Response to West Cumbria MRWS consultation:

Why a deep nuclear waste repository should not be sited in Cumbria

By

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NON-TECHNICAL EXECUTIVE SUMMARY

The Managing Radioactive Waste Safely (MRWS) process uses the unique concept of a 'volunteer approach' to siting a deep geological nuclear waste repository. There a suspicion of predetermination because the only district that has come forward is West Cumbria.

A national site search based on geological criteria was carried out in the 1980s. The site finally selected was Longlands Farm, near Sellafield, but this was very different, geologically, from the 'Sellafield' in the original list of 437 potential sites. Criteria were manipulated and the site location moved twice, to ensure that a near-Sellafield location was chosen. But the Inspector at the Public Planning Inquiry of 1995-96, held to determine whether Nirex could go ahead at Longlands Farm, rejected Nirex's proposals. He said that the underground laboratory was the precursor to a full underground repository, that the site had been chosen on manipulated criteria, that the geology and hydrogeology were unsuitable, and that some of the 'more promising' sites elsewhere in England should be investigated instead.

National and international guidance on how best to select potential sites for deep geological nuclear waste disposal is being ignored. Among the desirable criteria cited the same themes emerge; of geological simplicity and slow, predictable groundwater flow, because the final and most important barrier to escaping radioactivity is always the natural geology. Defra has misled the public in implying that 'voluntarism' abroad has taken precedence over geological search criteria, whereas in all other countries the geological search came first.

Topography is the driving force for groundwater flow, and in Cumbria it is extreme compared to chosen repository sites in Finland, Sweden, the Wash/Norfolk region (a potentially suitable area for search), and even to Switzerland. Thus the Cumbrian topography alone is a sufficient ground to exclude the whole region.

Cumbria is geologically very well understood, so we already know enough to be able to make decisions about its suitability. Every possible district and rock formation is reviewed. The location of the geologically complex original Longlands Farm site is highly constrained, and there is no possibility of relocating it to a better position. It is the 'least unsuitable'site in the district. Northern Allerdale should have been excluded from further consideration, both on its hydrocarbon potential and on current groundwater use; nevertheless the rocks there are unsuitable. The Eskdale granite is a highly fractured body of rock next to a major fault line, and therefore unsuitable. Limestones around the fringes of the national park are similarly too faulted and complex. The offshore zones up to 5 km from the coast do not have any suitable rock bodies, and in any case, a site offshore would contravene international conventions. In summary, there are no districts, localities, or suitable rock types which could host a repository, irrespective of the extreme topography.

The current MRWS process depends upon the assent of an undefined 'community'. It is now claimed that Longlands Farm is, after all, potentially suitable; in so arguing the Inquiry Inspector is misquoted, and non-existent BGS support is cited. Analysis of Nirex's modelling used in this argument shows that if realistic assumptions are made about the faulting, the flow will be upwards, straight to the surface, in 5000 years. The site is demonstrably unsafe.

There are no criteria for finding suitable host rocks in MRWS Stage 4. There are no measures, nor funding, to enable truly independent, critical assessment, in contrast to Sweden and Canada. To return to West Cumbria would be scientifically irrational.

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DETAILED SUMMARY

This document is necessary because there has been a revival of the search for a UK radioactive waste repository within the last decade, under the aegis of 'Managing Radioactive Waste Safely'. The current search has become focussed around the concept of a unique 'volunteer approach', which has a strong air of predetermination because the only district that has come forward is West Cumbria.

The history of site search in the UK is reviewed. The 1970s approach of mapping potentially suitable host rocks was replaced in the 1980s by a classification of suitable hydrogeological environments. A national site search resulted in 537 potential sites being pinpointed. A coastal Sellafield site was included, in the expectation that thick evaporites would be present. When this site was found to be geologically unsuitable, another inland site near Sellafield was identified, even though it it did match any of the hydrogeological categories, in particular BUSC (basement under sedimentary cover). That site was itself shifted, to end up at Longlands Farm. The history of this manipulation to retain a 'Sellafield option' has itself been obfuscated. The new site was added to shortlists at a late stage, and the Secretary of State endorsed the two 'nuclear'options in the final shortlist. Sellafield was selected and Dounreay, the other such site, was dropped. Longlands Farm is not a true BUSC site; a fact with which the 1995-96 Inquiry Inspector concurred. The Inspector found that the site did not conform to the then-prevailing IAEA guidelines on site selection.

Evolution of international guidance and practice since 1997 is reviewed. The 1994 IAEA guidelines are being replaced by a new IAEA draft. BNFL held a majority stake in Pangea, a company set up to find a site for the world's nuclear waste. Pangea drew up a comprehensive list of site desiderata. The BGS, which drew up the 1980s hydrogeological environment list, still uses that list. Similar criteria are employed by the Geological Survey of Finland, and by the Joint Research Council of the European Union. In Finland, Sweden, France and Switzerland systematic geological searches were carried out, with local community assent or veto coming in at a later stage. From all these sets of guidelines and instances, a common list of desirable criteria can be drawn up, but West Cumbria fulfils none of them. The UK once had a leading role in nuclear waste disposal research, but the futile concentration on Sellafield has meant that the UK is now 20 years behind other leading countries. The overriding emphasis on voluntarism is unique and unsupported either by any guidelines or by practice anywhere else.

Cumbria is geologically very well understood, and has been so in a relative sense since the dawn of geology as a science. Topography is the driving force for groundwater flow. The extreme topography of Cumbria is compared with that of the two chosen repository sites in Finland and Sweden, and with the Wash/Norfolk region, which is a potentially suitable area for search. A detailed topographical comparison between Cumbria and northern Switzerland, where there are three possible sites for HLW and ILW, shows that Cumbria is twice to four times as unfavourable as Switzerland in terms of potential to drive groundwater flow. Thus the Cumbrian topography alone is a sufficient ground to exclude the whole region.

The relevant geology of the following districts and/or formations is examined in turn, to account for every possible volume of rock not already excluded by the BGS screening report. The Borrowdale Volcanic Group (BVG), the host rock in the Nirex Site area selected and studied in the 1990s, is extremely complex. The location of the site is highly constrained geologically on all four sides, and there is no possibility of relocating it to a better position.The coastal strip south of Longlands Farm is underlain by limestone above the BVG, and lies adjacent to the Lake District Boundary Fault (LDBF). The locality is therefore worse than Longlands Farm. Similarly if one moves northwards from Longlands Farm, to seek an alternative BVG location, the complexity increases further. Longlands Farm could be said to be the 'least unsuitable'site in the district.

Northern Allerdale has been thoroughly explored for hydrocarbons over the last 40 years. A compilation of all past and current exploration licences forms a contiguous area from Carlisle and points east, round the northern and western margins of the National Park, and down to Longlands Farm. The BGS screening report (2010) is inconsistent and illogical regarding the hydrocarbon exploration that has been carried out here, and the risk of possible future 'intrusion'. The hydrocarbon exclusion criterion is illogically limited only to areas where there are discovery wells, whereas it remains possible that future exploration efforts may intrude into a repository.

The Carboniferous limestone belt around the edge of the National Park is a textbook example of complex geology; it compares unfavourably with the northern Swiss clay site, which is a model of simplicity. No site can be found here in such complex geology and high relief terrain. The simpler Solway plain sediments do not host any evaporites. The Mercia Mudstone Group (MMG) is a Secondary B aquifer with current water abstraction wells. It should therefore have been excluded in the screening exercise, but the BGS claims, without justification, that only aquifers extending in depth from 200 to 800 m need be excluded. The MMG is less than 500 m deep, so its groundwater will be fresh; it is cut by large faults, and has all the characteristics of an oxidising environment. There is nowhere a repository could realistically be sited within the MMG. Lastly, the hydraulic conductivity is 10^4 to 10^6 times higher than that considered desirable.

The Eskdale granite is older than most UK granite bodies, and pre-dates the Acadian orogeny which has severely faulted it. There may be hyperpermeable fracture zones, as found within the Weardale granite. The groundwater environment is oxidising and therefore unsuitable for a repository. It is close to the LDBF, one of England's largest faults. These factors, plus the high relief, rule it out for investigation.

Lastly, the offshore zones within 5 km of the coastline are shown to be unsuitable even though the groundwater within the submarine rock formations will be saline. In summary, the detailed geological review confirms that there are no districts, localities, or suitable rock types which could host a repository.

The current MRWS process depends upon 'community' assent, but 'community' is not properly defined; there are large tracts of the UK, including several promising short-listed sites of the 1980s, in which there is simply no 'community'. The process claims transparency, but the concept of peer review is misunderstood and limited to a type of technical peer review. Nirex, NDA and MRWS have suggested that the Longlands Farm site is, after all, potentially suitable; in so arguing they misquote the Inquiry Inspector; they claim that the Nirex 97 set of documents demonstrates that the site is safe; and they cite BGS support for this claim, which the BGS categorically denies.

My analysis of the Nirex 97 modelling shows that permeability assumptions have been manipulated to give a predicted groundwater pathway from the putative Longlands Farm repository to the coast, with a travel time of 55,000 years, whereas if realistic and honest assumptions are made about the faulting, the flow will be upwards, straight to the surface, in one-tenth of that time or less. My view is corroborated by recent water well drilling. So the Nirex 97 safety case is a failure.

The NDA analysis of how suitable host rocks will be found in MRWS Stage 4 says, in effect, that 'suitable host rocks will be found'. This inference is meaningless. There are unanswered questions on regulation; for example, the Office of Nuclear Regulation and the Environment Agency have no remit to comment upon voluntarism and the resulting selection of West Cumbria. The Committee for Radioactive Waste Management declines to comment on the suitability of West Cumbria. As a result, the public may have no confidence in the assertion that UK regulation will ensure that no unsuitable repository site is developed. But there are no measures to enable truly independent, critical assessment, in contrast to Sweden and Canada.

There is some evidence that the entire MRWS process presumed that West Cumbria could be revived under the guise of voluntarism. This would be predetermination, not consultation. The completion of the Nirex 97 set of science documents, after the Inquiry had been decided, and the more recent claims that the Sellafield area is, after all, potentially suitable, support this view; it is backed up by some assertions that are clearly unfounded, for example that the BGS supports this view.

In conclusion, there are more than 30 concerns and questions to be addressed. There are too many factors against the search for a site in West Cumbria – the previous search history; the outcome of the Planning Inquiry, the geology and hydrogeology, the international view, the unique but dubious search methodology adopted, and the strong suspicion, backed by evidence, that the entire consultative approach is predetermined on returning to that area.

My analysis of the geology and hydrogeology uses all available information. The rational way forward is for the government to drop any idea of trying to find a waste repository site in West Cumbria. We owe it to future generations not to try to site a repository in such an unsuitable region.

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ACRONYMS AND ABBREVIATIONS

Andra	Agence nationale pour la gestion des déchets radioactifs (French national agency for management of radioactive wastes)
AOS	Area of search
ARIUS	Association for Regional andInternational Underground Storage
ASN	Autorité de Sûreté Nucléaire (French Nuclear Safety Authority)
BGS	British Geological Survey
BNFL	British Nuclear Fuels Limited
BVG	Borrowdale Volcanic Group
BUSC	Basement under sedimentary cover
CoRWM	Committee on Radioactive Waste Management
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DWR	Deep waste repository
EA	Environment Agency
EU	European Union
HSE	Health and Safety Executive
IGS	Institute of Geological Sciences
GDF	Geological disposal facility
GTK	Geologian Tutkimuskeskus (Geological Survey of Finland)
HLW	High level waste
IAEA	International Atomic Energy Agency
ILW	Intermediate level waste
LDBF	Lake District boundary fault
LDBFZ	Lake District boundary fault zone
LLW	Low level waste
MMG	Mercia Mudstone Group
MOD	Ministry of Defence
Nagra	Swiss National Cooperative for the Disposal of Radioactive Waste
NGO	Non-governmental organisation
NII	Nuclear Installations Inspectorate
ONR	Office of Nuclear Regulation
PDF	Probability Density Function
RCF	Rock characterisation facility
RWMD	Radioactive Waste Management Directorate
SFOE	Swiss Federal Office of Energy
SKB	Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Company)
SSM	Strål säkerhets myndigheten (Swedish Radiation Safety Authority)
STUK	Säteilyturvakeskus Strålsäkerhetscentralen (Finnish Radiation and Nuclear Authority)
TVO	Teollisuuden Voima Oy (Finnish company responsible for nuclear waste disposal)
URL	Underground research laboratory

1 INTRODUCTION

1.1 Relevant personal details from my CV

I am Emeritus Professor of Geophysics in the University of Glasgow. Although I am now a French resident I remain a British citizen, and take an active interest in UK, French and foreign affairs, as well as in various facets of scientific research.

Prior to my taking up the Chair of Geophysics at the University of Glasgow in 1988 I was employed by the British Geological Survey (BGS) in Edinburgh, from 1973 to 1987. I was a research scientist, rising to the post of Principal Scientific Officer. During that phase of my career I remember being asked to comment briefly on the suitability of offshore islands west of the UK, and of offshore salt domes in the southern North Sea, as potential nuclear waste repositories.

I served on the BNFL Geological Review Panel from 1990 to 1991. I was invited to join the panel by one of its members, Professor John Lloyd, a hydrogeologist from the University of Birmingham. The panel comprised four university professors, with expertise in: hydrogeology (Lloyd), structural geology (Coward), sedimentology (Williams) and geophysics (myself). I served on this panel to support BNFL's case for a Sellafield site for a Potential Repository Zone (PRZ), at the time when Nirex was investigating both Dounreay and Sellafield. I resigned from the panel after the case for Sellafield had been successfully made.

I was closely involved with Nirex during the early 1990s. I was surprised that Nirex had ruled out the feasibility of three-dimensional (3D) seismic surveys at Sellafield, and offered to conduct for Nirex an experimental 3D survey, which took place in 1994. The survey encompassed the volume of the proposed rock characterisation facility (RCF) – a deep underground laboratory planned as a precursor to actual waste disposal. This was a double world 'first' – the first ever 3D seismic survey of such a site, and the first academic group to use this method, which at the time was just emerging as an essential tool of the oil exploration industry. Unfortunately, the 3D seismic imaging showed that the geology of the site was far more complex than Nirex had assumed, and that the geological structure differed greatly from Nirex's predictions.

The Sellafield public planning inquiry appeal of 1995-96 by Nirex into Cumbria County Council's refusal of planning permission to develop the RCF took evidence from a number of expert scientists and engineers, myself included.

1.2 Why this document is necessary

There has been a revival of the search for a UK radioactive waste repository within the last decade, under the aegis of the banner 'Managing Radioactive Waste Safely'. The current search has become focussed around the concept of a unique 'volunteer approach', in contrast to a period between 1997 and 2002, when after the failure of Nirex to gain permission to develop its underground site near Sellafield in West Cumbria the government, through its company British Nuclear Fuels Limited (BNFL), tried to find a 'world-class' geological site for international disposal of such waste.

The current campaign has a strong element of predetermination about it, in that there appears to be a hidden agenda geared towards reviving the failed site search in West Cumbria, the only district to have volunteered, notwithstanding its evident unsuitability as demonstrated by the Public Planning Inquiry documentation of 1995-96.

I have been obliged to put online for the public record the relevant documentation from the 1995-96 Public Planning Inquiry, including the submissions by Nirex as well as by the Objectors. Part of the government's strategy (by 'government' I include its agencies such as Nirex, the Nuclear Decommissioning Agency, etc., as well as departments) has been to suppress information about its comprehensive failure at the Planning Inquiry, particularly on the geological aspects of the safety case.

I have also been obliged to recount the history of site selection between the 1970s and 1980s which led to the selection of Sellafield (Longlands Farm) as the only site which was thoroughly investigated by Nirex between about 1988 and 1997. I shall show that this choice was influenced almost entirely by political factors, and not by sound science. Furthermore, the publication of such a history in 2005 by Nirex is misleading and partial, despite claims by Nirex to have learned lessons about openness and transparency as a result of its Planning Inquiry fiasco. The Inquiry Inspector concluded that Sellafield should never have been chosen, and recommended that a new search should be instigated at one of the more promising sites elsewhere.

The new overriding policy of so-called 'community voluntarism' was fed to the Committeee on Radioactive Waste Management (CoRWM) by Nirex in 2004, ostensibly as a means of circumventing the difficult political decisions involved in persuading affected members of the public to accept a deep waste repository. At around the same time Nirex promoted the view that the Longlands Farm locality could, after all, be a potential repository site, and that the Inquiry failure by Nirex was one of prematurity and local planning issues - and not a fundamental problem with the geology and hydrogeology. One of the arguments put forward was that if only the 'Nirex 97' set of scientific documents had been available in time for the Inquiry, the Inspector would probably have been persuaded of the soundness of the safety case. This is not so, as I shall show by analysis of these documents.

Part of the campaign of disinformation led by the NDA and WestCumbria:MRWS has included the misleading suggestion that voluntarism, rather than sound geology, has been successful in other countries. This is untrue, as I shall demonstrate below. The NDA has even deceitfully tried to suggest that the British Geological Survey (BGS) supports the new-found feasibility of the Longlands Farm site; papers commissioned by MRWS have also proposed that there is BGS support for certain aspects of the geology of West Cumbria which might favour a repository site. This so-called support is merely hearsay.

The volunteer approach to the search for a waste repository is unique worldwide, and ignores all national and international guidelines. It has gone ahead even though only one locality has come forward - the two district councils which host Sellafield and much of its workforce, plus the umbrella county council. If the hidden agenda has indeed been to revive the Sellafield option, then it has succeeded so far; no matter that no other districts or local councils have volunteered.

The schedule for following the MRWS process, now confined to West Cumbria, is designed to delay real geological decisions for as long as possible. The strategy employed here has been one of *agnotology* - pretended ignorance of knowledge and understanding of the geology of the region. A preliminary 'screening' review has been commissioned from the BGS, contrary to international guidelines (e.g. from the International Atomic Energy Agency), which propose that regional and then local surveys should precede 'screening-out'. The screening-out review by the BGS has left about three-quarters of the so-called 'partnership area' in play; this has given the misleading impression to the lay public that a full geological study has already been carried out and that most of the area has 'passed' the test. But even within the remit of its preliminary screening, the BGS has subverted some of the guidelines, particularly regarding groundwater resources.

The geological and hydrogeological facts are simple. In principle; the proximity of high mountains and sea is in itself enough to rule out the low-lying coastal areas of West Cumbria, whatever the geology might be. But added to that, the geology is highly complex and unpredictable in hydrogeological terms. It could be argued that Longlands Farm was, in fact, the 'least unsuitable' site available in the region - but this is where, after the expenditure of some £400M, the Inquiry found it wanting.

It was suggested, in the discussion following a public lecture I gave in Cockermouth on 2 February 2012, that the UK regulatory process will eventually discover whether or not there are fundamental problems with any site or sites in West Cumbria, once they have been chosen. In other words, let the MRWS process proceed. I do not share this confidence in the either the Office of Nuclear Regulation or the Environment Agency. Since the government has removed the right of objectors to call for a Public Planning Inquiry in cases involving national infrastructure, the only recourse in law may be Judicial Review.

This document is a compilation of various submissions that I have sent to MRWS since October 2010, but it also contains new material. There is a small amount of repetition within a couple of geological sections, as I have tried to preserve some flavour of the ongoing debate over the year 2011 between myself and a consulting geologist employed by MRWS, who tried to respond to some of my technical issues. But the priority has been to get the facts into the open and into the consultation, even at the risk of some duplication.

The Conclusions section includes a list of concerns to be addressed.

2. HISTORY OF SEARCH IN THE UK UP TO 1997

2.1. Evolution of repository criteria

The BGS (then called the Institute of Geological Sciences, IGS) was involved in early searches for suitable high-, intermediate- and low-level nuclear waste (HLW, ILW and LLW, respectively) repository sites in the 1970s. Areas of crystalline rocks, argillaceous and evaporite formations, considered to be potentially suitable host rocks, were mapped (Mather *et al.* 1979), and specific drilling and research programmes proposed. The slates of the southern Lake District were also identified. The three types of host rock mapped are shown in Figure 2.1.1a.

After the failure of this search due to objections by local populations, a change of geological emphasis took place within a decade.

Bredehoft and Maini (1981) published an influential new strategy for disposal of radioactive waste in crystalline rocks, beneath a 'blanket of sedimentary rocks'; their concept became known as BUSC (basement under sedimentary cover). They illustrated it with a 200 km long cross-section through the coastal plain of Maryland, USA (Fig. 2.1.2). BUSC will be discussed in detail below.

