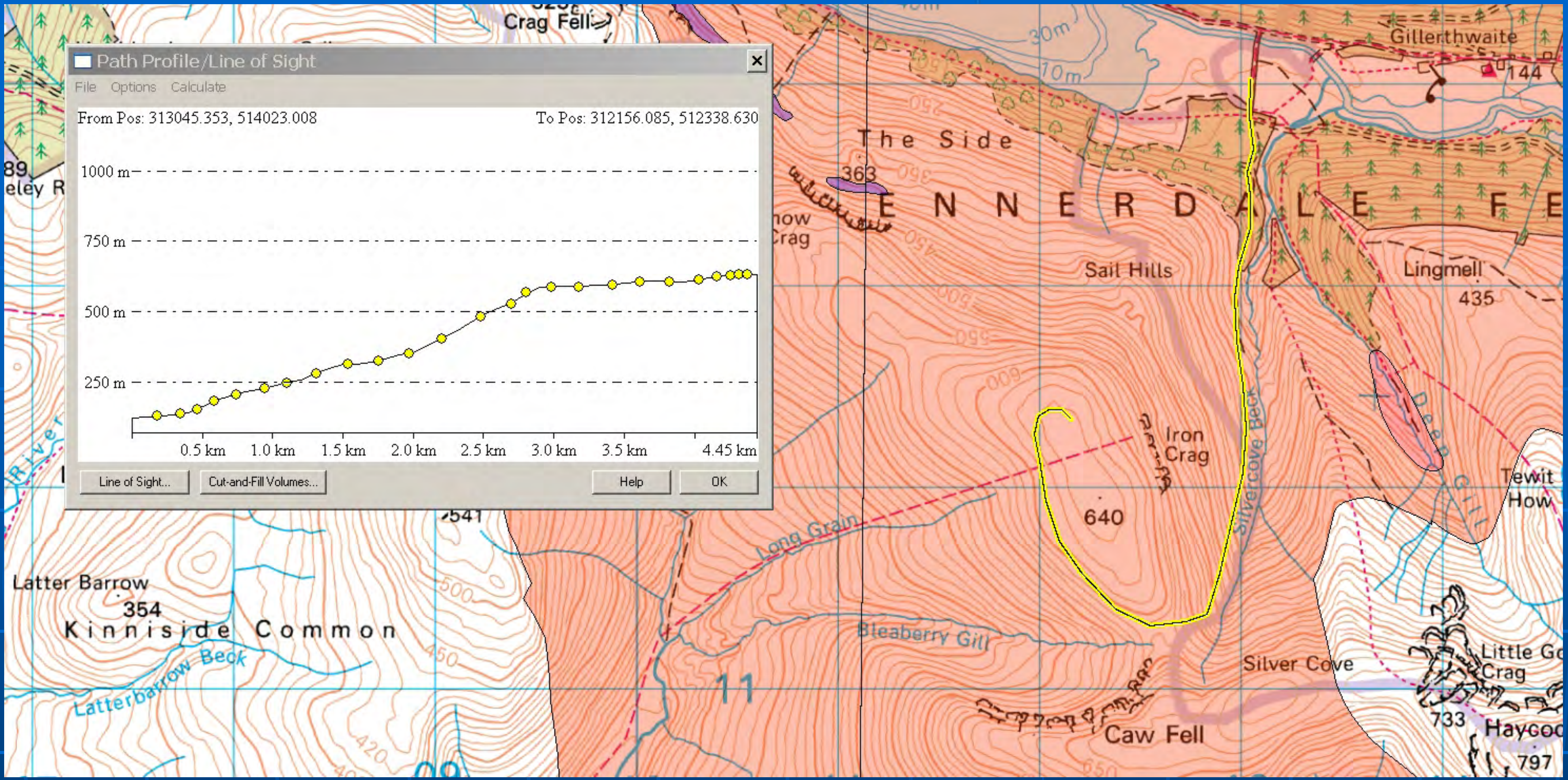
Perspective view (vertically exaggerated) looking east to the head of Ennerdale Water