Chapman *et al.* (1986) devised a new set of criteria for disposal of ILW, adapted to the UK. Their comment on the 1970s approach and the new approach they were adopting was stated thus:

> "*the old approach to HLW disposal resulted in the definition of the now widely known and accepted group of host rocks (salt, crystalline rocks and clays), largely on the basis of their low permeability and their thermal stability ... The approach we adopt here differs from earlier exercises, however, in that it is the requisite features of the geological environment (rather than simply the host rock alone) which are considered. In the simplest terms these features will be characterized by:*
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> *- Predictable groundwater flow paths, preferably long and resulting in progressive mixing with older, deeper waters or leading to discharge at sea;*
> *- Very slow local and regional groundwater movements in an area with low regional hydraulic gradients;*
> *- Ease of construction to allow for economic repository design;*
> *- Conformity with the many accepted restrictions regarding seismicity, depth, etc.*
>
> *While this approach inevitably finds us looking again at clays and salts, it considerably restricts what might be considered suitable crystalline rock terrains, and introduces new possibilities where the host rock type may be subordinate to the flow regime (e.g. small island environments ...).*"

The five hydrogeological environments were:

1. Hard rocks in low relief terrain
2. Small islands
3. Seaward dipping and offshore sediments

4. Inland basins
5. Low permeability basement rocks under sedimentary cover (BUSC),

Chapman *et al.* went on to identify potential rock formations in the UK, showing them separately in a series of maps, followed by a compilation map. It is interesting to compare the summary maps from the earlier and the later search exercises (Fig. 2.1.1a and b, respectively). The potential areas shown in each map are almost completely disjoint (that is, having no elements in common). The map of Figure 2.1.1b is the colour version of Chapman *et al.*'s map, eventually published in a review by Michie (1998). It was also published in a slightly simplified form by Nirex (1987) in its brochure *The way forward. A discussion document*. This version is shown in Figure 2.1.3. The 'potentially suitable small islands' were omitted from the map, but discussed in the text.

The Mercia Mudstone Group (MMG) of southern and central England was included in Chapman *et al.*'s analysis, but the MMG in Cumbria was excluded. The two sedimentary areas shown in the inset of Figure 2.1.3 refer to Permian at > 200 m depth. The MMG in Cumbria is discussed in Section 4.7 below.

2.2. How Longlands Farm came to be selected

2.2.1 National site search

The BGS effort which led by a roundabout route to the choice of Longlands Farm began afresh in the 1980s. It should be noted here that the general geological advice given to government by the BGS (that is, the areas of search and the categories of potentially suitable rock formations) has not subsequently been found by any later detailed investigations to be flawed or otherwise incomplete.

The national study by the BGS resulted in a map published in *The way forward. A discussion document* by Nirex (1987). The coastal plain of West Cumbria was included under 'Areas of potentially suitable sedimentary formations', contiguous with the eastern Irish Sea, Solway Firth and onshore Solway Basin around Carlisle (Fig. 2.1.3). The sediments identified were Permian (Chapman *et al.* 1986). But no BUSC environment was identified anywhere in Cumbria. This is a factually correct finding by the BGS; there was no inadvertent omission.

The site search was conducted for Nirex by Pieda (1989a), relying on the BGS for the geology input. The remit was to find potential sites onshore, accessed from a land base, or sub-seabed sites accessed from a coastal land base. The hydrogeological environments explicitly followed the classification by Chapman *et al.* (1986), listed above. An initial list of 537 sites (Pieda 1989b) was compiled, with the following classifications:

1. BUSC inland
2. BUSC coastal
3. Coastal
4. Hard rock coastal
5. Hard rock inland
6. Inland
7. Sedimentary coastal
8. Sedimentary inland
9. Small island

10. Ex-AOS coastal (AOS = area of search)
11. Ex-AOS inland.

In this initial list ‘Sellafield’ appears once, no. 433 in alphabetical order, and classified as ‘Sedimentary coastal’. This site later became known as Sellafield-A. The target host rock was impermeable anhydrites of Permian age known to be present in the region. However, the Sellafield-3 borehole, drilled in early 1991 at the coast inside the Sellafield Works, confirmed, as suspected a few years previously, that the anhydrites were too deep there, at 1270 m depth and deeper, to be of use as a potential repository. They feather out inland at approximately the same line as the limit of the Carboniferous Limestone.

2.2.2 Any site - as long as it is at Sellafield

Nirex (2005b) has recently tried to document the history of the site selection process, as part of its new, belated, policy of transparency. However, this account is disingenuous, because it describes the site ‘sieving’ from the initial 537, down to the last few, and then leading to the final choice of Longlands Farm, without ever clarifying when, exactly, this particular version of a ‘Sellafield’ site appeared in the lists. Thus, for example, the document lists comprehensively the sites *excluded* at each stage of the sieving process, but without declaring the initial list. To rectify this omission I compiled a fresh initial list (Smythe 2011a) from the Pieda documents. This list is reproduced herein as Appendix A.

The Nirex (2005b) site selection review goes on to account for the apparent “*late introduction*” of the ‘BUSC option’ at Sellafield by explaining that:

> “*Some* “*sites*” *had two or more repository options associated with them which would potentially exploit different geological or hydrogeological settings believed to lie under the site and which would be located at correspondingly different locations on the site*.” (Nirex 2005b, section 7.5).

This is incorrect; there are four instances in the initial list of 537 sites (Colchester Barracks, Farnborough, Long Marston and Risley) where sites under both the same ownership and geological setting have been identified separately, even though they are less than 5 km apart. So Nirex is trying to argue here that the initial single ‘Sellafield site’ was really intended all along to include the Pelham House School option (Sellafield-B), which lies 3 km north of Sellafield-A, *and* which belongs to a different classification. Nirex’s explanation is unconvincing. The reasonable conclusion is that Sellafield-B was in fact only introduced late on in the site selection exercise. The progressive migration of ‘Sellafield’ is depicted in Figure 2.2.1, based on the Pieda maps.

Even more curious than this omission is the assertion in the document that at the sieving exercise of December 1987, when 39 sites were whittled down to 17 onshore, Sellafield-A was not “*discussed*”, whereas a new site Sellafield-B was discussed - having evidently just been introduced. Apparently the interpretation of the seismic data by then available had suggested that the anhydrites (the Sellafield-A option) would be too deep – as was later confirmed by the Sellafield-3 borehole. Clearly, the attempt to find a site within the vicinity of the Sellafield Works was distorting the whole process in 1987 – just as it is doing now.

McEwen (2011) disputed the version of events described above, and has tried to provide more detail. He was the one of the principal BGS geologists collaborating with Pieda in the site search, as well as being a co-author of Chapman *et al.* (1986). However, his account tends only to confuse matters further because he quotes very few dates. He stated:

> "*The arguments that Smythe* [Smythe 2011b] *uses to distinguish between Sellafield-A and -B and when and why they were chosen is far more complex than actually took place. One of the problems is that Nirex insisted on using the term BUSC to refer to Sellafield-B, when this term should never have been used – in fact they tended to refer to Sellafield-B as a* '*modified BUSC environment*'. *They were advised by me and others that the use of this term would only confuse matters, but to no avail.*"

McEwen seems to accept here that the inland 'Sellafield' sites with BVG as a host rock were not BUSC at all, but he does not offer an alternative description. He goes on:

> "*it was at this stage that two potential sites at Sellafield, Sellafield-A and Sellafield-B, came into existence and it was decided, in order to allow more definitive decisions to be made, that a seismic survey should be organised - this was done and the results interpreted by the BGS. However, in late 1987, before the seismic survey took place, which was in February 1988, the Sellafield-A option had already been dropped in favour of Sellafield-B – this was in part due to the fact that developing a repository in anhydrites was thought to be a less feasible option than the possibility of developing a repository in basement rocks*"

Sellafield-B, the original so-called 'BUSC option', was located at Pelham House School. But even Sellafield-B was not the final choice of Potential Repository Zone (PRZ). As the Inquiry Inspector (McDonald 1996) states:

> "*Nirex moved the location to Longlands Farm in 1989 to avoid the Carboniferous Limestone present under Sellafield B. The Newton Manor Estate, including Longlands Farm, had been offered for sale to BNFL in 1987, but was not purchased until March 1989* (McDonald 1996, para. 6B.31).
>
> *6B.34 The geological and hydrogeological requirements within the PRZ include a minimum of 100 m to 200 m of BVG cover over the DWR and a maximum depth below ground level of 1000 m. The PRZ is contained by the presence of permeable Carboniferous Limestone to the north west, the Fleming Hall Fault Zone (FHFZ) to the southwest, the Seascale Fault Zone (SFZ) to the southeast and the National Park boundary (A595T), where BVG cover is reducing, to the north east .... The 2 fault zones are presumed to be associated with enhanced hydraulic conductivity*". (McDonald, op. cit.).

2.2.3 Why Longlands Farm is not a BUSC site

Nirex insisted on calling Longlands Farm a 'modified BUSC site'. It is worth summarising what Bredehoft and Maini (1981), the authors of the original BUSC concept, said. Their motivation was stated at the outset:

> "*Public acceptance of a waste repository depends on credible predictions of waste movement. Such predictions are difficult because the waste movement (or nonmovement) must be predicted for periods approaching geologic time. For nuclear wastes, predictions for periods of at least 1000 years are required, and, depending on*

> *the particular nuclide, perhaps 100,000 years or even longer.*"

The essence of the hydrogeological system is that the blanket of sedimentary rocks overlying the basement crystalline host rock controls the overall system, and is *credibly* predictable. The water in the crystalline rocks may also be saline, and unlikely, therefore, to be sought out for consumption. But the length scales of their example coastal plain system (reproduced in Fig. 2.1.2) are completely different from the available geology on the coastal plain of West Cumbria.

Figure 2.2.2 shows the Bredehoft and Maini coastal plain cross-section mirror-imaged and rescaled to match the Cumbrian cross-section. Vertical exaggeration in both cases is x10. We see that in the Cumbrian section:

- Horizontal scale is compressed by x 20.
- Height of terrain within zone of interest is higher by x 20.
- Dip of the sedimentary layers higher by x 40.

So the relative proportions of BUSC, compared to the prototype model are distorted by 20 x 20 = 400, or about two and a half orders of magnitude. This makes a mockery of the BUSC concept, with the result that the water flow patterns within West Cumbria are far too vigorous and complex – it is not a BUSC environment.

The geology, hydrogeology and safety case modelling will be discussed in more detail below; this section merely demonstrates that it did not, and does not, conform to acceptable standards of hydrogeological environment. In short, the Longlands Farm is a highly complex piece of three-dimensional geology comprising complex volcanic rocks underlying faulted sediments which are major drinking water aquifers; the whole complexity being compounded by mountains to one side and sea to the other.

To summarise the site search exercise; nowhere in West Cumbria was there to be found a true BUSC environment. The only sound environment identified by BGS in the search exercise was the (seaward-dipping) coastal sedimentary strip west of the Lake District Boundary Fault, within which it was hoped that the known anhydrite formation would prove to be a suitable candidate. Neither Sellafield-B nor Longlands Farm were in the initial search list. The Inspector was not impressed by Nirex's attempts to justify these two sites as so-called 'BUSC variants':

> " *... there seems to be little strength in the belated argument that Sellafield B is itself a form of BUSC site. The claim tends to confuse the description with the basic concept. The BGS has not mapped any BUSC area in West Cumbria.*"(McDonald, op. cit., para. 6B.99).

Leaving aside the politically-driven site selection process which led to Longlands Farm, and considering that PRZ on its own merits, it can be concluded from the Inquiry evidence that the location was nevertheless the best available within the region. It had already been shifted from the earlier 'BUSC' option of Pelham House School, to avoid the Carboniferous Limestone subcrop there. It is highly constrained on all four sides.

The deep geology of West Cumbria is now so well-understood that there is no realistic possibility that a new PRZ could be discovered that is geologically simpler than at the chosen

Site. Since Longlands Farm failed the test of the Inquiry, it would now be irrational simply to move to a new location somewhere else within West Cumbria. But in order to pre-empt a possible counter-argument along the lines of '*We have not yet studied in detail the other localities, so how do we know that other suitable locations do not exist?*' I shall summarise in Section 4 the relevant geological detail in each locality, to demonstrate that the other localities in West Cumbria are even less suitable than Longlands Farm.

2.3. The Nirex inquiry and international guidelines on siting

The International Atomic Energy Agency (IAEA) published a guide (International Atomic Energy Agency 1994) to the siting of radiactive waste disposal repositories. The IAEA key locational criteria were summarised by the Nirex Inquiry Inspector (McDonald 1996) as follows (the guide was referred to in the inquiry as GOV/507; DWR means deep waste repository):

> "*6A. l l The key locational principles are set out as site selection guidelines at GOV/507 paragraphs 404 et seq. to achieve* "*adequate isolation of radionuclides from the accessible environment for desired periods of time*" *[idem, para. 301]. The guidelines are not meant to be complete, neither should they be applied in isolation but used in an integrated fashion for an overall optimisation of site selection [idem, para. 403]. In summary, the DWR locational criteria are:*
>
> > *a. a geological setting to inhibit the movement of radionuclides from the (DWR) to the environment during the time periods of concern [idem, para. 404];*
> >
> > *b. sufficient distance from geological discontinuities that could provide a rapid pathway for radionuclide transport: uniform rock formations in comparatively simple geological settings and formations with few major structural features or potential transport pathways are preferred [idem, para. 405];*
> >
> > *c. favourable mechanical properties of the host rock to ensure long term stability and so safe construction, operation and closure of the DWR and resistance to gas transport [idem, para. 406];*
> >
> > *d. absence of unacceptable susceptibility to future geodynamic phenomena and consequent radionuclide release [idem, paras. 408-409];*
> >
> > *e. restricted groundwater flow but sufficient dilution capacity [idem, paras. 412-413];*
> >
> > *f. physicochemical and geochemical characteristics of the geological and hydrogeological environments that tend to limit the release of radionuclides from the DWR [idem, para. 416];*
> >
> > *g. minimisation of the risk of human intrusion [idem, para. 420];*
> >
> > *h. acceptable radiation exposures to the public from transportation of the waste [idem, para. 429].*"

The Inquiry Assessor reviewed the basic criteria for a UK repository in considerable detail

(Knipe 1996), and concluded:

> "*A.61 Although international and national guidelines emphasise that in judging a specific repository it is the total system that must be taken into consideration and the geological environment should not be considered in isolation, I consider that during the site selection stage in reducing the target areas to a small number, priority should be given to those qualitative geological and hydrogeological factors that are most likely to lead to a robust and demonstrable safety case: a preference for regions of low hydraulic gradients; a preference for uniform rock formations in comparatively simple geological settings with few major structural features or potential transport pathways since such environments are likely to be more readily characterisable and predictable; and a preference for regions that are relatively stable in terms of earth movements and other long term geodynamic effects*."

As we shall see in the following section, Knipe's summary of the then-prevailing guidance on how to select a site is pertinent today.

3. EVOLUTION OF INTERNATIONAL SEARCH CRITERIA AND PRACTICE SINCE 1997

3.1 International Atomic Energy Agency (IAEA)

The guidance given by the IAEA (International Atomic Energy Agency 1994) referred to by the Inquiry and discussed above, on waste repository siting is due to be updated or superseded by a new safety standard, of which the draft form is referred to as document DS334. This draft document has been available since 2007, but has not yet been ratified. Here I quote the May 2010 version of the draft (International Atomic Energy Agency 2010). One of the 29 authors is Dr T. McEwen. The draft states:

> "*This Safety Guide is primarily concerned with activities associated with the development of geological disposal facilities after a site has been selected. ... Whilst site characterization and site confirmation are addressed in this Safety Guide, site selection is not because it includes many aspects that are non-technical and specific to the societal context*",

but nevertheless has an appendix providing "*General recommendations regarding the technical and scientific aspects of siting*". These recommendations are anodyne, often self-evident, highly generalised, and so full of caveats and let-out clauses that they allow complete freedom of action; for example:

> "*The regional mapping or investigation may, for example, cover the whole territory of a region defined by natural or political boundaries, or may be restricted to lands adjacent to major waste generators in a State.*"

The statement above does not provide any guidance of substance. The state in question is clearly free to define the so-called 'regional investigation' how it sees fit. In the current MRWS process, the region could be defined to be the whole of England and Wales, or could equally be defined as the locality within (say) a 2 km radius of the Sellafield works. The upper limit of the 'region' is defined as the boundary of the state, which is of the order of 150,000 km^2 for England and Wales; the lower limit could be as little as 5 km^2. Such a permissible ratio of 30,000 in magnitude for the definition of a region renders it effectively meaningless (in the case of the USA, for example, the ratio would be 200,000).

Nevertheless, a sequence of steps is identified in DS334 which may be compared to the current MRWS process. These are:

1. Conceptual and planning stage.
2. Area survey stage, comprising, in order:
   "*(a) A regional mapping or investigation phase to identify areas with potentially suitable sites;*
   (b) Screening to select one or more potential sites for further and more detailed evaluation."

Stage 1 above has presumably included the consultations, definition of the multi-barrier concept, and so on, which have taken place in the UK since the inception of the MRWS process in 2001. But stage 2 has not been correctly followed in the UK.

Stage 2(a) starts by definition of the criteria for choosing regions of interest, which include: "*geographical, geological and hydrogeological attributes beneficial for the disposal concept*". In stage 2(b):

> "*potential sites are identified within the suitable areas. The screening of potential sites may involve some factors not considered in the regional mapping phase, including socio-political criteria if not previously used. For example, in the regional analysis and the subsequent screening of potential sites many national laws and regulations will need to be considered (e.g. important groundwater resources, national parks, historical monuments).*"

In the UK stage 2(a) has not been followed. The call for volunteer communities to come forward has resulted in only one contiguous area of the state to become the 'region of interest', and this has not been selected by the required attributes mentioned above. There was no 'definition of criteria' other than the volunteer approach. Stage 2(b) may or may not have been fulfilled by the BGS (2010) screening exercise.

If, on the other hand, the BGS exercise is considered to be the "*regional mapping or investigation phase*" of DS334 stage 2(a), it follows that:

1. A pre-selection phase (voluntarism) was carried out.
2. "Initial unsuitability screening" (the title of the BGS report) really means "regional mapping or investigation".
3. The screening exercise has yet to take place, presumably in MRWS stage 4.

But this explanation is inconsistent with the various references to '(initial) screening-out', and '(initial) (subsurface) (geological) screening' (the adjectives in brackets being optional) in the MRWS White Paper (Defra 2008), which all explicitly refer to MRWS Stage 2. There is no reference to screening in connection with MRWS Stage 4. So this latter explanation has to be rejected. In short, the BGS screening exercise was indeed Stage 2(b).

In conclusion, a volunteer approach has been used at Stage 2(a) *in place of* the recommended criteria for choosing regions of interest. The draft international recommendations have not been followed.

3.2 BNFL and Pangea

Some of the information herein comes from Pangea's archived website:
http://wayback.archive.org/web/20090601000000*/http://pangea.com.au,
from the Wikipedia webpage http://en.wikipedia.org/wiki/Pangea_Resources,
and from Hansard written answers of 1999:
http://www.publications.parliament.uk/pa/cm199899/cmhansrd/vo990505/text/90505w11.htm, as well as the citations below.

Pangea Resources Australia Pty Ltd and Pangea Resources International ('Pangea') was a commercial joint venture of BNFL, Golder Associates and Nagra, set up in 1997 and wound down in 2002, being replaced by an association ARIUS. The holdings were: BNFL (80%), with Golders and Nagra each holding 10%.

BNFL was a company wholly owned by the government, which became aware of BNFL's involvement with Pangea in September 1997 (this fact is confirmed by a House of Commons Written Answer). The aims and policies of Pangea are therefore those of the government, albeit approved at arm's length by the intermediate investment in BNFL.

Pangea's aims were to promote the development of international long-lived radioactive waste repositories. Particular emphasis was put on Australia, which had the characteristics for a 'high-isolation' waste dump (Black and Chapman 2001). Dr Chapman of Pangea previously worked for the BGS, and was the lead author of the 1986 paper on geological environments discussed in section 2.1 above. Pangea had a scientific review group chaired by Dr P. Cook, Director of BGS 1990-98, who had previously had strong links to Australia.

Pangea identified the ideal repository site "*which would be not only extremely safe but also so simple that the safety case could be demonstrated with most transparency - for the public as well as for the experts*" (McCombie 1999). The essential or favourable characteristics of such a site were listed as follows:

1. Stable geology (needed because of the long isolation times aimed at).
2. Flat topography (reduces driving forces for advective groundwater flow).
3. Near-horizontal sedimentary strata (simpler to explore and extrapolate).
4. Stable, arid climate with little erosion (eases problem of extrapolation into the future).
5. Low permeability (reduces groundwater movements in host rocks).
6. Old and saline groundwater (indicates slow natural circulation; non-potable).
7. Stratified salinity (counteracts thermal buoyancy effects).
8. Reducing geochemical conditions (reduces solubilities of radionuclides).
9. Absence of complex karst systems (simplifies hydrogeologic modeling).
10. Low population density (reduces intrusion risks).
11. No significant resource conflicts (reduces intrusion risks).

In addition to the list above there is a promotional Pangea video clip:
(http://www.youtube.com/watch?v=UjBSAlu0hjM) in which the voice-over states

> "*Migration in groundwater is most serious when there is high rainfall, permeable rocks, and hills or mountains to drive the water flow.* [2 min 48 s]
> ...
> *So, we are looking for large flat remote areas with very stable and long-lived geology, no economic mineral resources, with an arid climate, and no prospect of short term climate variation and glaciation* [3 min 28 s]" [timings added in square brackets].

3.3 British Geological Survey (BGS)

What is the most recent published BGS view on search criteria? Shaw (2006) asserted that the UK offers a number of options for radwaste disposal, thanks to its "*highly varied*" geology. He listed what is ideally needed for long-term isolation:

- Physical stability (constructability/operational safety);
- Long groundwater return time;
- Relatively simple, predictable groundwater flow regimes;
- Slow groundwater movement/low hydraulic gradients;
- Long term stability.

He also repeated the categorisation of "favourable geological situations" drawn up by Chapman *et al.* a decade earlier:

- Basement under sedimentary cover (BUSC)
- Large inland sedimentary basins
- Low permeability sedimentary rocks
- Low permeability 'basement'rocks
- Low relief terrain (including small islands)

And went on to illustrate these. In conclusion, BGS was following its own (and Nirex's) guidelines of the previous decade. No more recent statement has been published, to my knowledge.

3.4 GTK (Geological Survey of Finland)

Under the heading 'Geological suitability criteria' the GTK (Ruskeeniemi and Paulamäki 2010) stated that it had followed the "*International OECD/NEA guidelines (1977)*" for nuclear waste disposal and site selection, but adapted to Finnish conditions as follows:

- Geological unit of sufficient size to host a deep repository
- Stability of bedrock in terms of tectonics and underground facility
- Sparsely fractured bedrock unit avoiding faults and fractured zones
- Stable groundwater conditions in terms of chemistry and flow
- Retardation capacity for radionuclides
- Smooth topography (low hydraulic gradient, homogeneous stress field)
- Bedrock of common rock types not interesting for raw material exploration

3.5 Joint Research Council (JRC) of the European Union (EU)

Falck and Nisson (2009) summarise the host rocks currently being envisaged within the EU as "*(indurated) clays, fractured hard rocks and salt*". They note that salt is only (currently) relevant in the German case. They stress the importance of the regional geological setting and the timescale to be considered:

> "*A geological repository will form together with the wider surrounding geology the system that is necessary to prevent radionuclides from reaching the biosphere. Therefore, system parameters and materials properties not only in the immediate vicinity of the repository are of relevance, but also those of the surrounding 'catchment area'.*"

The timescale required for consideration is of the order of a million years.

> "*Fundamental criteria include, for instance, long geological stability, low hydraulic gradients and permeabilities, low geochemical and other potentials, etc. In other words, a geological system is sought out that exhibits in its natural state a low potential for change and very slow rates of change.*"

They also state that "*The basic criteria for site selection are host rock independent*", by which I understand that the overall environment is basically more important than the particular rock type, at the site selection stage.

3.6 Search methods abroad

3.6.1 Assertion by Defra on overseas search methodology

The Defra white paper *Managing Radioactive Waste Safely* (Defra 2008) cites examples of other countries where a search for a geological repository is underway. But the history of such searches elsewhere is written up or summarised by Defra in such a way as to wilfully mislead the public about the relative importance of 'voluntarism' over the international guidance on geological search criteria discussed in the previous section. The accounts are essentially dishonest. They are analysed in the following sections, where relevant, as part of a summary of how search methods have been carried out abroad.

3.6.2 Finland

Here is how Defra (2007b) summarises what it calls 'the Finnish experience':

> "*In 1983 TVO ... drew up a list of 101 potential sites and undertook a consultation process with the affected communities. This resulted in the identification in 1985 of 5 potential* '*volunteer*' *sites at which more detailed investigations were carried out. From the investigations four sites were shortlisted for detailed characterisation ...*" [my underlining; TVO is Teollisuuden Voima Oy, the company then responsible for nuclear waste disposal]

This account implies that community consultation and voluntarism progressed in parallel with potential site selection – the elision of the list of 101 sites with a 'consultation process', and the 5 'volunteer' sites later being 'identified'. Neither geology nor any other criteria are mentioned. The impression is given that progress was made overwhelmingly or even completely by 'voluntarism'.

Here is a more trustworthy account from GTK, the Geological Survey of Finland, from its website under the rubric 'Site selection survey and site investigations':

> "*During 1978-1982 GTK conducted a general survey of the suitability of Finnish bedrock for final disposal of spent nuclear fuel, with reference to the international guidelines adapted to the Finnish conditions. ...*
> *The grounds of the subsequent site selection survey, carried out in 1983-1985, was the block mosaic structural model of the bedrock, in which fracture zones of different sizes border the bedrock blocks ...*"

This is illustrated in Figure 3.6.1 (Ruskeeniemi and Paulamäki 2010). The website continues:

> "*In the first phase, 327 regional bedrock blocks* [see Fig. 3.6.2] *surrounded by fracture zones were identified on the basis of interpretation of satellite images, aerial photos, and geological and geophysical maps. After the evaluation of environmental factors and complementary geological studies, 62 regional blocks remained. Inside these large bedrock blocks, 134 potential investigation areas were identified. After the geological classification, including the field checking, evaluation of environmental factors and*

> *evaluation by authorities, 85 potential investigation areas remained. … The preliminary site investigations in five selected sites, carried out in 1987-1992, included deep drillings, and geological, geophysical, hydrogeological and hydrogeochemical investigations.*"

There is no mention of voluntarism anywhere in this extensive process. The five sites are shown in the upper map in Figure 3.6.3. Two of the sites were dropped, and the remaining three were the subject of detailed site investigations between 1993 and 2000.

The first mention of any non-scientific activity I have been able to find in relation to site selection is in a summary table in a sociological review of the process by Litmanen (2008), where, at this juncture "*public protests and local movements started*" during the period 1998-2002. The two sites mentioned above may have been dropped from the shortlist by communal veto.

A new site, Loviisa, was added in 1997 after a new law had been passed in 1994 forbidding export of waste (up till that time the waste at the nuclear plant there had been exported to Russia). It went into operation in 1997 for disposal of ILW/LLW, not for HLW. A new company, Posiva Oy, was established in 1995 to manage final disposal of spent fuel (HLW) for the two operators in Finland. The lower map of Figure 3.6.3 shows the four sites. According to Lidskog and Andersson (2001) the local populations of two of these sites were against hosting a disposal facility, so the choice devolved to the two communes which host nuclear power installations. Olkiluoto in Eurajoki commune was selected in 2001.

So after the extensive geological search, 'voluntarism' in the form of a municipal veto was applied in Finland at the short-list stage of five communes which had been deemed to be geologically suitable in the early 1990s.

3.6.3 Sweden

Defra (2007b) sumarises "*The Swedish experience*" thus:

> "*SKB has been using a staged, volunteer process to identify potential sites since the beginning of the 1990s. After the first attempt to find volunteers failed SKB re-launched the initiative, including proactively approaching existing nuclear communities. This resulted in 8 volunteer communities (5 nuclear communities and 3 communities from next to nuclear communities) coming forward …*"

Again, this statement over-emphasises voluntarism, with no explicit mention of geological criteria.

The Swedish staged site selection process has been summarised by the Swedish Waste Management Company SKB (Svensk Kärnbränslehantering AB 2009). A map from this report is reproduced with annotations in Figure 3.6.4. I have numbered the four maps in this figure. Map 1 shows the "*comprehensive investigations*" carried out at twelve sites (red dots) between 1977 and 1985. The accompanying text refers to only eight sites, in part because hard rock laboratories at Äspö and in the Stripa Mine are shown. These were "*geoscientific*" studies, and met with mixed reactions from the local populations.

The site search was restarted in 1993, with the realisation by SKB that it was reasonable to focus of finding areas where the geology was suitable (of which there were evidently many in Sweden) *and* where communities were willing to participate.

In 1995 the government required that site-specific feasibility studies must have been undertaken at 5-10 sites, and that site investigations have been undertaken at a minimum of two sites, before an application be submitted to construct a repository.

With reference to map 2, SKB states:

> "*During the period 1993–2000, SKB conducted feasibility studies in eight municipalities: Storuman, Malå, Östhammar, Nyköping, Oskarshamn, Tierp, Älvkarleby and Hultsfred. The purpose of the feasibility studies was to determine whether premises existed for further siting studies for a final repository in the municipality in question, while the municipality and its inhabitants were given an opportunity to form an opinion, without commitments, on the final repository project and their possible further participation. A principal task was to identify areas with bedrock that could have potential for a final repository. Geological studies therefore comprised a main component, but no drilling was done at this point.*"

Note that neither of these two phases of investigation included a UK-style voluntarist approach, but in the latter phase communities were given a right of comment and veto. In fact the first feasibility studies were carried out at the two most northerly communes shown in Map 2, but the communities here, having initially shown an interest in the repository siting, later withdrew.

In parallel with the feasibility studies SKB looked at the possibility of siting a repository in a municipality which already hosted nuclear facilities. In brief, three such communities gave their assent to the study, one declined, and the last was found to be geologically unsuitable.

Map 3 of Figure 3.6.4 shows the 'selection pool'of eight sites in five municipalities, covering three different geological environments. Two detailed site investigations were initiated in 2002 (Map 4), leading eventually to the selection of Forsmark, adjacent to a nuclear power plant.

The Swedish case history shows that the geology has always come foremost, albeit with community assent in the form of a veto, which was indeed exercised by several municipalities. Even the proactive search for sites at existing nuclear facilities was carried out with geology in mind. Even so, the final shortlist of two sites, each beside nuclear installations, has been questioned, as well as the decision to drop possible inland sites (Bråkenhielm 2010).

3.6.4 France

Between 1988 and 1989 the French *Agence nationale pour la gestion des déchets radioactifs* (Andra; the national agency for management of radioactive wastes), in collaboration with the the *Bureau de recherches géologiques et minières* (BRGM; office of geological and mining research; the French equivalent of the BGS) found four *départements* (counties) suitable in principle for waste disposal. The fieldwork was abandoned due to local protests.

After a moratorium on further work, a new law was passed in 1991, no. 91-1381, known as the *Loi Bataille* after its sponsor, the *deputé* (MP) Christian Bataille. This law cleverly changed the emphasis from one of final disposal of high-level radioactive waste, to underground research laboratories (URLs) with retrievable storage. Furthermore, Article 6 of the law stated:

> "*Tout projet d'installation d'un laboratoire souterrain donne lieu, avant tout engagement des travaux de recherche préliminaires, à une concertation avec les élus et les populations des sites concernés, dans des conditions fixées par décret.*
>
> *English translation : Each project for construction of an underground laboratory shall require consultation with the elected representatives and populations of the relevant sites, under conditions decided by decree* [ministerial order]*, before any preliminary research works are started.*"

Most of the law, including Article 6 above, was repealed in 2000.

According to Nirex (2000), the siting process for the URLs began in January 1993, and by the end of the year some thirty communes had volunteered. It is not clear whether some geological selection preceded the volunteering; there are 36,000 communes in France, and it is unlikely that the offer was open to all of them to volunteer. Nevertheless, the result enabled M. Bataille to recommend four sites, which by a merger were reduced to three in 1996:

- Bure (on the border of Meuse and Haute Marne *départements*) - clay
- Marcoule (Gard; an existing nuclear site on the Rhône) – clay
- Vienne *département* - granite

The following is summarised from the Andra website (the history pages are only available in French). Andra applied for three permits for URL construction, one for each site, but after the election of the Jospin government in 1997 the multi-URL project was suspended. By the end of 1998 a political compromise was reached, and the go-ahead was given to Andra to begin construction of the URL at Bure, where the Oxford Clay is the potential host rock. The Marcoule site was dropped, and surface-based research at the granite site continued, culminating in a final report on granite sites (Andra 2005). At the end of 2006 Andra was authorised to proceed with the URL at Bure.

Communities had volunteered for a URL in 1993 on condition that the URL would never be used for final disposal, and that the waste would be retrievable. Beginning in 2007, Andra investigated a triangular subsurface zone of 250 km^2 lying mostly north of the Bure URL (Figure 3.6.5, from Landais 2008) for a deep repository, and then focussed on a 30 km^2 zone of interest (ZIRA; Zone d'Intérêt pour la Reconnaissance Approfondie), publishing a proposal (Andra 2009a) which the government accepted in 2010. The ZIRA area is shown in Figure 3.6.6.

So while it is not clear whether the 30 volunteer communes of 1993 had already been pre-selected on geological grounds, it is evident that French progress from this generous initial offering has systematically refined the site search always using geological criteria, together with the promise that shortlisted sites would only house a URL. The current search area has been progressively narrowed down (Figs. 3.6.5 and 3.6.6), but the final repository waste is still supposed to be retrievable. It is also noteworthy that a non-nuclear clay site (Bure) was selected in place of the alternative clay site at Marcoule, where there are nuclear facilities.

The principle of retrievability is described fully by Andra (2009b). The law of 2006 prescribes a period of at least 100 years from emplacement, during which removal must be be possible. This fact is glossed over by Defra (2008), which states "*France is investigating a site at Bure with a view to it becoming the final disposal facility*".

3.6.5 Switzerland

The Swiss Federal Office of Energy (SFOE) has produced a factsheet (SFOE 2011) which clearly outlines the site search procedure:

> Step 1. Identification by Nagra in 2008 of six potentially suitable geological zones (Fig. 3.6.7). After examination by "*competent authorities*", SFOE called a 3-month consultation period. Step 1 was accepted and made law by the federal authority in November 2011. The subsequent steps are ongoing.
>
> Step 2. The potential zones will be reduced to a minimum of two for each category of waste. Outwith technical safety aspects, the population and communes of the regions affected can now register their needs and interests.
>
> Step 3. More detailed technical studies of the sites, including economic impact. Nagra will put forward its proposed sites for federal approval.

3.7 Summary

3.7.1 Fundamental criteria

The following fundamental criteria can be drawn from the research, experience and recommendations both in the UK and abroad since the early 1990s:

- The basic criteria for site selection are host rock independent.
- The regional setting of the site is of paramount importance, with:
  - Long geological stability,
  - Low hydraulic gradients.
- The site and its surrounds must have simple geology.
- Search for suitable geology precedes community assent or veto.
- Implantation of waste should be reversible for a minimum of 100 years.
- The ultimate timescale for a safety case is one million years.

3.7.2 Comments

The current UK process is very far from fulfilling the criteria listed above; indeed, the concentration on West Cumbria means that the well-founded international geological and hydrogeological criteria are going to be wilfully ignored. This is irrational. DECC (2012b), in its document on how the desk-based site search will be conducted, makes no mention of any of these developments, but cites only the old guidance drawn up almost 30 years ago (International Atomic Energy Agency 1994).

In addition, the brief histories of site search internationally summarised above show that UK is now about 20 years behind in its search, relative to Finland, Sweden and France, for example (although there are many other countries even further behind).

Referring back to the history of site search discussed in section 2, we can see that the UK has moved from being abreast of the leaders in waste disposal research in the late 1980s, but has lost two decades of what could have been productive progress by its futile and misguided concentration on the Sellafield disposal option. It is ironic that the government has devised a plan which implies a return to the same district, now expects to find a site there for HLW (not merely ILW as in the 1990s) and, furthermore, thinks it can now simply accelerate the geological waste disposal programme (Hendry 2011).

It should be noted here that both Finland and Sweden are somewhat exceptional, in that the geology of their respective countries is (by and large) flat terrain, comprising ancient granitic-type rocks. So both countries were limited in their choice of geological environment to the category of hard rock in low-relief terrain, but, on the other hand, had great freedom within this single category in finding sites.

France and Switzerland are more akin to the UK geological array of possibilities – very varied terrain, a vast variety of rock formations and geological environments within which to select suitable sites, and no fundamental problems of tectonic stability.

Lastly, it is evident from the review of the history of site search in several countries that geological suitability has always preceded community assent or veto.

4 GEOLOGY AND HYDROGEOLOGY OF WEST CUMBRIA

4.1. Introduction

4.1.1 Prior knowledge

The science of geology was largely developed in the UK in the late 18th century. The Lake District, or Cumbria, has been a classic study area since around 1800. David Oldroyd, an historian of science, has written a memoir on the history of geological research in the Lake District (Oldroyd 2002). He recounts the development of Nirex work in West Cumbria, the geological arguments put forward pro- and anti-Nirex at the planning inquiry, and the subsequent events up to 2001. Even before any Nirex-sponsored research was started in West Cumbria, the region was already as well understood as any other region in the UK. Post-Nirex, the region has become exceptionally well understood.

4.1.2 The BGS screening exercise

According to the draft IAEA guidelines discussed in section 3.1 above, the screening exercise (British Geological Survey 2010) has not been carried out in the correct order, as it has not been preceded by a "*regional mapping or investigation phase*". It would have been more rational for the BGS to have considered the suitability or otherwise of the whole of West Cumbria; such a project would have hardly taken any more time than the initial unsuitability screening actually undertaken.

There are two unsatisfactory features of the screening report - the potential for oil or gas discovery, and the groundwater resources. These are discussed in more detail below in section 4.4 Northern Allerdale, and 4.7 Mercia Mudstone Group, respectively.

4.2. Topography of West Cumbria compared with elsewhere

4.2.1 Comparison with sites in flat terrain

By any objective standard the topography, or relief, of West Cumbria is extreme. That in itself should have been sufficient to rule out, *a priori*, the region for consideration, based on the guidelines and standards discussed in the previous section. It is only for historical and essentially political reasons that West Cumbria is under consideration yet again.

Let us compare the relief of West Cumbria firstly with that of two other sites, one in Sweden and one in Finland, where repositories are actually being developed, and secondly with the area around the Wash, which is a potentially suitable region. Figure 4.2.1 shows where the four sites are located. Figure 4.2.2 shows the relief of West Cumbria, with the colour scale bar on the left the same as in all the diagrams of this section. The extreme relief comprises mountains above 500 m in elevation within 10-20 km of potential sites. The position of Longlands Farm is noted for reference.

Topographic maps of the regions around the four sites are presented together at the same scale in Figure 4.2.3; each area is then shown in perspective view in the succeeding four diagrams (Figs. 4.2.4 – 4.2.7). All have the same degree of vertical exaggeration of the topography, and all cover a similar area, viewed from the same elevation angle. It is evident that the relief of West Cumbria is completely different from the two Scandinavian sites, and also from the Norfolk/Wash area of England.

4.2.2 Comparison with sites in Switzerland

McEwen (2010) criticised the examples that I had cited above (Smythe 2010), but wrongly assumed that I was giving undue importance to topography while ignoring various other factors. He cited Switzerland which "*is currently in the middle of a site selection programme for repositories for both ILW (intermediate level waste) and HLW (high level waste), in a country, some of which has very marked relief, and therefore the potential for considerable hydraulic gradients.*"

The implication here is that if Switzerland, renowned for its mountains, can find potential repository sites, then what is wrong with searching in West Cumbria? So let us examine the topography of Switzerland. Figure 4.2.8 shows the three areas identified by Nagra, the Swiss nuclear waste authority. Figure 4.2.9 shows the topography of West Cumbria (left) compared with that of northern Switzerland (right). The centres of the three target Swiss sites (Fig. 4.2.8) are shown by red circles. Note that the colour key is different from the one used above, as it now extends to 2000 m elevation. Two sample topographic cross-sections are shown; a dog-leg one crossing West Cumbria, and a linear NW-SE profile for northern Switzerland. The Cumbrian profile runs through Sellafield, but has *not* been made to traverse Scafell Pike, which lies 10 km to the SE. The relief is of the same order in both maps – about 500 m. However all three Swiss sites are 30-50 km distant from the high ground, whereas potential Cumbrian sites onshore cannot be more than a maximum of 30 km from the same relatively high ground.

Another way of expressing the fact that the relief in Cumbria is much more extreme than in northern Switzerland is to show the equivalent areas within which the variation of relief occurs. This is illustrated in Figure 4.2.10. The >500 m of relief variation in West Cumbria is concentrated in the available area (the councils boundary shown by the dotted blue line) of approximately 2000 sq km, but in the Swiss case one has to consider the whole map area of about 7000 sq km to observe the same variation in relief. Alternatively, the 2000 sq km of available West Cumbria land, represented as an ellipse of around the same area on the Swiss map enclosing the three potential sites there, shows that the relief variation within that ellipse is under 200 m, taken from any one of the three sites. Note that the region outlined by the ellipse on the Swiss map has similar topography to eastern England.

Lastly, the localities for potential sites are shown side by side on the two topographic profiles (Fig. 4.2.11). These regional relief profiles show that potential sites in West Cumbria are much nearer the mountainous area than are the potential sites in Switzerland. The West Cumbria dog-leg profile does not run through the highest peaks, which would add a further 300 m to the profile vertically, but is laid out to follow published Nirex geological profiles through Longlands Farm, the 1995 Potential Repository Zone, then to run NW along the cross-section published by the BGS.

So in Switzerland Nagra appears to have found three suitable sites within a strip of relatively gentle terrain about 50 km wide. In contrast, the lower flanks of the Cumbrian mountains available for a repository are only 10-15 km wide.