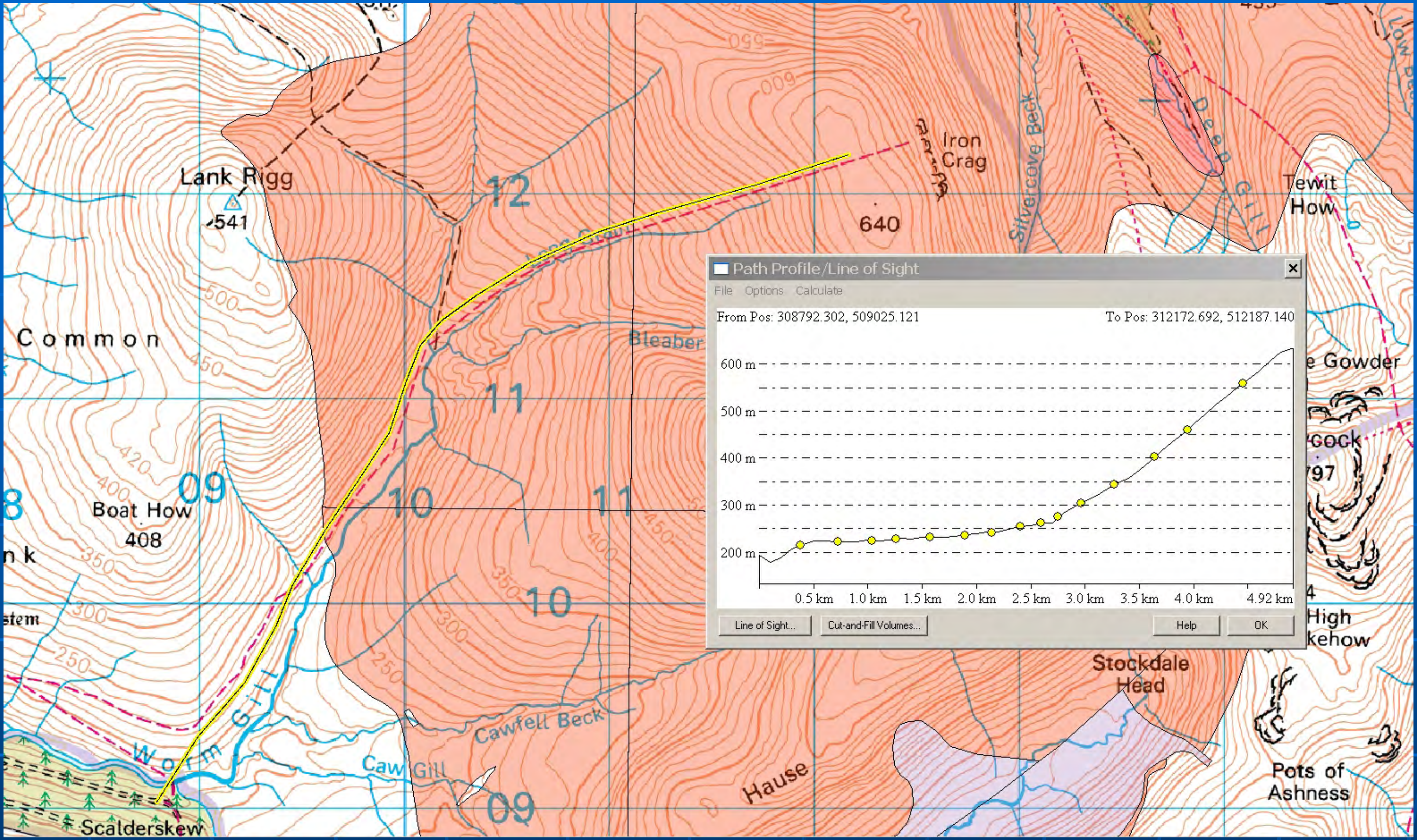
Access road to site
Drill site HQ, waste storage
Red dashed line - access road to top of Ennerdale Fell for drilling rigs
Brown How
Bowness
333 Bowness Knott
Clews Gill
633 Starling Dodd
Little Dodd
ENNERDALE WATER
Smithy Beck
273
Ennerdale Forest
116
Gillerthwaite
144
The Side
363
ENNERDALE FELL
Boathow Crag
Sail Hills
Low Beck