Details of the geology of the most easterly of the three Swiss sites are provided in section

4.4.3 below, as an illustration of what is to be understood by simplicity in a repository search.

In conclusion, the relief variation of the relevant region of Switzerland is a half or a quarter of the Cumbrian equivalent. Therefore McEwen's attempt to make a comparison between Switzerland and West Cumbria is invalid. In addition there is a vast difference in the geology of the Swiss sites, compared to the potential West Cumbrian sites. The geology is discussed below.

The topography is important, because it supplies the hydraulic head, or gradient, which drives groundwater flow, but of course how fast the groundwater will flow under this potential driving force depends on the regional and local hydraulic conductivities of the rocks.

4.3. Borrowdale Volcanic Group

4.3.1 The site of the 1990s investigations

Nirex defined several areas of study within West Cumbria and offshore in the Irish Sea in terms of decreasing area but increasing geological study detail, as follows (Fig. 4.3.1). The Region extends from Workington in the north to Barrow-in-Furness in the south, inland for 15-20 km from the coast, and 50-70 km out to sea to the west. Within this region there is defined a District, and within that the Site, a rectangle of 8.0 x 6.5 km^2. The Nirex definition of District corresponds approximately to the British Geological Survey (BGS) definition of the 'west Cumbria district' in its 1997 memoir (British Geological Survey 1997). Inside the Site there is defined the Potential Repository Zone (PRZ).

There is a point of potential confusion regarding the use of the word 'site'. Nirex documents generally refer to the site as defined above, whereas in the Planning Inquiry documents the Inspector refers to the site of the planning appeal, meaning the Potential Repository Zone (plus access roads). He also refers to other sites within the UK, meaning the sites, or specific localities investigated by Pieda and the BGS.

I have juxtaposed the BGS exclusion zone map from its initial screening report (British Geological Survey 2010) with a preliminary outline map showing the potential areas of interest in Figure 4.3.2. The Site rectangle is outlined in red, and the National Park boundary is denoted by red dots. These outlines will help to serve as points of reference on later maps.

Starting in the Longlands Farm Site district, Figure 4.3.3 shows the 1:250,000 geology map overlain by the sub-Permian map (British Geological Survey 1997, fig. 29). The Lake District Boundary Fault (LDBF) runs NNW, then widens out into the LDBF Zone. The zone of complex faulting to the west, including part of the offshore area, comprises the Lakeland Terrace (British Geological Survey 1997, fig. 16). Both the histories and displacement senses of the faults are highly complex. For example, the High Sellafield Fault Zone in the centre of Figure 4.3.3 is interpreted as

> "*a continuous structure with normal displacement down to the east. However, at shallower levels ...it is an echelon structure consistent with a sinistral component of strike-slip. Where the fault zone is mapped onshore it includes a significant antithetic fault and has the character of a complex flower structure with oblique and reverse components of displacement*" (British Geological Survey 1997, pp. 31-32).

Both the Woodland Fault and the Seascale-Gosforth Fault Zone, each with a NE-SW trend, acted as transfer faults. Figure 4.3.3 shows how tightly constrained was the Sellafield PRZ, as the Inspector noted. The limit of the Carboniferous Limestone subcrop is marked by the change from fawn to hatched-grey. Tracing this northwards on Figure 4.3.3 it runs into the LDBF Zone, then into the BGS exclusion zone marked by red hatching.

Lest anyone remain under the illusion that the chosen Site was simple and predictable, geologically speaking, Figure 4.3.4 should serve to remind them of the complexity of the Site. The faulting at base Brockram (Permian) is shown (Nirex 1997f, fig. 8) with the limit of the Carboniferous Limestone subcrop again superimposed. A 3D block model view of the structure at base of the Permo-Triassic is shown in Figure 4.3.5 (Nirex 1997f, fig. 14). The view is to the NW, and there is no vertical exaggeration. The Permo-Triassic has been removed to leave just the Carboniferous (blue) and repository host rock, the Borrowdale Volcanic Group (BVG – green). The sticks are the boreholes. It should be borne in mind when looking at this model that a the top-basement surface of a true BUSC model should be planar and flat-lying. The faults, shown here as white surfaces, extend up into the overlying cover rocks – again, this is contrary to the BUSC concept.

This structure is extremely difficult even for a trained earth scientist to interpret, in the sense that it is not at all clear which faults moved in which order. It is very probable, given the uncertainties in building the model, that it contains errors. Furthermore, the chances of predicting accurately the fluid flow through such a model, when the fluid-mechanical properties of the faults and fractures is so ill-understood, are very poor. That is why a regime like this is too complex to be considered for a repository.

4.3.2 Post-1997 studies

The NDA has recently claimed (Nirex 2005c) that the Nirex 97 set of science documents, issued after the end of the 1995-96 Planning Inquiry, had solved many of the problems discovered by the Objectors at the Inquiry itself, and that the outcome of the Inquiry might have been different, had Nirex 97 been available in time. This assertion, which implies that the Longlands Farm locality is indeed suitable, is not true. Nirex 97 is discussed in detail below.

4.3.3 Coastal zone south of Longlands Farm

Could a similar site to Longlands Farm be found to the north or to the south, but with better characteristics? Figure 4.3.3 shows that just 1 km to the NW along strike the BVG is covered by Carboniferous Limestone, as it is down dip to the SW. We also encounter the exclusion area as defined by the BGS. Evidently such a putative relocation is out of the question.

Figure 4.3.6 shows the coastal geology south of the Sellafield site. There is a narrow strip of onshore Triassic outcrop, up to half a kilometre wide, from Haverigg in the south up to Sellafield, bounded by the Lake District Boundary Fault (LDBF). The fault surface dips west at about 60°. The Carboniferous Limestone seen at outcrop in the SE corner underlies the whole Triassic outcrop here (British Geological Survey 1997, map 5). To be more precise, the coastal zone lies within the Lake District Boundary Fault Zone (LDBFZ), a 2-3 km wide zone of normal faulting (British Geological Survey 1997, fig. 12) bounded by the LDBF *sensu stricto* on the east. The LDBF has suffered earthquake fault movement within historical time. The strip is entirely within the National Park (the boundary marked by red dots).

In conclusion, the geology of this coastal district south of the Nirex site rectangle is unsuitable for considering a repository site either within the sediments, or within basement below the sediments west of the LDBF, on the grounds of its proximity to the major fault and the presence of Carboniferous Limestone within the sedimentary succession. If a repository site within BVG below sediments was being sought in West Cumbria, then it is clear the Longlands Farm site was the most or only suitable (or rather, the least unsuitable) such site.

The possibility of emplacing a 'hard rock' site within the Eskdale granite will be discussed in section 4.8 below.

4.4 Northern Allerdale

4.4.1 Hydrocarbon exploration and understanding

The deep structure of the northern part of Allerdale District Council is geologically very well understood thanks mainly to oil exploration surveys (seismic reflection profiles and drilling) that has taken place over the last 40 years.

Figure 4.4.1 shows a selection of maps demonstrating the existence of hydrocarbon exploration licences in the region, some dating back to the 1970s and possibly earlier. I have put these together (Fig. 4.4.2) to show that they form one contiguous area, which runs from Carlisle and points east, round the northern and western margins of the National Park, and down into the Site quadrant defined by Nirex around Longlands Farm.

The BGS screening report (2010) is inconsistent and illogical regarding the hydrocarbon exploration that has been carried out here, and the risk of possible future 'intrusion'. Firstly it states:

> "*Natural Resources exclusion criteria are based on a potential geological resource that might be the focus of exploration and/or exploitation in the distant future, leading to penetration or 'intrusion' by boreholes or mining activities into an 'unknown' engineered repository located at between 200 to 1000 m depth.*"

The logical deduction from this statement is that if there is sound geological or historical evidence that exploration boreholes have been, or might be, drilled, then the area should be excluded.

However, the interdiction is then restricted – illogically - only to *discovery* hydrocarbon wells. Defining the exclusion criteria in more detail, the screening report continues:
"*These include …The presence of known hydrocarbon (oil or gas) resources*" [my underlining].

> "*Exploration for oil and gas ('conventional hydrocarbons') has taken place in the north of the Partnership area, but no resources have been proved. Consequently, although a part of north Allerdale is currently licenced for oil and gas exploration, the area has not been screened out at this stage since it does not represent a known oil and gas field.*"

> "*A third exploration well, Fisher Gill 1 indicates that the area is still prospective for oil and gas*"

Firstly, we cannot rule out the possibility that hydrocarbons remain to be discovered, even though they have not been to date. Secondly, how can we know that a future society will not try again to find hydrocarbons here, and, whether or not they are successful, perhaps penetrate an unknown waste repository? In conclusion, the fact that hydrocarbon exploration has been going on for a generation or more should be sufficient evidence to rule out the area.

Notwithstanding this general stricture on hydrocarbon resources as an exclusion criterion, let us examine the geology summarised in the map of Figure 4.4.3. There are two geologically distinct districts left in play following the BGS screening exercise (red square hatching):

- To the south, the belt of Carboniferous Limestone outcropping approximately around the edge of the National Park, and
- To the north, the deep sedimentary basin with Triassic at outcrop.

4.4.2 The limestone belt

The Carboniferous Limestone outcrops in a fringe around the crystalline basement rocks of the National Park, the latter forming the mountains. Concentrically outward from the limestones are the Coal Measures, which have been excluded by the current BGS exercise, and are therefore hidden below the hatching. The Carboniferous dips generally radially outwards away from the heart of the Lake District mountains.

Figure 4.4.4 is an extract from the 1:50,000 scale geology map used by the BGS for the screening exercise (2010, fig. 8). Being more detailed (and of more recent origin) than the 1:250,000 scale map used previously herein, it shows that the Carboniferous is sliced up by a myriad of faults, particularly with NW-SE and E-W trends. Such a density of faulting probably exists also within the Triassic as well, but has not been mapped due to poor exposure. In contrast, both the limestones and the coal measures have been mapped extensively in the past because of their economic value.

4.4.3 Complexity vs. simplicity in structure and lithology

Figure 4.4.4 demonstrates the essential three-dimensionality of the geology; for example, shifting the location of a NW-SE cross-section, such as that along line AB, by as little as 1 km will yield the same generalised section, but the detail of the faulting and other structures will be very different.

The purple segment of cross-section AB located in Figures 4.4.3 and 4.4.4, extracted from the screening report (2010, fig. 9), is shown in Figure 4.4.5 to illustrate the complexity of the limestone and coal measures belt. By ‘complexity’ in the context of a potential repository, I mean features including:

- Variety of lithologies
- Folding
- Angular unconformities
- Faults cutting through both basement and cover rocks
- Faults intersecting the ground surface
- Faults intersecting each other at shallow depth (< 1 km)

- Three-dimensionality

All these features are present in the limestone belt. They would make it effectively impossible to characterise accurately the hydrogeology by three-dimensional fluid flow models. In brief, the limestone belt is even more complex structurally and stratigraphically than the Longlands Farm Site.

In contrast, *simplicity* is exemplified by the down-dip cross-section of the proposed repository site in Switzerland, shown in Figure 4.4.6 (Nagra 2000):

- Flat-lying parallel layers (dip about 5°)
- Choice of depth range down to 900 m over zone of interest.
- Potentially excellent Opalinus Clay host rock layer about 100 m thick.
- Host rock sandwiched in a 300 m thick clay sequence.
- No faults with throws of greater than a few metres.
- No angular unconformities.
- Tectonically undisturbed.

In addition, the hydrostatic head of the nearest mountains to the Swiss site is about half that of the Cumbrian example. The site (which is the most easterly of the three sites shown in Figures 4.2.9 and 4.2.10) has been further examined by the Benken exploratory borehole and a full 3D seismic survey.

4.4.4 Solway coastal plain

This leaves the localities underlain by thick Triassic and older rocks shown in Figure 4.4.3. This corresponds in part to the area identified in the mid 1980s by the BGS near Carlisle as having potentially suitable sedimentary formations (Fig. 2.3). This area is discussed in the three following sections.

4.5 Evaporites

Evaporites comprise one of the three potential host rock types. As discussed above, ‘Sellafield-A’ was the original Sellafield site identified in the national search of the late 1980s. The target host rock was impermeable anhydrites of Permian age known to be present in the region. However, the Sellafield-3 borehole, drilled in early 1991 at the coast inside the Sellafield Works, confirmed, as suspected a few years previously, that the anhydrite (the St. Bees Evaporite Formation, within the Sherwood Sandstone Group) was too deep there, at 1270 m depth and deeper, to be of use as a potential repository.

The St. Bees Evaporite Formation is not present onshore in northern Allerdale, where it would underlie the Sherwood Sandstone Group indicated in Figure 4.4.4. If it were present offshore beneath the Solway Firth it would be at too great a depth for a repository, as was the case in West Cumbria.

In the Solway basin area there are thin beds and stringers of gypsum and/or anhydrite, but too thin to be considered as a host rock formation. The Preesall Halite Formation, within the Mercia Mudstone Group, was encountered in the Silloth-1A well at about 180 m OD, but is only 7 m thick (Holliday *et al.* 2004).

In conclusion, there are no evaporite formations in the region suitable for consideration as a potential host rock.

4.6 Solway Basin: state of knowledge and hydrocarbon prospectivity

Dearlove (2011b) commented on my summary of the state of knowledge of the Solway Basin area, discussed in section 4.4.1 above, as follows:

> "*Professor Smythe suggests the most recent BGS review of the geology of the Solway Basin, based on numerous and recent lines of evidence (including more than 40 years worth* [of] *oil industry data) already provides* "*a proper evaluation*" *of the Solway Basin. This opinion is not shared by BGS.*"

But Dearlove does not provide any evidence or documentation to support his statement that the BGS does not believe that a "*proper evaluation*" of the Solway Basin exists. Does his information come from his "*brief discussions with the BGS*" to which I alluded in my critique (Smythe 2011c) of his letter of 13 May 2011 (Dearlove 2011a)? If so, it is evidently unsatisfactory that alleged opinions of the BGS (including the apparent consideration of the Mercia Mudstone Group in the Solway Basin as a potential repository host rock, discussed in section 4.7 below) are reaching the MRWS process, filtered *via* informal discussions with a third party. What we need for the supposedly 'transparent' process are papers, statements, reviews, etc. directly from the BGS itself; anything else is hearsay.

Dearlove (2011b) continued:

> "*It is also worth mentioning that following 40 years of exploration there are no oil/gas production fields identified in this area and thus it was not excluded by the BGS on the grounds of intrusion risk.*"

The area was not excluded by the BGS screening exercise (British Geological Survey 2010) on grounds of intrusion risk, but it should have been. The BGS did, however, exclude most of the Solway Basin in its national search of the late 1980s. Dearlove (2011a) did not comment on the fact that three sites in the Solway Basin were considered and rejected on geological grounds. Although it is correct that after 40 years of continuous hydrocarbon licensing and exploration in the basin, hydrocarbons have yet to be found, exploration is currently proceeding. The BGS screening report (British Geological Survey 2010) stated:

> "*Identification of suitable trap structures in the Partnership area has not been carried out as part of this exercise. However, two wells: Silloth 1 and West Newton 1 (Figure 11) have been drilled to test for hydrocarbons in potential trap structures and were abandoned as dry holes (Young et al., 2001). A third exploration well, Fisher Gill 1 indicates that the area is still prospective for oil and gas (DECC, 2010).*"

The figure 11 referred to above in the BGS screening report (British Geological Survey 2010) shows the three wells and the three licence blocks. For a relatively simple basin such as the Solway Basin, it has been well-explored; it is well understood in overall geological terms, even though hydrocarbon reserves remain to be discovered. There is an active oil exploration licence as well as an active coalbed methane licence.

I therefore conclude that there is ample background information and understanding for an assessment of the potential for finding a repository site in this basin. Figure 4.4.1A shows the current coverage of 2D seismic lines and exploration wells. The formation of interest here is the Mercia Mudstone Group, of Triassic age. It overlies the Sherwood Sandstone Group, a Principal Aquifer.

4.7 Mercia Mudstone Group

4.7.1 Recent introduction of the Mercia Mudstone Group as a potential host rock

The Mercia Mudstone Group (MMG) in England was considered as a potential host rock by Chapman *et al.* (1986, fig. 3), but this did not include the Solway Basin area, presumably on the ground that the MMG was too shallow. Chapman *et al.*'s map corresponds to the right-hand map of Figure 2.1.1, which was presented in colour by Michie (1998). There are two small patches of Permian sediments marked on Chapman *et al.*'s preceding map (op. cit., fig. 2), one underlying the coastal strip west of the LDBF, and the other in the Solway Basin. The latter happens to correspond closely to the outcrop of the MMG, but in fact refers to Permian subcrop of greater than 200 m depth. This subcrop appears on the compilation map and on the map in *The Way Forward* (Nirex 1987, fig. 5.4). It is the rust-red elliptical area shown in the inset of Figure 2.1.3. Some of the MMG outcrops and subcrops shown elsewhere in England in 1986 seem to have disappeared from the 1987 map.

The MMG outcropping in the Solway Basin was discussed by Dearlove (2011a), who stated "*I understand from brief discussions with the BGS that the Mercia Mudstones within this area would also form part of the BGS's* "potentially suitable sedimentary formations".". Since I had not previously considered the MMG as a potential host rock (Smythe 2011b), therefore, according to him, CoRWM's position (that suitable host rocks remain to be found) remains tenable. I responded to his comments with a response (Smythe 2011c); Dearlove answered with a further commissioned letter (Dearlove 2011b), to which I responded in December 2011 (Smythe 2011e). The following account is based on the last three documents, but with corrections where appropriate, and addition of explanatory diagrams and citations. There is a certain unavoidable degree of repetition because of the need to preserve the development of the discussion represented by these three documents.

4.7.2 Previous exclusion of the MMG in northern Allerdale during the 1980s site search

Dearlove (2011a) did not mention that three sites within the Solway Basin were investigated by the BGS in the 1980s as part of the nationwide site search, but were then rejected on grounds of geological unsuitability. These are:

Site	**Environment**	**OS grid square**	**Easting**	**Northing**
Anthorn	sedimentary coastal	NY 1758	317300	558100
Longton	sedimentary inland	NY 3567	335100	567300
Eastriggs	coastal	NY 2664 [inaccurate]	324100	565100

I have corrected the erroneous grid square reference to Eastriggs in the Pieda documents. The most relevant of these sites is Anthorn, a former airfield. It lies in a zone not excluded by the BGS in 2010, and is about 6 km NE of the Silloth-1A well (Fig. 4.7.1). The site is representative of the deeper basinal Permo-Triassic geology (including the MMG) in the non-excluded area running from Abbeytown in the south to Bowness-on-Solway in the NE. The

Solway Basin, and Anthorn in particular, was initially considered by the BGS because of the possible presence of thick anhydrites at appropriate depths for a host rock. But the outcropping MMG was never thought of as a potentially suitable host rock within the Carlisle – Solway area. That is why I did not consider it further. Had it been so, then additional areas of MMG outcrop would have been marked on the BGS regional map of the late 1980s, for example on either side of the Severn estuary, and a much wider area of the Staffordshire Basin than was actually depicted.

4.7.3 Unsuitability of the MMG – summary

The area (and indeed the MMG in general outside the areas where thick halite is present) was rejected by the BGS in the late 1980s, so why is it now apparently being considered? I considered it to be *a priori* an unsuitable repository host rock formation, for the following reasons (Smythe 2011c):

1. The area is lies within a region of high topography and hence high hydraulic gradient, even though the gradient due to the Cumbrian mountains may only be about half of that on the western coastal strip.

1. It is a Secondary B aquifer. This is amplified in section 4.7.4 below.

2. The MMG comprises laminated mudstone and subordinate siltstone and calcareous sandstone. In the Solway basin area there are thin beds and stringers of gypsum and/or anhydrite, but too thin to be considered as a host rock formation. The Preesall Halite Formation was encountered in the Silloth-1A well at about 180 m OD, but is only 7 m thick.

3. The MMG is cut by faults with throws of up to 100 m, trending NNW-SSE. Structure and potential rock volume available is discussed further below in section 4.7.7.

4. Mudstones and siltstones with subordinate sandstones and halites do not comprise a suitably impermeable formation, unlike claystones.

5. Their chemistry implies an oxidising environment, a highly undesirable attribute for a host rock (see section 4.7.6 below).

Within the boundary of Allerdale District Council there are two outcrops of MMG outwith the excluded area (Fig. 4.7.1). The small area to the east, centred on (OS grid coordinates 332, 551) can be discounted because the MMG is at less than 300 m depth. The larger area, to the west, runs northwards from Pelutho, through Seaville and Silloth, and NE past Moricambe Bay and then through Anthorn to Bowness. At Anthorn the MMG is at about 200 m depth, thinning out northwards; so the area north of the bay can be discounted. That leaves the Silloth – Seaville – Pelutho area to the south of the bay – the area cut by the large faults.

Hydraulic conductivity measurements of the MMG from various locations in England range from as low as 10^{-5} to 10^{-9} ms^{-1}. BGS reports quote a mean of 10^{-6} in one case and 10^{-7} in another. In contrast, the Opalinus Clay currently being considered as a host rock by Nagra in Switzerland has laboratory measurements of conductivity from shallow boreholes below 20 m depth in the range 10^{-10} to 10^{-11} ms^{-1}, plus good evidence for *in situ* conductivity of $<10^{-13}$ ms^{-1}. The Lower Cretaceous Gault Clay of England has a laboratory-measured conductivity of 10^{-11}

ms^{-1}, although this may be larger *in situ* by an order of magnitude, due to the presence of fractures. Put simply, the MMG has a hydraulic conductivity ranging from ten thousand to millions of times higher than other potentially suitable claystone host rocks. This is not surprising, as it is an aquifer. The city of Leicester's water supply used to come from the MMG.

It is misleading of the 2010 BGS screening report to have cited the Borrowdale Volcanic Group (BVG) as the example of a Secondary B aquifer under the new Environment Agency definitions (table 4). The BVG has a conductivity of the order of 10^{-10} ms^{-1}, that is, three to four orders of magnitude smaller than the MMG. The MMG is a better example of a Secondary B aquifer. Therefore under the screening criteria it should have been excluded.

In the East Irish Sea Basin it is reported that at least 600 m of MMG is required for it to be an effective hydrocarbon seal there, due to the inversion uplift (Duncan *et al.* 1998). This effect will also apply to the Solway Basin. However, the MMG is an effective seal in the Wessex Basin, where 300 m of MMG caps the oil of the Wytch Farm field, together with another 200 m of Liassic mudstone above. The difference in the latter case is that the Tertiary uplift has never taken the MMG into the brittle tensional strength regime, which is the reason for the higher hydraulic conductivity in the Irish Sea region.

The Preesall Halite Formation is far too thin to act as a seal, not least because any fault cutting it with a vertical throw of >7 m will place the mudstones above and below the halite into direct contact.

In conclusion, the MMG is quite unsuitable as a host rock *per se*, and in the locality available for consideration it is in fact exploited as an aquifer. Lastly, the shallow depth available and the large-scale normal faulting in the centre of this locality would rule it out even if it did have properties more appropriate to a claystone host rock.

Therefore Dearlove's (2011a) statement:

> "*the conclusion must be that the Solway Plain within the West Cumbrian MRWS Partnership area remains, on geological evidence, an "area of potentially suitable sedimentary formations*". (para. 6.3)

is invalid, and his logical follow-on statement "*This clearly supports CoRWM's position*" is therefore also invalid.

Given that my previous statement (Smythe 2011b) on the unsuitability of the Solway basin area was confirmed by the summary discussion above, I concluded (Smythe 2011c) that there is no area which I have considered in depth in West Cumbria (the so-called partnership area) which remains to be investigated. However, Dearlove responded with a further commissioned letter (Dearlove 2011b), to which I responded in December 2011 (Smythe 2011e).

4.7.4 MMG as an aquifer

The MMG is a Secondary B aquifer. There several water abstraction wells within the outcrop area of the MMG, some of these penetrating to more than 100 m. The combination of this fact, together with the presence of the underlying Sherwood Sandstone Group (a Principal Aquifer) implies that the MMG should be excluded on the grounds both of intrusion risk and of loss of future groundwater resource. The Defra white paper (2008) states in table B1 'Summary table of initial sub-surface screening criteria' that aquifers should be used as an exclusion criterion "*Where all or part of the geological disposal facility host rock is located within the aquifer*".

So why was the MMG not excluded by the BGS screening process? Table 1 of the screening report unambiguously states that aquifers shall be excluded "*Where all or part of the geological disposal facility host rock is located within the aquifer*" (British Geological Survey 2010), but then qualifies that statement:

> "*Some, but not all, of the rock volume in areas where aquifers and shallow permeable formations are present in the Partnership area are excluded. However, nowhere does the exploitable aquifer rock volume extend over the whole of the depth range between 200 m and 1000 m below ground level and, consequently, the total area is not excluded at this stage. The isolation of a GDF* [geological disposal facility] *from exploitable water resources will be a major issue for providing the eventual suitability of any proposed GDF. These aquifer rock volumes will need to be considered in more detail at later stages in the MRWS process ...*" [my underlining]

The first sentence in the quotation above demonstrates an inconsistent approach ("*some, but not all* ...") without explaining why. The second sentence requires that an aquifer must be exploitable over the whole vertical range from 200 to 1000 m depth below ground level for it to have been excluded. This depth range corresponds to the depth range for a repository. There is no rational reason for such an aquifer to have to be greater than 800 m thick before it can be excluded, therefore the use of the conjunction 'consequently' is false, because it does not follow that aquifers of less than 800 m thick, but lying within the depth zone of interest, should be included. Very few aquifers in the UK are anything like 800 m in thickness. The rest of the paragraph goes on to say that, in effect, a decision on these aquifers has merely been postponed.

The screening report uses the Defra (2007a) definition of an aquifer, covering both actual and potentially exploitable "*permeable formations*". This definition retains permeable formations below a depth of 500 m as potential host rock volumes, because the groundwater will be saline at these depths and therefore not exploitable. There are three objections to this approach, as applied to the sedimentary formations illustrated by the BGS in their cross-sections of their figure 14:

> 1. Since in both cases illustrated (the Solway plain and the west Cumbrian coastal plain) the groundwater flow is generally down-dip and seaward, the fresh-saline interface will be somewhat deeper than the arbitrary 500 m selected.
>
> 2. Since the Sherwood Sandstone is a Principal Aquifer, and highly permeable, it is highly unlikely to be suitable as a repository host rock even at the depth where the groundwater may be saline.
>
> 3. The MMG is nowhere deeper than 500 m onshore anywhere in West Cumbria (section 4.7.7 below).

Dearlove (2011b) accepted that the MMG is classed as a Secondary B aquifer, and went on to quote the detailed description of such an aquifer, whilst also pointing out, superfluously, that it was formerly classified as a non-aquifer. He contrasted the MMG with the Borrowdale Volcanic Group (BVG), even though both are classed as Secondary B aquifers.

Dearlove (2011b) cited the following as a summary of the hydrogeology of the MMG:

> "*Patrick (Ref. 7) states the Stanwix Shales are similar to the St Bees and Eden Shales and form* [the] *confining aquiclude over the Kirklington Sandstone. Limited water movement will probably occur within them, as in the St Bees Shales, but faulting is never sufficiently intense to provide a breach. ... 7 Patrick, 1978. Hydrogeology in The Geology of the Lake District Edited by F. Moseley. Yorks. Geol. Soc. Occasional Publication No.3.*"

This very out-of-date reference is erroneous because faults with throws of the order of 100 m are now known to cut the MMG (Fig. 4.7.1). Therefore the combination of the "*limited water movement*" combined with the faulting, which breaches otherwise possibly isolated water bodies, in fact corroborates my conclusion that the MMG is inherently unsatisfactory as a host rock.

In my previous paper (Smythe 2011c) I referred to the fact that the MMG is used today for water abstraction. I said that:

> "*There are a dozen or more water abstraction wells within the outcrop area of the MMG. Some of these penetrate to more than 100 m.*"

Dearlove (2011b) did not comment on this. I have since studied the well database in more detail. Some of the wells over MMG outcrop in fact abstract water from the overlying Quaternary, which can be up to 50 m thick, and not from the MMG itself. However, there are seven wells either abstracting, or have been tested for potable water abstraction, from the MMG, in the area north of NG northing 540000 and west of NG easting 336000. These are shown in Figure 4.7.1. Tests of their flow rate yielded flows from 1.5 to 5.8 m^3/h (mean 3.7 m^3/h), and the boreholes depths were from 41-105 m (a mean of 77 m). Thus there is good evidence that the MMG in northern Allerdale is an aquifer, capable of supplying local needs such as farms. Incidentally, the greater concentration of water abstraction wells (of all types) towards Carlisle, as opposed to the western area around Moricambe Bay (NB not to be confused with Morecambe Bay south of Cumbria), presumably reflects the greater population density in the east, rather than a decrease of MMG aquifer potential to the west.

4.7.5 Regional continuity of MMG lithostratigraphy and hydraulic conductivity

The BGS (Holliday *et al.* 2004) describes the MMG of the Solway Basin lithology thus:

> "*The Mercia Mudstone Group comprises dominantly red-brown, locally grey-green, mudstones that are commonly silty; a few interbeds, up to 1 m thick, of very fine-grained sandstone have been noted. Two principal mudstone lithofacies have been noted, massive (structureless) and laminated. Cross-cutting fibrous gypsum veins are common throughout, and some intervals contain numerous gypsum-anhydrite nodules.*"

Another BGS report (British Geological Survey 2008) states:

> "*As a basis for the rationalisation of Mercia Mudstone Group lithostratigraphy, we have identified a framework of five lithostratigraphical units (A to E, described below) that*

> *either possess, or can reasonably be inferred to have once possessed, a high degree of continuity. These units are mappable both at surface and in the subsurface on a regional rather than local basis, and thus comply with the definition of a formation*".

A 2008 sedimentological study emphasises the aridity or hyperaridity of the palaeogeography of the late Permian – Triassic sediments (including the MMG) of the Solway Basin, the lack of tectonic control, as well as their great areal extent (Brookfield 2008). An analogy is drawn with the modern Chad Basin:

> "*In fact the entire assemblage of late Permian to mid-Triassic basins of Western Europe may simply be sub-basins within a larger Chadian-type intracontinental mega basin stretching from central Europe to eastern North America*"

So with such a high degree of lithostratigraphic continuity over 500 km within England (from Carlisle to the Channel coast), extrapolation and/or interpolation of physical parameters such as hydraulic conductivity, which depend primarily on lithostratigraphy (but also later diagenesis and in burial history), can certainly be made. Therefore the variety of hydraulic conductivity measurements of the MMG throughout England, particularly in the West Midlands and Cheshire, yielding values tending to the range $10^{-6} – 10^{-7}$ m s^{-1}, can be applied with confidence to the Solway Basin. Indeed, in central England, parts of this Group are known as 'Waterstones', because of their flowing groundwater characteristics, and this suite of rocks is correlated by BGS to be present in West Cumbria.

I therefore repeat my previous conclusion, that the MMG has a hydraulic conductivity ranging from ten thousand to millions of times higher than potentially suitable claystone host rocks elsewhere, and that this range of high values will be as applicable in the northern Allerdale district as elsewhere in England and Wales. Dearlove's (2011b) counter-claim, that "*Until we understand better ... we can only speculate on the hydraulic conductivity of the MMG*" is a classic example of the appeal to ignorance (agnotology) made by those who wish to muddy the waters.

So there is a vanishingly small chance that any significant volume of the MMG will turn out to have the required desirable hydraulic conductivity 10^4 to 10^6 times *lower* than what we can now infer from the existing database.

4.7.6 Redox environment

Falck and Nilsson (2009) have summarised the state of knowledge of redox processes. The oxidised state of radionuclides of interest is generally more mobile than the reduced state (e.g. U(VI) *vs.* U(IV)). They observe that it is tacitly assumed that "*the corrosion of structural steel and ferrous metal packages would result in a reducing near-field environment*". They point to the difficulty of achieving anaerobic conditions either in the laboratory or in underground research laboratory installations. They observe:

> "the *construction and operation of a deep repository will result in a redox anomaly underground that is likely to take considerable time to dissipate. This process requires a sufficient redox buffering capacity of the surrounding host rock and of the far-field as a whole. While this may be not so much of concern in the context of clay host rocks, as these frequently contain significant amounts of reducing minerals such as pyrites, the situation is different for fractured hard rock. The question here is also whether the*

> *radionuclides experience sufficiently long residence to become reduced*".

The lack of evidence of reducing minerals like pyrite was a major obstacle in the case of the BVG at Longlands Farm (Haszeldine 1996). The same problem arises with the MMG, which comprise overwhelmingly redbeds.

Dearlove (2011b) appealed to the reduction haloes (and bands) commonly seen in redbeds such as the MMG, arguing that this is evidence against an oxidising environment for the MMG:

> "*I assume Professor Smythe means that, as the MMG is generally red in colour due to the iron being in an oxidised state, this implies an oxidising environment. This is not true.*"

He went on to say that:

> "*interstitial groundwater at depths in excess of 500m (the proposed minimum depth for any potential repository facility) will be reducing as any oxygen from recharging groundwater will be consumed through biogeochemical reactions. It will also most likely be saline*."

In short, he argued that below about 500 m the hydrogeological environment will be extremely reducing; whether or not this is linked to the likely salinity of the groundwater below the same depth is not clear. Dearlove links the geochemical attribute of 'oxidising' to the presence of dissolved oxygen, whereas it is well understood that geochemically oxidising (or reducing) depends on the electron flow between an assemblage of mineral ions dissolved in the groundwater. In that context, the desired oxidation state around an engineered repository is intended to be extremely reducing, with an Eh around -200 mV. That extreme Eh would geochemically change red iron III to green iron II, so that the rock colour would change. Dearlove provides neither evidence nor measurement to support this assertion. However this is clearly unjustified, as drinking water extraction occurring from similar MMG mudrocks in Shropshire, Nottinghamshire and NW England shows that produced waters from the Sherwood Sandstone are very oxidising, with positive +500 Eh, which extends for 5 kilometres laterally beneath the MMG. The groundwater does, undoubtedly, become less oxidising with depth, and occasionally mildly reducing, but nothing as extreme as the values suggested by Dearlove.

Additionally, the BGS reports that the Permo-Triassic formations encountered in the Silloth-1A well, in the centre of the basin (Fig. 4.7.1), are typically red-brown, all the way down to about 1300 m (Holliday *et al.* 2004). This would not be the case if the groundwater – particularly through the highly permeable Sherwood Sandstone aquifer – were severely geochemically reducing. I do not have access to the completion log for this well, but supply here instead two well log examples of MMG from the south of England – one onshore and one offshore. Table 4.1 below shows the lithological descriptions of the cuttings from the MMG for these two wells, where the MMG is between about 1.4 and 2.0 km depth. Undoubtedly the porewater will be saline, but note the mention of red coloration and explicit mention of haematite – i.e. there is no sign of reduction. If Dearlove's argument were valid, then all Permo-Triassic redbeds below 500 m or so would be reduced, and no longer red. This is not the case.

Dearlove (2011b) mentions reduction haloes in the MMG: a reducing environment is desirable in such rocks because it inhibits transport of radionuclides. This ignores the common observation that reduction haloes are small in size (centimetres to metres), and typically formed around isolated individual fragments of fossil organic debris, or reduced minerals such as isolated sulphide grains. These haloes, in fact, clearly demonstrate that the rock formation outside the halo is geochemically oxidising compared to the formation within the halo. That rather disproves the point that Dearlove is trying to make. But the presence of these haloes, or even bands, within the predominantly red, oxidising layers will have a negligible effect on inhibiting radionuclide transport; water will take the easy path around them. The haloes will be as about effective as putting isolated individual sandbags around a house to prevent it from flooding.

Table 4.1. Well log descriptions of Mercia Mudstone Group

	Completion log comments
Depth	**Bransgore-1 (BP, Dorset 1986)**
1354	*Top Mercia Mudstone*
1380	MUDSTONE: orange brown, red brown, firm, crumbly to angular break, silty, non-calcareous
1430	MUDSTONE: red orange brown, firm, crumbly break, slightly silty, slightly calcareous, slightly swelling
1460	MUDSTONE: red brown, crumbly break, firm, silty to sandy, very slightly calcareous
1560	MUDSTONE, red brown, firm, crumbly break, silty, occasionally slightly sandy, slightly calcareous
1570	SAND: translucent, medium to coarse quartz, sub rounded, loose
1600	MUDSTONE: red brown, firm to moderately hard, angular break, silty, slightly sandy, slightly calcareous
1620	SAND: transparent to red stained quartz, medium to coarse grained, rounded
1635	*Top Sherwood Sandstone*
	98/12-01(Elf, Bournemouth Bay 1993)
1733	*Top Mercia Mudstone*
1740	CLAYSTONE: medium grey to dark grey black, very calcareous to slightly calcareous, on bottom, firm to hard, subfissile grading to SHALE, micromicaceous, locally greenish, glauconitic
1750	CLAYSTONE, purplish red brick, red, hard, iron oxyde [sic] stained, locally dolomite or anhydrite specks
1800	CLAYSTONE: brick red, iron oxyde stained, locally grey green, generally non-calcarous, monotonous, occasional white anhydrite mottles
1910	SAND: light grey to off white, very fine to silty, well sorted, firm to friable, slightly calcareous, abundant carbonaceous spots locally grain coating. Traces of fluorescence ...
1950	CLAYSTONE: dark red brown, compact, uniform, Fe staining, in parts very calcareous, rare beds of ANHYDRITE …
1975	CLAYSTONE: red, red brick, iron oxyde [sic] stained, occasionally dark grey, slightly to non calcareous, hard shaley, sandy, vey [sic] fine to fine, streaks to very thin levels of DOLOMITE …
1990	… intercalations of SANDSTONE: pale grey, off white, very fine to fine, well sorted, spherical, subrounded to rounded, argillaceous, slightly calcareous, anhydritic …
2040	CLAYSTONE: becoming mainly medium dark grey to reddish brown, non to slightly calcareous, anhydritic. Stringers of SANDSTONE: light dark grey, speckled black, very fine to fine …
2090	CLAYSTONE/Shale: red purple, grey micaceous, haematitic, with very fine sand grains, opaceous, translucent, pocellanous, arenaceous, cherty
2095	SANDSTONE: light grey, white very fine, rounded to subangular, well sorted, well cemented, calcareous, argillaceous, becoming red brown, very argillaceous, no visible porosity …
2115	SILTSTONE: red brown, dense, haematitic, very micaceous, slightly sandy, traces of disseminated quartz grains
2120	CLAYSTONE: red brown, uniform, silty, haematitic, basal cherts lense [sic]

So his hope that, thanks to the reduction haloes, "*the international requirement for a geological setting to inhibit movement of radionuclides could be achieved within the MMG*" is completely unrealistic.

4.7.7 Volume and depth of MMG available

The MMG in the Silloth area (Fig. 4.7.1) is cut by faults with throws of up to 100 m, trending NNW-SSE; therefore it cannot to be compared with unfaulted flat-lying geologically simple claystone formations currently being considered as potential host repository rocks elsewhere in Europe. The continuation of the Crummock Fault, downthrowing to the E, runs north to the coast, flanking a narrow horst block lying just east of the well. To the west of this block the base of the MMG is at a maximum of 500 m depth; to the east the base of the MMG forms a circular basin with a maximum depth of about 400 m.

Dearlove (2011b) did not seem to notice that the maximum depth of the MMG in the one area where the MMG is deeper than 200 m (south of Moricambe Bay; see Figure 4.7.1) is 500 m. According to him, the minimum depth for a repository is 500 m in this type of environment – presumably because he wants to place it where the groundwater will be saline. This is clearly not possible. The only possibility left is for a repository sited in the MMG between 200 and 500 m depth, in a *freshwater oxidising environment*.

Unfortunately for him this very limited option is even further constrained by the geology. The zone in question lies between two areas of BGS exclusion, one to the west, the other to the east. The southern part of the available area, around Edderside, is 3-4 km wide, and cut by the Crummock fault and other faults trending NNW-SSE. Here the MMG is around 400 m thick and deep. Further north the available area widens out to about 8 km in the Silloth – Seaville district, but is bisected by at least two important normal faults. There is further evidence (from interpretation of the logs of the Silloth-1A well by the BGS) that otherwise undetected normal faults transect this well, cutting out part of the succession. This is not surprising, as the well lies only about 1 km from one of the major N-S normal faults mapped by the BGS using seismic reflection data.

The minimum underground footprint of a repository (including Pu/U) in 'lower strength sedimentary rocks', such as the MMG, is around 20 km^2, according to the Entec environmental assessment report (Entec 2010). Considering this as an area of dimension 4 x 5 km^2, for example, it is unlikely that a repository could be accommodated within this zone, which comprises two sub-areas on either side of the faulted horst block, each of about 30 km^2 in total area.

4.7.8 Hydraulic conductivity of faults cutting sediments

Dearlove (2011b) states:

> "*The MMG is cut by faults which can provide higher flow pathways. However, much depends on the nature of material infilling these faults/fractures/joints. Not all faults act as high hydraulic conductivity pathways. I don't believe there is a detailed hydrological* [sic] *study of these faults available to make this interpretation*."

The literature on the fluid sealing or conducting properties of faults in sediments is large and confusing. Research is driven by the need to understand sealing of hydrocarbon reservoirs at depths of 2-3 km on the one hand, and engineering properties of faults in the near-surface (down to a few hundred metres), especially in unconsolidated sediments. Nuclear waste repositories fall between these two stools. In addition, the subset of research into the effects of faulting in pelitic rocks is very limited.