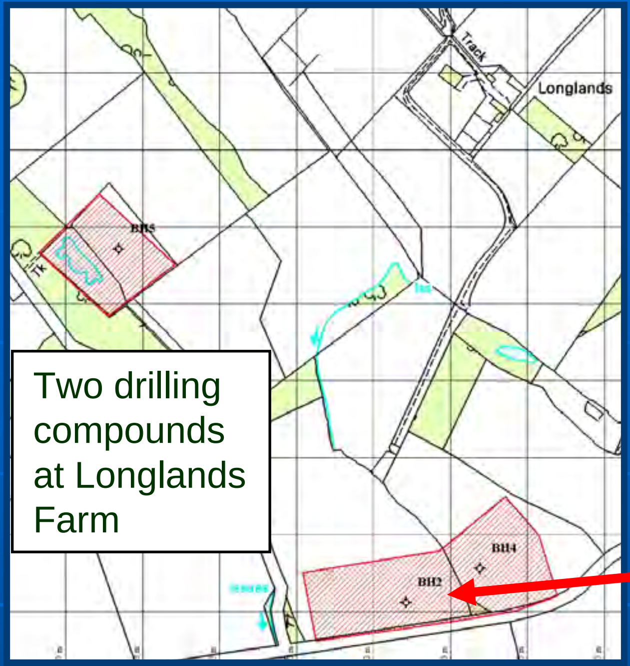
View of existing road near Bowness Knott, looking north.
This is unsuitable for industrial traffic, which would include drilling rigs and waste spoil wagons; either it would have to be doubled in width, or else a new road constructed from the car park at Bowness Knott to Cleator Moor.
The current track from Bowness Knott to Gillerthwaite is already wide enough, but would need to be metalled.

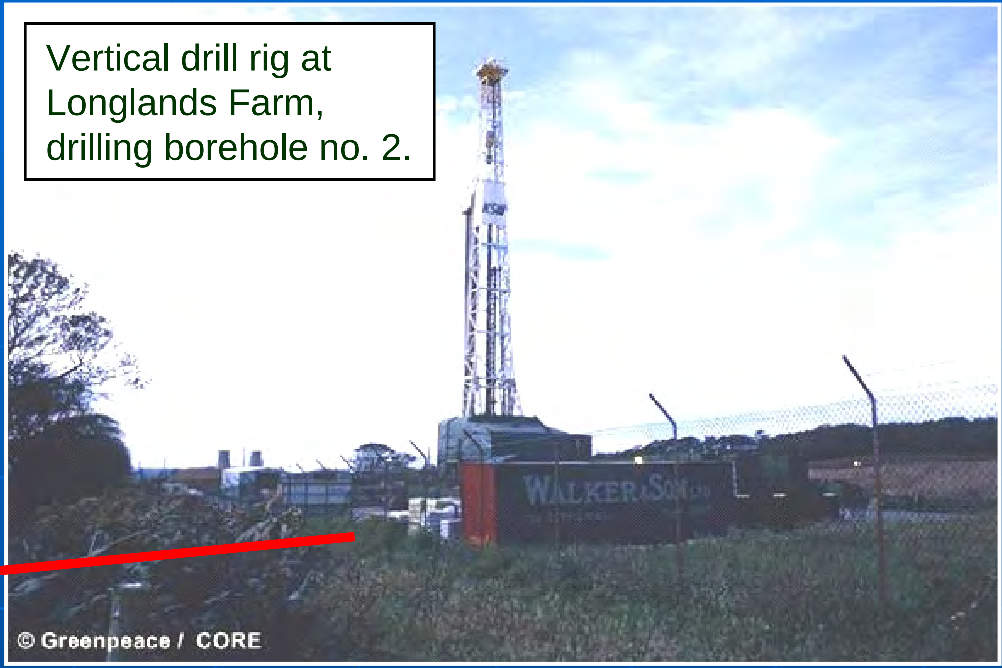


A roadway from Gillerthwaite to the top of Ennerdale Fell would have to spiral clockwise round the back of Iron Crag. The inset profile shows that the maximum gradient is beside Silvercove Beck – 1 in 4.4 (23%).



Alternatively, a roadway from Scalderskew to the top of Ennerdale Fell would have a maximum gradient of 1 in 4.0 (25%).





Drilling at the Nirex Longlands Farm site in the 1990s demonstrates that the rig needs a flattish compound area of about 100 m x 100 m (=1 Ha - red diagonal hatching in map above; OS grid shown at 100 m interval). The two compounds shown slope at about 1 in 10 to the SW.