My brief and necessarily incomplete review of the field leads me to the following impressions and tentative conclusions:

1. There are field measurements of faults at outcrop and at shallow depth; it is realised that small-scale structures associated with faults dominate the bulk hydrogeological properties. These are characteristically fractures sub-parallel to the master fault plane, which are collectively termed the 'damage zone'. Such zones can be several metres to tens of metres in horizontal width, and are often the locus of fluid flow up or downwards, rather than across the master fault plane.

2. In an unconsolidated mixed sand/clay stratigraphy, the conductivity in the damage zone can be enhanced by several orders of magnitude, but clay smearing along the core fault plane reduces the bulk conductivity.

3. Iron oxide re-precipitation in the core fault, due to the enhanced flow in the damage zone, is another mechanism which can reduce the core conductivity.

4. There are ample underground samples, tests and tunnel sections of the Opalinus Clay in Switzerland, which has an extremely low hydraulic conductivity (10^{-14} - 10^{-12} m s^{-1}), and in which even the fault zones show no sign of flow below 200 m depth.

5. Studies of the Opalinus Clay show that it has self-sealing properties; the excavation-disturbed zone in such rock initially has hydraulic transmissivities several orders of magnitude higher than the protolith, but that it decreases by two orders of magnitude in about two years.

6. The relative hydraulic conductivity of a fault cutting indurated low-conductivity clays is neutral; i.e. the conductivity of the fault zone remains within the same order of magnitude as the unfaulted clay. An example is the set of measurements across the Down Ampney fault, made by the BGS, in which Oxford Clay is juxtaposed against Oxford Clay or Forest Marble Clay.

7. However, the same dataset shows that the conductivity of the fault zone as a whole is enhanced by one or two orders of magnitude, because the succession includes limestones and sandstones as well as the aforementioned clays.

8. Smectite in shear zones can be dehydrated to anhydrous illite minerals as a shear fabric develops; this in turn can account for overpressure build-up. This mechanism accounts for high hydraulic conductivity observed in accretionary wedges, but contradicts laboratory experimental studies suggesting that sheared clays in fault zones represent aquitards.

Lunn *et al.* (2008) have modelled the fluid flow pathways across models derived from detailed outcrop observations. Starting with their summary that:

> "*Faults can be barriers to flow, conduits, or combinations of the two, and their hydraulic properties vary considerably over both space and time*".

They conclude from their study that the *micro* properties as opposed to the *average* hydraulic properties in a fault zone are crucial, but that these properties are *unmeasurable at depth*. A multi-variate stochastic approach is the only way forward, they say, which:

> "*implies that a very large database of fault architecture is needed to accurately characterize fault permeability distributions. This can only be achieved by pooling a large number of field datasets. This would require an international consensus on the recording of the gross parameters (e.g., lithology, offset, stress history) and the architectural detail at each site*." [NB authors' emphasis on *very large*].

Such a probabilistic approach to characterising the hydraulic properties of faults was tried by Nirex in its Longlands Farm site hydrogeological models, and found to be wanting. So the "*detailed hydrological study*" that Dearlove requires for the MMG faulting will never be achieved except in a generalised probabilistic manner, and after the internationally agreed database has been built up. Such a database will presumably take many years to assemble. Professor Lunn is a current member of CoRWM.

In view of the confusing and complex nature of the current research into hydraulic conductivity in faulted clay rocks, together with the pessimistic (but realistic) view that the microscopic properties of faults can never be predicted at depth, the only rational decision in the search for a suitable clay repository is to avoid all such areas of faulting, and to find a suitable unfaulted clay formation. I have already alluded to the Opalinus Clay and the Oxford Clay as examples of potentially suitable formations. The MMG is not such a formation. It is also worth mentioning that a 3D seismic survey of one of the prospective Opalinus Clay repository sites in Switzerland shows that there exists no fault with a throw of greater than 4 m within the proposed clay volume; 4 m is the resolution limit of the 3D seismic imaging.

4.7.9 MMG: summary

To recap and summarise why the MMG remains unsatisfactory for consideration as a repository host rock in northern Allerdale:

1. The MMG was (rightly) not previously considered as a host rock by the BGS during its national search in the late 1980s.
2. This region is the subject of current hydrocarbon exploration licences and should be excluded.
3. The regional hydraulic gradient is high, contrary to international guidelines.
4. A repository would have to be sited at an undesirably shallow depth of between 200 and 500 m.
5. The one candidate area with these depths available, near Silloth, is bisected by normal faults with throws of up to 100 m, which may act as water conduits.
6. The geology is well understood, thanks to oil industry seismic and the Silloth-1A well.
7. The geochemical environment of these haematite-bearing red beds is oxidising.
8. The groundwater is fresh, and exploited within this zone as an aquifer.
9. The hydraulic conductivity is 10^4 to 10^6 times higher than that considered desirable by reference both to international guidelines and to current international practice.

10. It is an ineffective seal for hydrocarbons if less than at least 600 m thick; this is *a priori* hydrogeological evidence that if used as a repository host rock it will be ineffective as a barrier.

It is therefore irrational for Dearlove (2011a) to have proposed the MMG as a possible repository host rock. I therefore re-affirm my previous conclusion that the MMG is an unsuitable host repository formation.

In addition, unless Dearlove can produce documentary evidence that the MMG is seriously now being considered as a host rock by the BGS, I also conclude that he introduced the concept as a debating tactic, with a view to demonstrating that I had not considered all of the partnership area geology, and that CoRWM's conclusion would therefore stand.

4.8 Eskdale granite

4.8.1 Introduction

Could a site be found within the National Park itself, assuming that such a possibility was politically acceptable? The discussion above has been confined either to sites in sediments, or else to the BUSC category. The National Park comprises hard rock at outcrop. However, it does not come into the hydrogeological category of 'Hard rocks in low relief terrain' used by Pieda in 1988, because of the extreme topography. Pieda did find a number of sites categorised as 'Hard rock coastal'or 'Hard rock inland' in its initial list of 537 sites (see Appendix A below). One site in the former category and one in the latter category (Dounreay and Altnabreac, respectively) made it into the final ten-site shortlist.

Figure 4.8.1 shows the topography of Cumbria compared with that of Sutherland, at the same scale and with the same colour relief shading. The Sutherland sites come into the category of 'Hard rocks in low relief terrain', although the relief is a lot higher than the hard rock sites being investigated in Canada, Sweden and Finland.

For illustration, consider a potential hard rock site such as within the Eskdale granite, shown in red in Figure 4.3.6. A putative site could be located in lower Eskdale, but just east of the LDBF. The hydraulic gradients here would be several times higher than at the Sutherland sites, and probably an order of magnitude higher than at the international hard rock sites. So such a site may be in hard rock, but it is certainly not in low relief terrain; therefore it does not conform to any acceptable generic category, quite apart from the fact that it is close to a major UK fault zone.

Dearlove (2011a) stated, in the context of the Eskdale granite as a possible host rock:

> "*It should be noted that a number of radioactive waste research facilities were located in areas of high hydraulic gradient (for example, Grimsel in the Swiss Alps)*". (para. 6.5).

The mention here of Grimsel, the hard rock undergound laboratory developed by Nagra in Switzerland, is misleading. It was located in the heart of the Alps as a way to bore horizontally from a public road into crystalline rock below 400 m of mountain cover rock. This is far more convenient and cheaper than sinking 400 m deep shafts, than tunnelling horizontally. The site is explicitly designed for research, and will never be used as a waste repository, precisely because of the high hydraulic gradients due to the mountainous topography.

No other potential waste repository sites internationally are located in areas of high hydraulic gradient.

Following Dearlove's intervention, I expanded my views on the unsuitability of the Eskdale granite (Smythe 2011d), as will now be discussed.

4.8.2 Age, shallow structure and relief

The Eskdale granite is 450±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, as shown in Figure 4.8.2, taken from British Geological Survey (2006), but the individual granites are distinct.

The crucial point, which differentiates the Eskdale granite from most of the others of northern England, is that it pre-dates the Acadian orogeny. It has therefore been fractured and faulted, unlike, for example the Shap granite (Fig. 4.8.2). Figure 4.8.3 shows a geological cross-section (Kneller and Bell 1993) 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 4.8.4 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 are extracted 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^2.

The more regional solid geology map of Figure 4.8.5, 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 4.8.6. 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 4.8.6 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 4.8.7, 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 4.8.5, 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 4.8.5.

The present day topographic relief of the Eskdale granite is considerable. Figure 4.8.7 shows the shaded relief with the solid geology map draped over it. 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 (Millward *et al.* 2000). 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 (Evans *et al.* 1994), or laccolith, of leaves of granite alternating with country rock (Figs. 4.8.8, 4.8.9). 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), is inferred to 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.

4.8.3 Mineralisation and heat flow

Veins of haematite are common in the Eskdale granite. They frequently occupy large faults of NNW-SSE trends (Fig. 4.8.10). 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 (British Geological Survey 2010).

Comparison of the southern granodiorite block of granite on Figure 4.8.10 with the superficial geology map of Figure 4.8.6 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

(Haszeldine 1996). 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 (Millward *et al.* 2000) discusses the 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 alternative uranium mineralisation sources for the stream sediment concentration have been discovered, the BGS concludes that "*scavenging of this element is still considered the most likely explanation for these relatively high values*" (Millward *et al.* 2000). In other words, present-day oxidising groundwater is leaching out uranium from the granite.

The BGS screening report (British Geological Survey 2010) 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 (British Geological Survey 2010). The granite is within one of the three principal granitic batholiths of the UK having exceptionally high heat flow values (Barker *et al.* 2000).

4.8.4 Stress regime

A variety of different types of data show that West Cumbria is under a compressional stress regime (Michie 1996), 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 (Rogers 2003). 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 (Firman 1960). Joints of this orientation (Fig. 4.8.11) will open easily under the current stress regime.

4.8.5 Faulting: comparisons with other UK granites

Since 'granite'is being considered as a suitable host rock, let us briefly examine faulting in some other UK granite bodies, 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 4.8.12 and 4.8.13, respectively. The Northern Granite of the Isle of Arran is similarly depicted in Figures 4.8.14 and 4.8.15. 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. 4.8.5 and 4.8.6). 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 the field observations that are necessary to identify faults.

Dearlove (2011b) disputes my conclusion that "*it is clear that the granite is heavily faulted, unlike most other granites in the UK*". He contrives to finesse this simple observation, demonstrated by reference to the BGS maps of the Eskdale and other granites, with my further, and perfectly reasonable, inference that, due to the poor exposure, the observed degree of faulting as shown on the BGS maps of Eskdale is an underestimate. Table 4.2 shows the degree of faulting of the three granites for which I showed maps (Smythe 2011d). The fault lengths quoted above include any faulted margins. My further analysis of the underestimate of faulting in the Eskdale granite, due to poor exposure and lack of lithological variety, suggests that the faulting is underestimated by a factor of 2 to 5, depending on the locality.

Table 4.2. Fault density in granite bodies

Granite	**Area (km^2)**	**Fault length (km)**	**Fault density (km per km^2)**	**Exposure of solid geology (%)**
Eskdale	77.2	86.7	1.1	20
Arran	107	0	0	70
Red Hills, Skye	41	1.2	0.03	95

I presume Dearlove is not trying to denigrate the mapping expertise of the BGS. On the other hand, he produces no evidence to support his assertion that the Eskdale granite is in fact unexceptional in its degree of faulting. Whether one accepts my inference that the true degree of fault density is up to about 5 km^{-1}, or agrees only that the minimum observed mean density of 1.1 km^{-1}, from Table 4.2 above, my conclusion remains that the *Eskdale granite is heavily faulted*.

Lastly, if we go by the rule of thumb that the throw of a normal fault at any point is of the order of one-tenth of the distance to the end of the fault, then within the observed (mapped) faults within the Eskdale granite, there are 15 fault segments with throws of more than 100 m at the centre of the mapped fault, within the total set of 53 fault segments which all have throws of more than about 17 m.

4.8.6 Permeability: the Weardale granite

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. 4.8.16). 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 (Younger and Manning 2010). 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 and reply by Smith *et al.* (2010), and presentation of more detailed investigations, suggests that the permeable flowing fractures are a consequence of the present-day stress field. Dr. Smith is a colleague of Dr. Dearman in FWS Consultants Ltd.

In reply to my discussion of high permeability zones within the Weardale granite, Dearlove (2011b) stated:

> "*High permeability zones were reported on in* [sic] *the Weardale Granite, and commented on by my colleague Dr F W Smith. The high permeability zones* <u>*he*</u> *attributes to a lack of infilling of hydrothermal fractures during mineralisation in a known vein fissure, and* ***NOT*** *to the present day stress field as claimed by Professor Smythe*." [my underlining].

I did not mean to imply that Smith himself attributes the high permeability zones to the present-day stress field, but my statement was not clear enough. I used the phrase "*A recent discussion by Dr F.W. Smith*" when I should also have included the other authors Younger and Manning in the Discussion and Reply; it was they who made the suggestion in their Reply, not Smith. However, what Younger and Manning propose is based upon one of two explanations offered by Smith for the unusually high permeability:

> "*The approximate north–south strike of the fractures is almost orthogonal to the trend of the Slitt Vein itself, which perhaps favours the second of the two structural explanations offered by Dr Smith (i.e. Tertiary reactivation). This is because the present principal stress direction for this region of England is currently considered to be approximately north–south ... , and it may well have maintained a similar orientation back into the Tertiary period. It may be that uplift and exhumation within a stress field with a principal axis oriented north–south led to orthogonal faulting along the margins of the vein-filled Slitt Vein wrench fault, and that these fractures provide hydraulic connectivity into the Slitt Vein structure as a whole, which despite lying subparallel to the minimum stress axis for this region still appears to be highly permeable*."

Note, however, that Dearlove does not comment on the main issue, which is the likely existence of extremely high permeability zones within other '*granitic terrains*', as postulated by Younger and Manning (2010) in a separate paper. This is surprising, given that his colleague Smith is clearly an expert on the subject.

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.

4.8.7 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 all the sites studied come into the category of 'hard rock in low relief terrain'.

Relief maps showing the extreme contrast in topography between West Cumbria and the relevant parts of Scandinavia have been discussed in Section 4.2 above.

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 (Macdonald and Sharifi-Asl 2011). 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.

Dearlove (2011b) addressed some of my points above on the Eskdale granite, which I answered in Smythe (2011e). These are discussed below.

4.8.8 Groundwater

Dr Dearlove is an expert on geochemistry of groundwater. He states:

> "*The* "*strong*" *evidence presented to support the argument that groundwater in the Eskdale Granite is oxidising, namely the speculative statement by the BGS that elevated uranium in stream sediments over the outcrop of the Eskdale Granite is from scavanging (although it should be noted not necessarily from the Eskdale Granite itself which is low in uranium), is* ***NOT*** "*strong*" *evidence. The presence of haematite mineralisation does not indicate the presence of modern day oxidising groundwaters at depths of up to 1 km within the Eskdale Granite. At a depth in excess of 500m it is highly unlikely that potable, oxidising ground waters will be present in the Eskdale Granite.*"

There are three points here:

- The explanation for the elevated uranium in stream sediments.
- Haematitite mineralisation and modern-day oxidising groundwaters.
- Depth limit of 500 m to potable oxidising waters.

Under point (1), he dismisses the BGS explanation as "*speculative*" while offering no alternative explanation.

Under point (2) he denies that there is a link between "*modern day*" groundwaters and the long-term oxidising environment implied by haematite; But the presence of haematite is just the sort of geological evidence we need to be able to infer with confidence the *long-term* groundwater state. Unless Dr Dearlove can come up with evidence that the groundwater, both today and in the geological past, is severely reducing, not around zero to oxidising, then he needs to re-enter discussions with the BGS geologists, this time about Eskdale, and ask them to revise and publish their explanation.

Under point (3) he introduces the 'magic' figure of 500 m as the depth below which the groundwater (he asserts) would be saline *and* reducing. Let us accept for the moment that he is correct, and that a repository could therefore be sited at (say) 600 m depth within the granite:

- Is he therefore relying on a purely fluid boundary between the reducing waters surrounding the repository and the oxidising waters above, all within a supposedly homogeneous rock, as the final barrier for the safety case?
- Will this barrier not migrate up and down over different climatic periods in the future, due to changes of sea level, and variations in groundwater flow beneath glaciers?
- Will it not be breached by convective flow, caused by the heat (and hence upward flow of groundwater) due to the storage of heat-generating HLW?
- How will this groundwater boundary resist gas escape from the repository?

In conclusion, his arguments against the postulated oxidising groundwater history are weak to non-existent, whether or not one accepts my qualifying adjective 'strong' for the arguments in favour of this oxidising history. As an expert in this field he should have been able to come up with some more convincing alternative scenarios.

4.8.9 No comment offered

Dr Dearlove offers no comment on the BGS interpretation of the western margin of the Eskdale granite, as seen on profile, as a complex 'cedar tree' structure, and with the interior of the granite holding large rafts of country rock.

4.9 Elsewhere in West Cumbria

4.9.1 Offshore

The BGS initial screening report (British Geological Survey 2010) included the coastal zone up to 5 km offshore. Offshore from the coastal plain of West Cumbria the Triassic sediments of the Sherwood Sandstone Group are about 1500 m thick, overlying Carboniferous sediments which in turn rest on presumed BVG. South of the latitude of Sellafield the overlying MMG is faulted into outcrop, about 1.5 - 2 km offshore. The throws of the normal faults shown in the extract from the geology map (British Geological Survey 1999; Fig. 4.8.17) are of the order of 100 m or greater. The structure map of the base of the MMG (Fig. 4.8.18) shows that it is nowhere more than 500 m thick within 10 km of the coastline (British Geological Survey 1997, map 1).

Even though the MMG here will host saline groundwater, many of the same strictures nevertheless apply here as for the MMG in northern Allerdale (section 4.7 above). The offshore zone lies between a very active area of hydrocarbon exploration and production, to the south (Fig. 4.8.19) and the former onshore exploration licences (shown above in Figure 4.4.2). The near-offshore zone is very well understood thanks to the Nirex surveys of the 1980s and 1990s, in addition to commercial surveys.

In summary, the MMG in the offshore zone west of Sellafield is unsuitable because of:

- Shallow thickness (less than 500 m).
- Faulted by faults with throws of greater than 100 m.
- Oxidising environment.
- Unacceptably high hydraulic conductivity.
- Ineffective seal.

The only feasible potential host rock for a repository, the anhydrite of the St. Bees Evaporite Formation, within the Sherwood Sandstone Group, is too deep, at 1300 m or greater, to be of use as a potential repository. It was proved by a coastal borehole, Sellafield no. 3, within the Sellafield works at a depth of 1270 m (section 4.5 above). The anhydrite itself is less than 10 m thick, overlying Magnesian Limestone which comprises the remainder of the formation, about 50 m in total. The borehole log of the relevant section is shown in British Geological Survey (1997), fig 32. Magnesian Limestone, although of evaporitic origin, is not a suitable repository host rock.

The structure map of the base Permo-Triassic offshore from Sellafield is shown in Figure 4.8.20. The anhydrites will be 100-200 m above this level. Therefore it might be anticipated that anhydrites will be present at a shallower depth below the NW quadrant of Figure 4.8.20. Could the anhydrite here be significantly thicker than proved at Sellafield no. 3, as well as shallower? The BGS regional interpretation (Jackson and Mulholland 1993) of the various Permian and Triassic evaporites of the East Irish Sea shows that they formed in a gentle basin or depression between the Isle of Man and the west coast of Cumbria (Fig. 4.8.21). The present-day coast and the contemporary Ramsey-Whitehaven Ridge evidently formed the basin margins, so the anhydrites further offshore to the west and north of the Sellafield no. 3 borehole are unlikely to be any thicker than encountered at the borehole itself.

Below the Solway Firth there are no evaporites at a shallow enough depth; the MMG and the Sherwood Sandstone Group are both unsuitable as potential host rocks, whether or not they are at a sufficient depth for the groundwater to be saline.

In conclusion, there are no feasible host rock environments offshore within the partnership area. This conclusion is independent of the fact that any proposal to site a repository offshore is contrary to the London Convention, OSPAR, etc., and will probably encounter resistance from the governments of Ireland, Norway, and from the Scottish parliament.

4.9.2 The National Park

Parts of the National Park have already been dealt with; the coastal zone south of Ravenglass (section 4.3.3) and the Eskdale granite inland (section 4.8). The remainder of the National Park within the borders of Copeland and Allerdale comprises Ordovician metamorphic rocks and subsidiary igneous intrusions, all in a high-relief environment. So there appears to be no merit in considering such environments further, as they evidently do not conform to any of the international guidelines or suitable environments as defined by Chapman *et al.* (1986).

5. THE CURRENT PROCESS

5.1 Nirex influence on CoRWM

Nirex continued to supply misleading advice and guidance to government and CoRWM until Nirex was absorbed into the NDA in 2006.

As we have seen, it was Nirex who introduced the concept of voluntarism to CoRWM in 2004 (CoRWM 2004), providing it with a handful of ready-written papers on the subject (including Nirex 2000, 2005a). These misleadingly imply that voluntarism is or was working in other countries (Nirex 2005b). Voluntarism had also been suggested by other bodies.