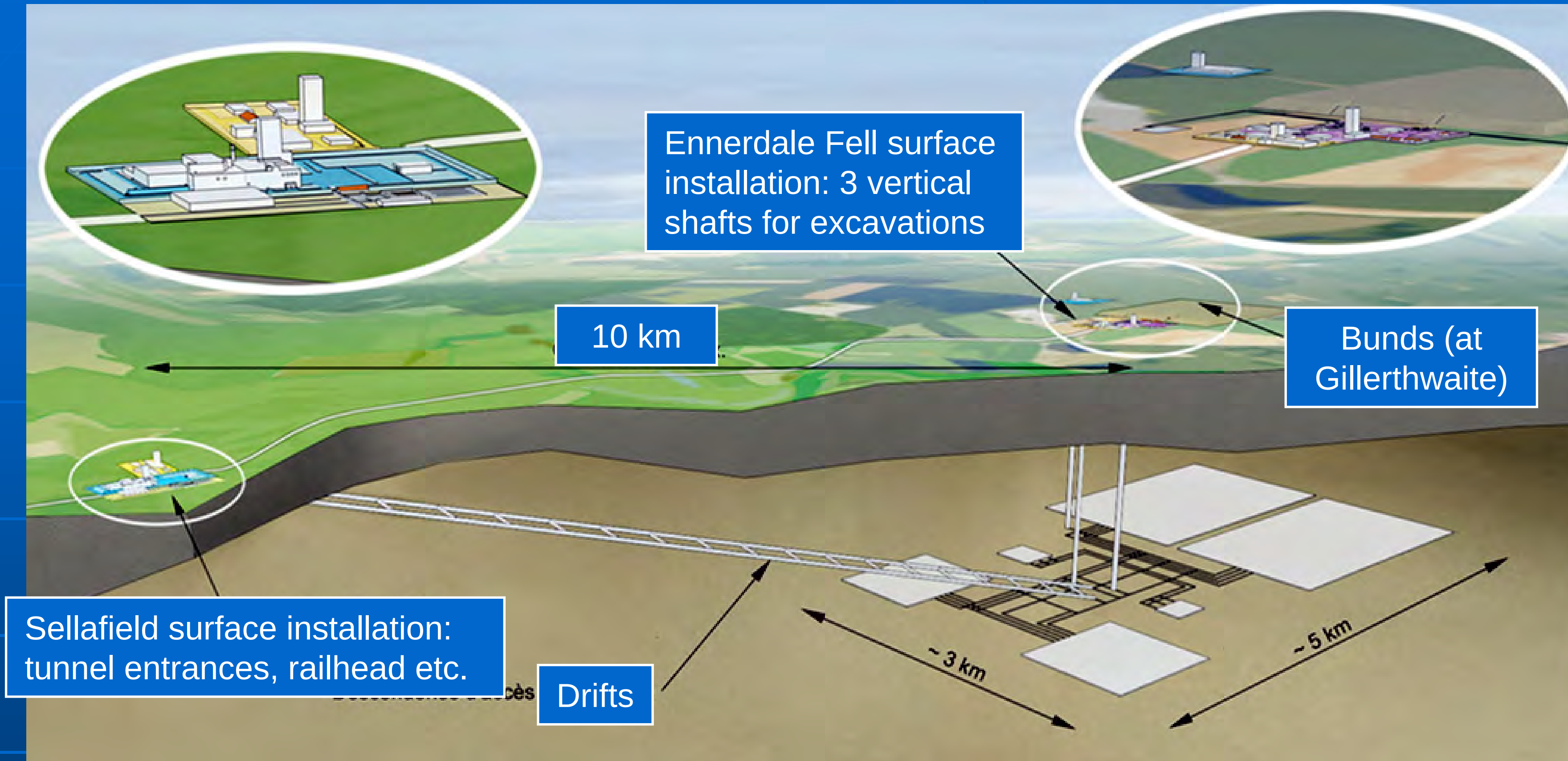
A single compound could be used for drilling boreholes in several different directions with a specialised inclined drilling rig (right).

Rigs like those shown are brought in, disassembled, in 10-20 lorry loads. The roadways constructed around the Longlands Farm site vary from 5 to 10 m in width.

MRWS Stage 6
"*Underground operations*"

Stage 6 is the excavation of the repository or GDF, in the event that a viable safety case could be made from the results of Stage 5.

The following diagrams are merely outline sketches, based on published information on the French site at Bure, and rock volumes discussed in the Entec report of October 2010.



MRWS Stage 6
Moving to construction of a repository below Ennerdale Fell

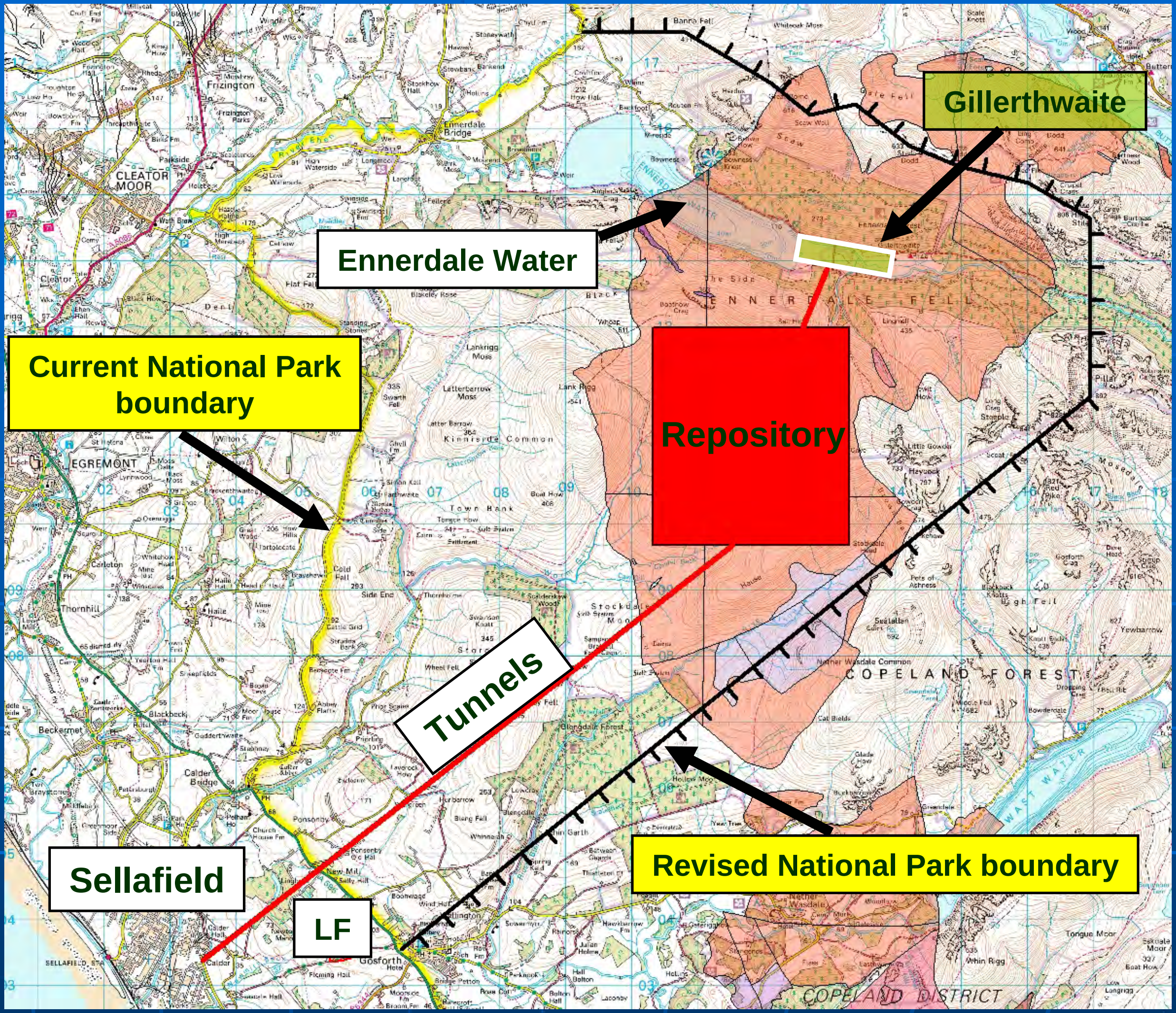
Schematic 3D view of the proposed French waste repository in clay at Bure, with English labels overlain, to illustrate how this would apply to the Ennerdale granite. The French subsurface area is about 5 x 3 = 15 km^2. In Ennerdale this area would be about 10 km^2.