Nirex continued to assert that 'Sellafield' (that is, the Longlands Farm locality) is "a suitable site for a repository" (CoRWM 2005, 2006).

5.2 Voluntarism and the 'community'

5.2.1 Definitions

CoRWM has not defined what it means by a 'community', although the phrases 'host community', 'local community' or their plurals are mentioned 60 and 19 times, respectively, in its final report. It begs the question of what is the appropriate 'community' in the cases of remote wilderness areas or uninhabited islands. To retort that a given area is under the jurisdiction of a local council is insufficient, for if no-one lives in or near the area in question then clearly there is no 'community' to give or withold its assent. Similarly, the offshore domain has been implicitly ruled out of consideration.

The concept of community involvement was introduced by Nirex in 2000, but CoRWM, created in 2003, apparently did not discuss it until 2004.

The 2008 white paper defined 'Host Community' as follows:

> "*The community in which any facility will be built can be termed the* '*Host Community*'. *The* '*Host Community*' *will be a small geographically defined area, and include the population of that area and the owners of the land. For example, it could be a town or village.*" [Defra 2008, para. 6.8]

It is understood that what constitutes a 'community' is continuing to tax MRWS.

5.2.2 Empty host communities

Extensive areas of hard rock, often in remote areas, were selected for investigation by the BGS in the 1970s (Mather *et al.* 1979). These outcrops, which included the entire Lake District, were excluded from the revised BGS national site search of the late 1980s, because by then the emphasis had shifted to a more advanced understanding of the hydrogeological environment, rather than simply the quality of the host rock. However, large areas of 'hard rock at or near the surface' were included in this later geological environment search, but this time excluding the Lake District. One hundred and twenty-six small islands were also included in the Nirex potential site list of 1988, of which many were uninhabited and some, furthermore, owned by public bodies such as the MOD. Three such islands made it to a late stage of the site sieving process, passing, in particular, the geological suitability test - Oigh Sgeir, Fuday and Potton Island. Oigh Sgeir was rejected at the 'site evaluation' stage, and the last two at the 'decision analysis'stage.

Even more remarkable is the case of Stanford, Norfolk, a BUSC site which ended up as one of the final four candidate sites in the 1980s search (Pieda 1989b). This site belongs to the MOD, and is allegedly used as a firing range. The old village had been cleared of inhabitants, and entry is prohibited. The Ordnance Survey maps blank out the area, in a form of censorship. Figure 5.2.1 shows the OS map, onto which I have placed a circle of 4 km radius, or about 50 km^2 in area, covering the censored area. This would evidently conform to the Defra definition of "*small geographical area*". The population is zero; the owner is the MOD.

5.3.3 Conclusions

I am not suggesting that the sites or regions mentioned above should be reconsidered. In any case the Scottish parliament has refused to envisage a repository site within Scotland; they merely illustrate how the concept of a 'volunteer community' has circumscribed the geological choices.

In conclusion, the emphasis on 'community' has pre-empted an objective and wide-ranging review of potentially suitable environments, by excluding many potential sites in remote or uninhabited areas, including the offshore and land owned by the MOD. The Defra definitions of 'host community' and 'wider local interests' appear to have been pre-defined with the well-populated area of West Cumbria in mind, while simultaneously ruling out many potentially more promising sites and regions.

5.3 Mis-use of the 'peer review' concept

When Nirex, DECC, NDA and Westcumbria:MRWS refer to 'peer review' they are in fact speaking of a limited form of in-house 'technical peer review'. The fact that they may have hired outside consultants to do the job does not alter this fact. The Wikipedia page (http://en.wikipedia.org/wiki/Technical_peer_review) states:

> "*The purpose of technical peer reviews is to remove defects as early as possible in the development process*."

In contrast, scholarly peer review, according to Wikipedia:
(http://en.wikipedia.org/wiki/Peer_review), is:

> "*the process of subjecting an author's scholarly work, research, or ideas to the scrutiny of others who are experts in the same field, before a paper describing this work is published in a journal. The work may be accepted, considered acceptable with revisions, or rejected.*"

In practice there will be several anonymous and independent reviewers (referees) chosen by the editors of the journal. The comments of the referees are passed back to the author for comment. The editor may:

- reject the paper outright,
- accept it subject to the flaws identified by the reviewers being first corrected, or
- (rarely) accept the paper for publication without revision.

A crucial distinction exists between the two types of peer review summarised above. Technical peer review is a purely in-house process; there is no publication. But scholarly peer review leads to eventual publication.

Nirex was criticised by the Royal Society (1994), which said:

> "*An essential feature of science in such a sensitive area of public perception ... is exposure to peer review at national and international levels. ... We were forcibly struck ... by the extent to which some scientific reports of Nirex are protected from wider scrutiny by being classified* "*commercial in confidence*"*. This applies particularly to reports dealing with PCPAs* [Post closure performance assessments] *for Sellafield.*"

From 1997 Nirex changed its philosophy (Nirex 1997), and reports formerly classified as 'commercial in confidence' have been made public, and the practice is little-used within NDA.

However, the peer review process which it defined remained the 'technical' version discussed above. In fact Nirex appears to misunderstand the scholarly version of peer review, by stating:

> "*The processes of public and academic debate, consequent upon publication, and which are frequently referred to as peer review do not generally fit the above definition because such review does not normally produce formal documentation.*"

The need for formal documentation expressed above is saying, in effect, that Nirex wanted to keep control of the process. Even the Royal Society report referred to above was commissioned by Nirex, and while the study group appointed for the task comprised eminent scientists, the terms of reference were essentially to review Nirex's ongoing science as of July 1994. So the choice of Sellafield as the location for the proposed repository at that epoch was not questioned.

In contrast, scholarly peer review is a formal documented process, but outside the control of the authors submitting the paper. Editors have no overwhelming desire to see the work in question published, and the referees remain anonymous, although their comments are returned to the authors for comment, revision and reply. So scholarly peer review cannot be rejected on the grounds of lack of documentation. It appears to me that the UK nuclear waste disposal industry - Nirex and its successors - dares not use truly independent reviewer scrutiny along the lines of scholarly peer review, because it fears genuine criticism. The review methods employed by Nirex and NDA are no more than dotting the i's and crossing the t's on its reports.

The Royal Society (1994) continued:

> "*We were informed about the methods used and had models described to us, but we were given few details of specific assumptions, did not have access to the databases of parameter values for models, and were given no detailed results of PCPA*

> *calculations.*"

This criticism still applies today, 17 years later. I have gone into some detail in this section because the Nirex 97 set of documents, which Nirex (2005c) has claimed makes Sellafield "*suitable*", despite the outcome of the Inquiry. The processes described here regarding limited technical peer review, plus the strictures of the Royal Society quoted above, apply to Nirex 97. The peer review process for Nirex 97 is described in the Nirex 97 summary report (Nirex 1998). The recommendation of the Royal Society (1994) that:

> "*The iterative process of developing post-closure performance assessments for UK deep repositories for radioactive wastes should be open to wide scientific peer review, particularly the databases, the interpretation of site-specific data and the analysis of assessment results for specific potential repository sites*"

has not been fulfilled in Nirex 97. I shall discuss Nirex 97 and its failings, within the context of peer review, in section 5.6 below.

Regarding Nirex's increased openness and use of external review after the Inquiry, Oldroyd has commented:

> "*Thus Nirex was moving more into the public domain, recognizing that its previous modus operandi had not helped its case at Cleator Moor* [the location of the Inquiry]. *It also began to send out its reports for external peer review, whereas earlier they had been scrutinized primarily by the special Nirex Panel of Review. However, one of the new referees, Ben Kneller, told me (pers. comm., 1999) that he found the process a little odd. He was asked to look at work that had been done a couple of years earlier, and found it difficult to form a fair judgement, given that the science had moved on in the interim.*"

Regarding Nirex's views on peer review and how it affected the Inquiry, Oldroyd concluded:

> "*In my opinion, another source of problems was Nirex's status as a semi-private company. For reasons of 'commercial confidentiality', it did not at first subject its publications to peer review in the normal scientific manner; and then, when it did open itself to closer public scrutiny, the damage was already done.*"

5.4 Reference to the Sellafield Inquiry in MRWS briefing note 91-BN

The briefing note published by WestCumbrian:MRWS (2011) tries to justify "*Why the current siting process for a geological disposal facility is very different to Nirex's approach in earlier decades*". This note is important because it reveals much about the NDA's intentions of returning to Sellafield. I quote extracts below from the note relevant to the scientific and technical aspects (my question numbering added):

> (1) "*What was wrong with Nirex's approach in the 1980s and 1990s?*
> *Nirex started by considering which geological areas in the UK could potentially be used to site a Geological Disposal Facility (GDF). It identified an initial 'long-list' of 537 possible sites within these areas and eventually whittled this down to a 'short-list' of 12 sites. The short-listed sites were then assessed against a range of criteria. This led Nirex to recommend that it should carry out geological investigations around*

> *Dounreay and Sellafield.*
>
> (2) *Why was permission to build the RCF near Sellafield refused?*
> *The Secretary of State's reasons for refusal were:*
> *• scientific uncertainties and technical deficiencies in Nirex's proposals*
> *• concerns about the selection of the site.*
>
> (3) *What did the Inquiry Inspector say about the scientific uncertainties and technical difficulties associated with the site near Sellafield?*
> *The Inquiry Inspector concluded in 1996 that:*
> *• Nirex had insufficient understanding of the groundwater conditions*
> *• there were not enough boreholes in the right places to check for water flow across faults in the rock*
> *• the conceptual model at the core of Nirex's modelling could not account for some basic processes of the hydrogeology*
> *• there was a strong need for more three-dimensional computer modelling*
> *• there were great uncertainties in the emerging safety assessment, for example, on the movement of radioactivity to the water-bearing sedimentary layers and the surface.*
>
> *The Inspector's overriding conclusion was that the RCF proposal was "seriously premature". Although emphasising that there were strong indications that the site was not suitable, the Inspector stated that his assessment did not completely rule out the possibility that the site could be suitable for a GDF.*
>
> (4) *What advances in understanding have taken place?*
> *A number of important advances have been made in the last two decades:*
> *• improved surveying methods (for example, 3-dimensional seismic surveying)*
> *• major advances in computing and modelling technology (for example, in the amount of data that can be handled and in 3-dimensional modelling)*
> *• an improved understanding of geological processes and their role in containing radioactivity.*"

Regarding (1) above, it was not Nirex that 'recommended' that geological investigations be confined to Dounreay and Sellafield; it was the Secretary of State who told Nirex that any other site would be unacceptable. The statement also glosses over the fact that the type of site chosen at Sellafield (BUSC) was a late entrant, and never in the original list of 537 sites. The Inspector noted in his conclusions:

> "*Cumbria's basic point* [Cumbria County Council being an Objector at the Inquiry] *is that the staged site selection process undertaken by Nirex in 1988-9 was detailed but flawed, and in essence I agree with Cumbria. ... Another fundamental difficulty is that the expert team and the Nirex Board, who should have interacted smoothly in the late stages of site selection, actually used different critical criteria in their final choices - geology for the one and local support for the other. [8.45]*
>
> *I consider that there were 3 crucial discontinuities in what should have been a methodical process. The first was the late introduction of an alternative Sellafield site which was not particularly promising according to the original criteria, and so probably would have been eliminated earlier if it had been included at the start. The second was the inconsistency between the team and the Board, which resulted in this*

> *lately introduced site and the doubtful Dounreay being kept in play whilst others with better safety potential were discarded. The third was the subsequent dropping of the alternative Sellafield site when it was realised after all that it is not suitable, and its substitution by the appeal site which, although nearby, had not been through the process at all. ... This cannot justly be described as following a rational procedure, in my judgement. It seems that the process was affected by a strong desire to locate the repository close to Sellafield. [8.46 – 8.47]*"

Regarding (2) and (3) above, the selection of Inspector's conclusions, backed by the Secretary of State's decision, is bland and incomplete, omitting the most critical comments. The Inspector commented on whether the siting of the Rock Characterisation Facility (RCF) at Longlands Farm could be decoupled from the selection of a final repository, and compared Sellafield unfavourably with other possibilities (Inquiry Report paragraph numbers are added in square brackets):

> "*The connection between the RCF and the repository is direct and obvious, and so cannot simply be set aside in the rest of the appeal determination process. ... any alternative sites which have been considered for the repository are alternative sites for the RCF too. ... The law, in my opinion, requires these alternatives to be examined by the state sooner rather than later, so that they must be looked at now if that is practicable [8.4, 8.6, 8.7]*
>
> *It also appears that a locational criterion required to comply with the UK's international obligations has not been applied in the site selection exercise. A repository near the sea would put the marine environment at greater risk of radioactive pollution than an inland site [8.9]*
>
> *it is now very evident that West Cumbria is too dependent on the nuclear industry, and so it would be an economic detriment, in my view, to significantly consolidate the nuclear industry by establishing the repository near Sellafield [8.33]*
>
> " <u>basement rock under sedimentary cover</u>" *(BUSC) ... seemingly could offer a range of inland locations. Nirex appears to misunderstand the concept, by claiming that the appeal site is within such an environment, whereas the area has never been so designated by its geological consultants. [8.43]*
>
> *...it is difficult to see the general public benefit in continuing to concentrate entirely on this site rather than any other. It has not been chosen in an objective and methodical manner, and there are strong ' indications that there may be a choice of sites in a different part of the earth's crust in the UK with greater potential to meet legal and regulatory requirements. [8.47]*
>
> *the practical difficulties of the deep disposal option were originally underestimated by the international consensus, which makes it all the more important to my mind to concentrate on an apparently favourable site. Also I consider that Nirex's emphasis on the relatively novel chemical containment concept in the mixed artificial and natural barrier suggests a lack of confidence in the geosphere. [8.48]*"

The Inspector's statement that Sellafield cannot be completely ruled out, quoted in the briefing note above, has been taken out of context. He said:

> "*Whilst this assessment cannot be claimed to completely rule out on its own any promise in the appeal site, it thus directly over-arches great uncertainties which would not be resolved by the RCF, and highlights the vulnerability of the concept of relatively rapid upward transport of the radionuclides, compared with the slow, downward flow of the favoured hydrogeological environments. The indications are, in my judgement, still overwhelmingly that this site is not suitable for the proposed repository, and that investigations should now be moved to one of the more promising sites elsewhere*." [8.53]

In summary, it is misleading to imply that the Inspector's overriding conclusion, according to the briefing note, was merely that the RCF was "*seriously premature*". To put this phrase once again in context, the Inspector said:

> "*But the fundamental point on this planning appeal is that, <u>to put it at its lowest</u>, the evidence shows to me that to go ahead with the RCF now would be seriously premature*." [6F.59] [my underlining]

Furthermore, this statement comes from the Report, section 6F: 'Role of RCF and promise of PRZ'. The Inspector put in the caveat underlined above, because in his Final Conclusions (section 8) he goes much further than that, as demonstrated by the various extracts reproduced above.

The fourth bullet point of item (3) of the briefing note attributes to the Inspector:

> "*there was a strong need for more three-dimensional computer modelling*"

This is untrue. There is no explicit mention of such a need in the Inspector's Final Conclusions; the phrase above implies that some more work is all that is required. In fact, the Assessor (Knipe 1996) devoted some 14 pages to his review of model development, including a paragraph (D.54) enumerating why more three-dimensional modelling would be required, <u>if more work were to be pursued at the appeal site</u>.

The statement quoted in the briefing note is not merely an inadequate summary; it is a travesty of the Inspector's conclusions. What the Inspector actually said in his Final Conclusions was:

> "*Also considerably more laboratory work and modelling development and refinement are required on matters specifically related to the local rock and groundwater before perturbation of the appeal site by the RCF can be justified. Nirex's modelling protocol also need to be generally improved, in my judgement, to recognise the absolute limitations entailed in the quality of input data and the span of human uncertainty and error.*" [8.55]

That statement (which is a *précis* of his Assessor's review) is a much more profound criticism of Nirex's modelling limitations, which were widely discussed by the Inspector in his conclusions on the then current state of Nirex's scientific and technical programmes (6C.145-6C.197) and model development (6D.59- 6D.76).

Regarding the fourth point (advances in understanding) it should be remembered that a 3D seismic survey was in fact carried out over the PRZ, and the results were fed into the Nirex 97 modelling, discussed in section 5.6 below.

5.5 Potential suitability of Sellafield according to Nirex

One of Nirex's last documents issued before it was absorbed into the NDA concerns the viabality of a phased repository concept (Nirex 2005c). Concerning what it says about Sellafield and the Inquiry, it has not been superseded by any later DECC or NDA publication.

Moving on from the general statement that it is possible to characterise a potential repository site, Nirex (2005c) then discusses Sellafield, asserting firstly:

> "*It has been argued that the rejection of the RCF planning application indicates that Sellafield was unsuitable as a repository site. However, we believe that this was never a conclusion from the RCF Local Planning Inquiry Inspector's report.*"

The document "*recognises*" two geological reasons for rejection (a third concerns planning issues); firstly, the flawed site selection process. Here Nirex claims that secrecy was the key issue. This is untrue; the real issues that the Inspector highlighted were:

- The late introduction of the site,
- The fact that it would not have got past the early screening rounds, had it been in the initial list,
- That it did not conform to the claimed hydrogeological environment ('BUSC'), and
- The measure of local support for, plus the 'endorsement' by the Secretary of State of, Dounreay and Sellafield in final shortlist.

We now know that the 'endorsement' by the Secretary of State was more of an instruction that the focus should be on Dounreay and Sellafield (Nirex 2005b). The second acknowledged reason for the appeal rejection was the prematurity of the application. This is correct, but prematurity was only one of many geological reasons for the rejection, as shown above. The document then goes on to claim that the 'Nirex 97' group of science documents, completed and published in 1997-98, after the Inquiry decision, shows that Sellafield "*is a potentially suitable site for a repository*". This important claim is unfounded, as will be shown in the next section.

5.6 The claim that Nirex 97 makes Sellafield 'potentially suitable'

5.6.1 Developments from Nirex 95 to Nirex 97

Nirex (2005c) asserts that the scientific information presented to the Inquiry was based on "*data obtained from the first few years of surface investigations only.*"and adds:

> "*Much more data from the surface-based investigations was obtained up to and including 1996. This information was not presented to the Inquiry.*"

The group of documents known as Nirex 95 is dated July 1995; the four main volumes of Nirex 97 are dated December 1997 (the summary report was issued one year later). In round terms, if one allows for writing up, and the fact that data collection for Nirex 97 continued till the end of 1996, then data collection for the earlier report set would have been up to around mid 2004. So at most, an extra 2.5 years' worth of data went into Nirex 97 that were not available for Nirex 95. The Nirex 97 summary (Nirex 1998) claims 2 years. But the bulk of the data collection had been completed in ample time for Nirex 95 – the drilling and logging of 18 boreholes, the various regional and local geophysical surveys, and borehole monitoring (e.g. Michie and Bowden 1994). Eleven extra boreholes were drilled subsequently, all except for two within the PRZ (Bowden *et al.* 1998). The additional period for long-term monitoring of salinity and heads would have been useful, plus the trial 3D seismic survey of the PRZ.

However, late documents were submitted to the Inquiry by Nirex, so it cannot reasonably be claimed that mid 1994 was the cut-off point for all data. The 3D survey, which I proposed, planned and carried out in summer 1994 for Nirex under a contract with the University of Glasgow, produced preliminary results by early 1995, but Nirex procrastinated in reviewing my reports through the technical peer review process referred to above. I believe that this was a deliberate move to keep the results from the Inquiry, because the results showed that Nirex did not understand the geological structure.

The crucial change between Nirex 95 and Nirex 97 is in the geology and hydrogeology:

> "*Using the resource-area based approach adopted in Nirex 95, the assessed performance of a repository at the Sellafield site has improved since Nirex 95. This is because the longer groundwater travel time in Nirex 97 provides enhanced geosphere performance.*" (Nirex 1997d, p. 9.10).

Therefore it is these aspects that I examine, in particular the claim that the later modelling demonstrates a longer groundwater travel time.

5.6.2 Instability of interpretations

If it were the case that Nirex 97 completely transforms the various failures of Nirex 95, highlighted by the Inquiry, into success, such a turn-around should be viewed, *a priori*, as suspicious; two grounds for suspicion are firstly, that the data acquisition and modelling are unstable, and secondly, that data modelling has been manipulated in such a way as to achieve the desired result. As there is no method of independent checking of Nirex 97, we cannot exclude the latter possibility. The inherent instability of Nirex modelling and interpretation was illustrated by myself for the Inquiry and published a few months later (Smythe 1996). Referring to my Figure 1, reproduced herein as Figure 5.6.1, I said:

> "*It may be seen from Figure 1* [Figure 5.6.1 herein] *that the geological interpretation is being substantially revised every year or so. There is therefore no reason to expect that the current version (Fig. 1f, July 1995) will turn out to be close to the true picture. It is important that this problem is resolved through the interpretation of all available survey results and the completion of additional geophysical surveys until a stable interpretation is established.*"

The later version of the structure of the PRZ, published in Nirex 97, is, as I predicted, very different again in detail. Nirex 97 used the results from the 3D seismic survey that I had carried out. It fulfilled the promise that I had made to Nirex scientists when proposing that a 3D survey was essential, and that in oil industry exploration in areas of complex structure, the

3D survey results usually require previous interpretations to be thrown out, so that new maps and cross-sections have to be built from scratch.