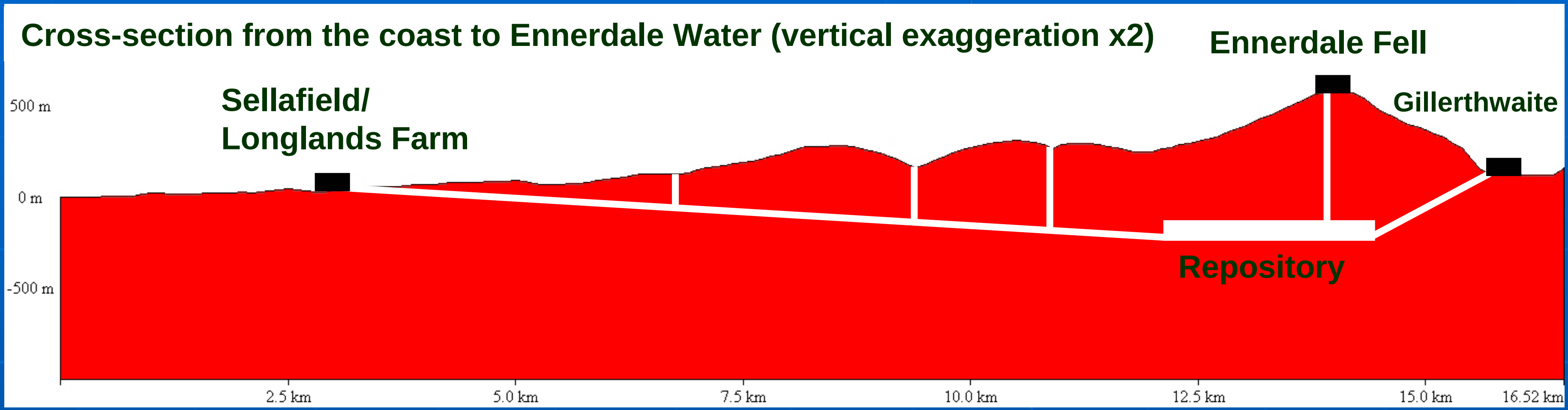
The topography in West Cumbria is clearly much more extreme than shown here.

A 10 sq km repository is shown here. It may be difficult or impossible to emplace a larger one.

Given the disruption to the National Park, and the need for long-term security of the surface installations, it would be logical to remove the Ennerdale granite area entirely from the park. The area shown here to be removed is about 115 sq km, or 5% of the park's area.

The 'Sellafield' surface installation is likely to be at Longlands Farm (LF). This explains why the NDA has inexplicably held on to the lease of this property 15 years after the end of subsurface investigations there.





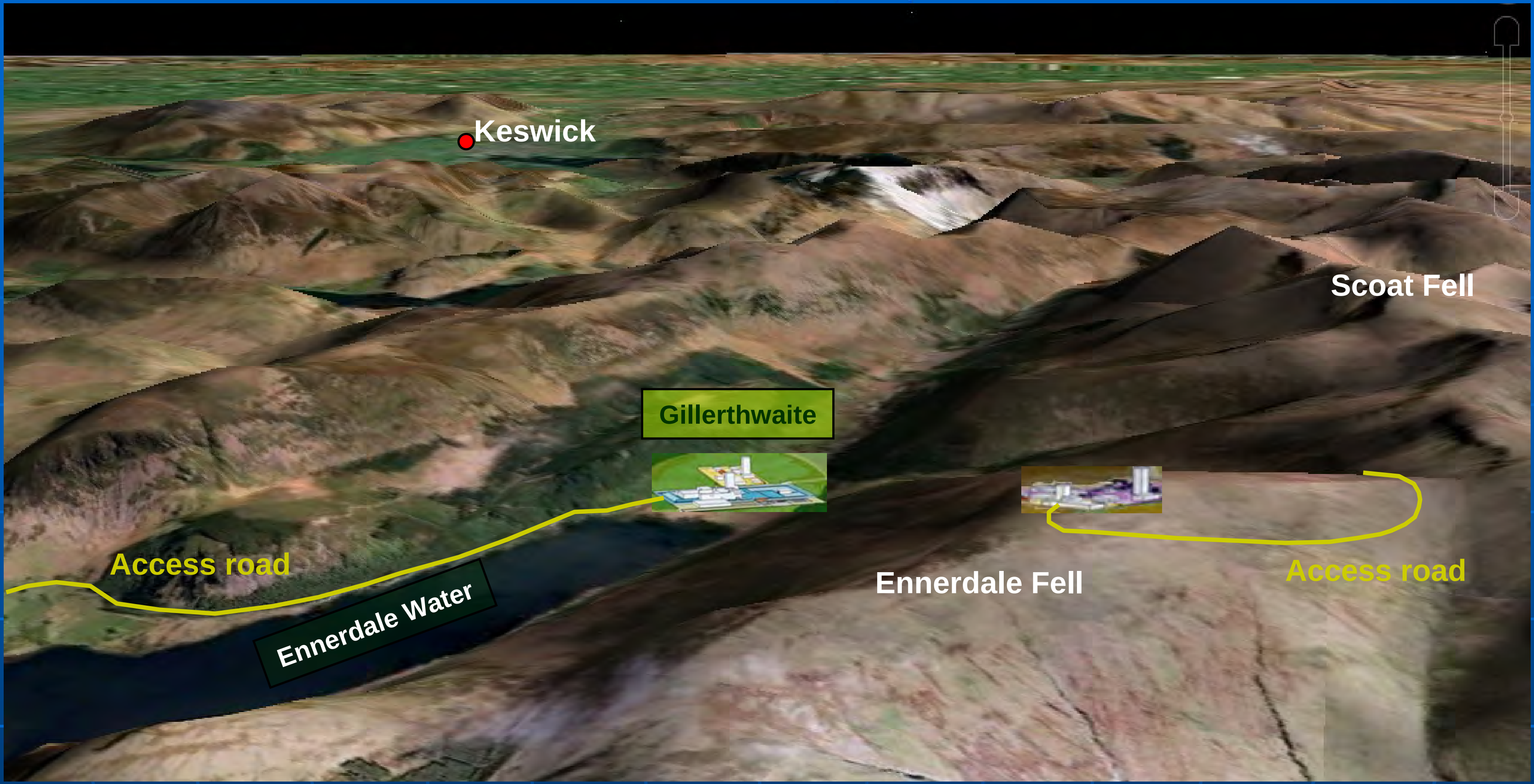
Schematic of repository in the Ennerdale granite

It is impossible to construct such a repository purely by tunnelling from Sellafield or Longlands Farm.

Likely permanent features would include:

- •Roads over Ennerdale Fell
- •Headworks on top of the Fell during excavation of vertical shafts
- •Base at Gillerthwaite for access to the fell
- •Tunnels from Gillerthwaite to the repository
- •10 km tunnels (‘drifts’) from Sellafield (Longlands Farm) to repository for waste emplacement
- •Emergency escape/ventilation shafts to surface

The repository would begin to be used while parts of it are still under excavation. The French nuclear safety agency has pointed to the importance of keeping the miners and the nuclear workers separate undergound.



Google Earth aerial view looking ENE from the western slope of Lank Rigg, at 2200 m eye elevation. The drift headworks and the vertical shaft headworks from the Bure diagram have been superimposed on Gillerthwaite and the top of Ennerdale Fell, respectively.

Ennerdale granite: summary

Unsuitable because of:

1. Extreme topography
2. Repository is within the hydrogeological recharge /discharge cycle
3. Near-impossible access and logistics for geological/geophysical studies
4. Complex internal structure, and/or too thin
5. Risk of undetected and undetectable ‘hyperpermeable’ veins and faults zones
6. Probably not big enough to accommodate a GDF > 10 sq km

Therefore unpredictable and unsafe as a GDF site

Further reasons to rule it out:

- It is a minor aquifer (water well at Nether Wasdale)
- Unavoidable pollution of Ennerdale Water
- Transformation of part of the National Park
- Permanent scarring of Ennerdale Fell

Notes on relevant legislation:

Ennerdale is a critical Public Water Supply for west Cumbria
Ennerdale Fell and Ennerdale itself are both SSSIs
The River Ehen when it leaves Ennerdale is a SAC
Ennerdale Fell is owned by the National Trust