5.6.3 Limitations and flaws of the probabilistic approach in Nirex 97

We have no independent way of checking the accuracy or reliability of the 3D geological interpretation used in Nirex 97, for it has never been published.

The treatment of uncertainty is limited to variations within a conceptual model. Parameters such as permeability have been 'upscaled' from laboratory or borehole measurements to the regional scale. But there is no allowance made for the possibility of unpredictable large anomalies in the regional model.

The statistical treatment of parameters is described thus:

> "*Uncertainties in the values of parameters are quantified using Probability Density Functions (PDFs). These PDFs are used as the basis of Probabilistic Safety Assessment (PSA) calculations in which results are obtained for a number of realisations of the system. In this approach to treating uncertainty, which is in line with regulatory guidance, calculations are undertaken for a large number of realisations of the system, with parameter values sampled from the PDFs. In this assessment, probabilistic calculations were undertaken for natural discharge and for water abstraction from wells. Other uncertainties were treated by undertaking a range of variant calculations for different parameter values or alternative conceptual models*."

This means that for each of volume or area element (in 3D or 2D models, respectively), the value chosen for (say) permeability will be selected from the PDF for that rock type. So the most frequently selected values will be around the mean value of the PDF, and a value of (say) two standard deviations from the mean (2σ) will be chosen, on average, once every twenty times (the 95% confidence limit, that is, the limit within which 19 out of 20 values lies, approximates closely to 2σ). But for every run of the model with parameters statistically chosen thus, the mean of the means will be the central value. It is highly unlikely that a model run will occur with many of the parameters biassed to one side, either high or low.

In short, all the model runs approximate to the overall mean value of the various parameters. But we should be concerned with the worst case scenarios for a safety case, not the average scenario, which is what emerges from the probabilistic calculations described above. What if, for example, there is a systematic bias in the estimate of permeabilities, such that the effective long-term permeability of any given hydrogeological formation has been underestimated? The range of error in the permeability estimates – as estimated by Nirex - is very large; the 95% confidence limit (2σ) is generally an order of magnitude or greater.

To illustrate this in a simple way; if all the permeabilities as estimated by Nirex are in fact underestimated by one order of magnitude, almost all of the new higher values would still be within the currently estimated 95% probability limit. Since permeability (and hence hydraulic conductivity) is linearly related to the flow rate of water through the modelled volume, a factor of 10 increase means a corresponding factor of 10 decrease in fluid travel time. This simple analysis neglects, of course, non-linear features of the modelling such as diffusion and mixing, but these are second-order effects. To put it even more simply, increasing all the permeabilities 'speeds up the clock'. A 50,000 year travel path would become 5,000 years if all the permeabilities are multiplied by ten.

In conclusion, if all the permeabilities have an uncertainty of a factor of ten either way in magnitude, then the corresponding final value of a travel time also has an uncertainty of the same order of magnitude. It is the most pessimistic case (i.e. the high permeability possibilities) that we should be considering, not simply the mean.

The approach taken by Nirex takes no account of unknown *and unknowable* factors such as hidden, unmappable fractures which could act as ultra-fast pathways for radionuclides to reach the surface from the repository. To take one example, the Eskdale granite is present in the eastern part of the 2D model, subcropping about 4 km NE of the repository. If there exist hyperpermeable flow zones within the Eskdale granite (such as proved in the Weardale granite discussed above), which have fracture permeabilities three orders of magnitude higher than ‘normal’ granite, Nirex’s flow models would be largely invalidated. This is the kind of eventuality which their probabilistic approach simply cannot encompass.

5.6.4 Calibration of probability density functions

The Probability Density Functions (PDFs) were calibrated using independent parameters. This constrains the permissible range of parameter space, as illustrated in Figure 5.6.2. Here the parameter space is two-dimensional (in practice it may be multi-dimensional). I have marked the peak value of the PDF function by a blue diamond. To refine and reduce the uncertainty we may have an independent constraint from calibration, which may be a linear zone traversing the initial PDF area, as shown by the parallel lines. So the region of parameter space allowed by this calibration is reduced to the elongated ellipse where I have marked the peak value by a red diamond.

To me this implies that the preferred region should now be the elongated ellipse, with the peak being displaced from the initial (blue) value to the calibrated (red) value. But the Nirex methodology does not follow this; instead, the calibration is used as a weighting factor (Fig. 5.6.3), so that the resulting ‘posterior PDF’ is the initial function multiplied by the calibration function. This is the solid curve marked by the green diamond at its peak in Figure 5.6.3. What Nirex is doing is a weak calibration – a compromise between the initial range and the calibration-supplied preferred range. It is as if Nirex does not trust the calibration, despite the fact that the calibration comes with its own PDF. The end result of this ‘weak’ or partial calibration yields parameters which are very little different from the initial ones.

It could be argued that multiplication, or weighting, is the correct procedure, because if the calibration function is at the extreme end of the range of prior PDFs, as is shown in the example of Figure 5.6.3 (also from Nirex 97), then it is unreasonable simply to assume the value shown by the red diamond as the posterior PDF. But if the two functions – prior and calibration – have barely any overlap, that implies that there is something wrong either with the assumptions or with the data. Simply to weight the one with the other would then be ignoring this problem. To return to Figure 5.6.2, where the two peaks are close; this example would indicate that the red value should be selected as it is well within the 95% confidence limit of the prior PDF.

Figure 5.6.4 shows the uncertainties ranked in increasing order. The prior uncertainties are taken from table 3.2 of Nirex (1997c), whereas the posterior uncertainties are taken from table 5.2 of the same report. The standard deviation σ has been multiplied by 2 to approximate the 95% confidence level. Note that there has been no perceptible reduction in overall uncertainty because of the calibration; in fact the average value of uncertainty before is slightly smaller than that after; 1.80 vs. 1.95.

In conclusion, the claim that Nirex 97 hydrogeological parameters have been calibrated by independent measurements is not really correct; they have merely been tweaked, with no substantive improvement resulting.

5.6.5 Treatment of major faults in Nirex 97

The probable high permeability of fault damage zones, relative to the unfractured rock of the same type, has not been properly accounted for in Nirex 97. The hydrogeological model development volume of Nirex 97 (Nirex 1997b) states, in Role of Faults and Fault Zones:

> "*Faults on all scales, from centimetres to kilometres, are present at Sellafield. For Nirex 97, certain seismically resolvable faults which are of significant lateral extent (more than a kilometre or so) were classified as major faults. The major faults have been represented explicitly in the groundwater flow models. Major fault zones composed of a number of major faults were also identified. The major regional faults are ...* [list].
> *Regional fault zones are ...* [list]. *On the District scale ... the identified major faults are ... [list].The identified major faults in the PRZ are Faults F1, F2, F3, F200, F202, F212, F117 and F210.*"

Specifically for the BVG, the report describes the conceptual model for faulting, shown herein in Figure 5.6.5. The figure illustrates semi-schematically the intersection of fault F2, trending NW-SE, with minor fault F201, cutting F2 in an apparent dextral shear sense. Evidently the faulting is highly complex, as shown by the classification. But, despite admitting that there is variability in fault properties, the uppermost volume of BVG between faults F1 and F2, enclosing most of the repository site at depth, is assigned a single isotropic permeability value (Fig. 5.6.6). This 600-700 m wide zone of faulting between F1 and F2 is called the F1-F2 structure. The upper part of this, within the Fleming Hall Formation, has been assigned a single value of effective regional permeability, 5.3 10^{-17} m s^{-1}, which is around one order of magnitude greater than other varieties of the same formation (Nirex 1997c, fig. 5.30 and table 5.2).

To reduce the fault complexity within the BVG to a single value of permeability is tantamount to conceding that the structure is simply too complex to be modelled, either deterministically or even stochastically.

Faulting within the Sherwood Sandstone Group has been classified by a permeability tensor to categorise the fault discontinuity and surrounding damage zone (Figure 5.6.7, taken from Nirex 1997b). Nirex 97 concludes that:

> "*permeability distribution associated with a fault plane is likely to be highly heterogeneous, with regions in which groundwater flow will be hindered adjacent to regions of unaffected or enhanced permeability. Such heterogeneity is likely on several lengthscales.*"

The permeability values chosen for faults cutting the several sedimentary formations can be summarised as follows (Nirex 1997c, table 3.2):

- Of the 8 pairs of tensor components, the normal component is generally (but not always) assigned a slightly higher permeability than the up/down dip component.
- Given the great width of the 95% confidence interval (illustrated in Nirex 1997c, fig. 5.29), the difference between the two quoted fault tensor components is statistically insignificant.
- The fault tensor components of the Calder Sandstone (all three varieties; Upper Near-Surface, Lower Near-Surface and Undifferentiated), Upper Near-Surface St Bees Sandstone, and Colleyhurst Sandstone are not statistically different from the two quoted components of permeability in the unfaulted rock (normal and parallel to bedding, respectively).

In short, the permeabilities assigned to fault zones are of the same order of magnitude as those for the undisturbed rock. This has unrealistic consequences for the modelling, as shown in the next section.

5.6.6 Discussion of the results of the Nirex 97 modelling

Figure 5.6.8 shows a detailed view of part of a flow model from Nirex 97 over the repository zone. There are unit vectors which show the predicted flow direction, but not its magnitude. The proposed repository within the BVG is shown by the red solid line. The two features of greatest importance are (1) the generally upward flow within the BVG, as shown over the bottom half of the diagram, and (2) the apparent non-influence of the faults on the flow pattern. The former is a regional effect (which is fundamentally adverse for the safety case), and not questionable in detail, but the latter is an unrealistic artefact of the model parameter assumptions.

The work of Lunn *et al.* (2008) has been discussed above in section 4.6.8, in the context of the MMG. From their observation (which was already widely known across the hydrocarbon exploration industry) that "*faults can be barriers to flow, conduits, or combinations of the two*", one can construct a cartoon of how normal faults cutting sediments will affect flow direction (Figure 5.6.9). I have indicated in this cartoon the general flow parallel to sedimentary bedding, down-dip towards the sea. But when the flow encounters a fault zone it will be redirected upwards; this is irrespective of whether the fault is acting as a barrier or as a conduit to fluid flow. This effect has been conveniently omitted in the Nirex modelling, by choice of what must be inappropriate permeabilities.

I have sketched onto the Nirex 97 predicted flowpath trajectory model what the flow should look like, bearing in mind what we know about fault permeabilities (Fig. 5.6.10). Instead of upward flow from the BVG, turning parallel to dip in the sediments, a more realistic flow pattern should be as shown by the added red arrows, that is, flow onwards and upwards along the major faults, straight to the surface. Instead of the flow emerging at the coast in around 50,000 years, escaping contaminated water from the repository will reach the surface in about one-tenth of that time (because the path length is ten times shorter). That is a conservative estimate, which assumes that the permeability of the fault conduits is the same as the undisturbed rock, and that the fault core acts as a barrier to flow. If the faults in fact act as low-permeability conduits, the flow will be faster and the transit time to the surface even shorter.

In conclusion, the safety case made in Nirex 97 is spurious.

Strong empirical evidence comes from the water company United Utilities, which states on its website:

> "*03 February 2011; We are using drilling rigs to explore for one of Cumbria's most precious natural resources - water. Our specialist teams have plunged four boreholes up to 120m deep in fields south of Egremont to pave the way for a potential new groundwater supply.*
>
> *Project manager Danny Brennan said: "The boreholes have been sited to target geological faults to give the best access to the yields. We started last June and have completed three of the four. "Our initial tests suggest the potential yield and quality of the water in the aquifer is good. Subject to further testing, we hope that the four sites could yield seven million litres of drinking water a day, which is enough to supply about 46,000 people," he said.*"

This evidence clearly shows that the faults, at least in the uppermost 100 m, are acting as conduits. The geology map of Figure 5.6.11 shows the area where United Utilities is drilling. It might be targetting any of the faults shown, but the drilling locations are secret, in case anyone were to use the information to contaminate the public water supply.

I find it ironic that Nirex might have succeeded in doing exactly that - contamination of the public water supply within an unacceptably short duration - had its appeal at the Public Planning Inquiry not been rejected.

5.6.7 Response to CoRWM questions on the suitability of the Sellafield site

The analysis above has a direct bearing on the assurance given by the Nirex to CoRWM regarding the modelling of the Sellafield site. CoRWM had asked Nirex the following question arising the the Nirex Viability Report (Nirex 2005c):

> "*12. The Suitability of the Sellafield Site*
> *The last paragraph on Page 91 in Section 8.4 states that Nirex and the BGS believe that Sellafield is a suitable site for a repository. How does this relate to the statements in the third paragraph from the bottom on Page 78, which refers to the advantages of a site that is simple and can be easily characterised, has a low groundwater colloid population and a low concentration of naturally occurring complexants?*" (CoRWM 2005).

Nirex responded with the following:

> "*The statement that Sellafield is a suitable site relates to the fact that there was confidence in the models for groundwater flow at the site developed from the results of the geological investigations. The models were tested successfully by obtaining a good match between their outputs and field observations that had not been used in their development. When the models were used in the Nirex 97 repository performance assessment, there was a significant margin of safety in the calculated peak risks compared with the regulatory target. ...*
>
> *In relation to the observations on page 78 of the Viability Report, the site had clearly*

> *been capable of sufficient characterisation. The ability to treat spatial heterogeneity through the modelling approach applied at Sellafield was specifically tested with an expert group that might be viewed as one of the key stakeholders in this area ...*" (CoRWM 2006).

My conclusions on the above response, bearing in mind the evident inadequacies of Nirex 97 is:

- There is no confidence in the groundwater flow models.
- The match between model output and field observations is spurious.
- The calculated peak risks are orders of magnitude too optimistic.
- The site is intrinsically incapable of sufficient characterisation.

The last fact was recognised by the Inspector, and access by the Inquiry to Nirex 97 would not have altered that.

5.7 The NDA claims that BGS considers Sellafield 'potentially suitable'

The Nirex report asserting that Sellafield is potentially suitable (Nirex 2005c) further claims support from the BGS:

> "*Based on the results of this work, we believe that Sellafield is a potentially suitable site for a repository. <u>This view is shared by the British Geological Survey</u> (BGS) and many other specialist consultants*." (my underlining).

I was unable to find such support in BGS publications and statements, therefore I asked the NDA and the BGS for correspondence and/or documentation in support of the underlined part of the statement above. This request elicited the following statements from (1) NDA and from (2) BGS:

> (1) NDA: "*We have now concluded a search of our records which retrieved no matching documents. Further enquiries have ascertained that the assertion in Chapter 8 of Nirex Report N/122, was based on verbal evidence, as a result of the then – Director of the BGS, Dr David Falvey, responding in the affirmative to the (paraphrased) question, "Does the BGS consider that Sellafield might be a suitable site?" posed to him by then - Minister of State for Energy and Construction, Brian Wilson, on the occasion of the official opening of the National Geoscience Data Centre Core Store extension. (This can be dated precisely as 5 November 2002, see p. 36 of BGS Annual Report for 2002-03). The statement was substantiated at further presentations and meetings where Nirex and BGS staff shared a platform. The statement was also further supported in BGS contributions to CORWM 1 and to the first Geological Society collective opinion on RWM.*"

> (2) BGS: "[on correspondence] *our radioactive waste expert, Richard Shaw has searched through all relevant material within our archive and confirmed that there is no correspondence between BGS and Nirex, between the specified dates, relating to the suitability of the Sellafield site for a radioactive waste repository ...* [on publications] *we have only published factual reports that relate to the Sellafield site and these will not contain the sort of statement you require for your research*."

So the so-called 'support' by BGS for Sellafield is, in effect, non-existent. Alleged verbal comments of support by a Director of BGS are no more than hearsay; Dr Falvey may have simply been congratulating Nirex on the high standard of science carried out at Sellafield, while flattering one of the BGS's most important former (and potentially future) clients; the Nirex contract with the BGS was worth some £3M p.a. in the mid 1990s (Oldroyd 2002).

The alleged further substantiation of the statement of BGS support for Sellafield is signally absent from the report of the meeting at Loughborough University in November 2006 (Hardy and Evans 2007) as well as from the presentation by Dr Richard Shaw of the BGS (Shaw 2006). The report of the one-day meeting at the Geological Society of London on 9 January 2006 (Chapman and Curtis 2006) makes no mention at all of Sellafield. The CoRWM note by Warren (2006) likewise makes no mention of Sellafield or Cumbria, nor does the CoRWM minute of a meeting with BGS in September 2008 (CoRWM 2008).

5.8 Analysis of MRWS Stage 4

MRWS Stage 4, the identification of potential sites, is discussed in the NDA document *Geological Disposal: Steps towards implementation* (Nuclear Decommissioning Authority 2010), which refers back to *A Proposed Framework for Stage 4 of the MRWS Site Selection Process* (Nuclear Decommissioning Authority 2008).

One might have expected geology to comprise a large portion of this document, given the subject-matter, but this is not so: Chapter 4 deals with the geology in two and a half pages, out of a total of 65 pages of text. The approach is to:

> "*define a limited number of generic geological settings, encompassing typical, potentially suitable UK geologies*".

The statement quoted above might further have been expected to lead the reader directly to the generic geological settings developed specifically for the UK by BGS and Nirex scientists in the 1980s by Chapman *et al.* (1986), which have become a somewhat of an international benchmark. These include the well-known settings such as seaward-dipping sediments, small islands, basement under sedimentary cover (BUSC), and so on. But this is not the case; it is as if 40 years of prior research never existed. Instead, the geological settings are defined by a brand-new table categorising *host rocks* and *cover rocks*, (reproduced herein as Fig. 5.8.1). There are no supporting sketch or generic geological cross-sections in support of this table.

What is the information content of this NDA table? I have ringed together the two entries in the middle Host Rocks column, because they say the same thing – sediments all the way from top to bottom. So there are only four distinct 'Possible' table entries. The table appears to have been devised by someone with poor logical faculties and negligible geological expertise. In particular, it does not allow for any lateral variation; that is to say, it is one-dimensional, in that rocks are either above or below. In contrast, the geology of West Cumbria is not merely two-dimensional; it is highly three-dimensional, as has been amply demonstrated in section 4 above. What that means, put simply, is that any given geological cross-section – which is a two-dimensional construct – has rapidly reducing validity as it is shifted sideways (in or out of the page), because the geology changes so rapidly.

For easier comparison with earlier work I next replace in the table 'higher strength rocks' by *Basement*, which is a valid and familiar term in the UK context, and 'lower strength sedimentary rocks' by *Sediments*. This does not alter the information content of the table. The table can then be expressed more succinctly by a simple list:

- Basement from repository depth to the surface
- Sediments from repository depth to the surface
- Sediments over basement
- Sediments over evaporite

The five white boxes in the table have become four items above, because of the duplication ringed in Figure 5.8.1. We can contract this list further, and also put the host rock (underlined) first:

- <u>Any rock</u> from repository depth to the surface
- <u>Basement</u> under sediment(-ary cover) i.e. BUSC
- <u>Evaporites</u> under sediments

provided only that the host rock is 'suitable', which of course should go without saying. Next, we omit evaporites, since they are not relevant to West Cumbria (for the reasons given in sections 4.5 and 4.9.1 above), and contract the list further, to obtain:

- Any suitable host rock - whether covered or not by sediments

The phrase above referring to the cover rocks is clearly superfluous, so we end up with:

- **Any suitable host rock**

In conclusion, once we omit the special case of evaporites acting as cover rocks, the NDA definition of '*generic geological settings*' is telling us nothing. The geological information content of the NDA analysis is essentially zero. The NDA is taking the geological aspects of repository search backwards by about 40 years, to the era when only the host rock was considered, and what lies '*Before, behind, between, above, below*' (John Donne) was of no significance.

In my opinion this is a scientifically disgraceful state of affairs. Not only is the large corpus of prior research on generic sites discounted as if it never existed; it has been supplanted by ill thought-out verbiage and pseudo-tabulation, signifying nothing. But such corporate amnesia appears to be a deliberate policy by the NDA, into which Nirex was subsumed in 2006. For example, the NDA website only provides online access to 36 documents dating from prior to 2004; the vast bulk of Nirex research has been removed from online availability, even though some of it was accessible a decade ago.

5.9 Regulation of MRWS Stage 4 and beyond

5.9.1 Government regulation

Regulation of most nuclear matters is currently in the hands of the Office for Nuclear Regulation (ONR), a branch of the Health and Safety Executive (HSE), set up in 2011. Changes were made to make the former Nuclear Installations Inspectorate (NII) more autonomous from the HSE, and to allow it to offer better rates of pay in hiring and retaining nuclear inspectors.

The Environment Agency (EA) is the other major regulator named in the MRWS process. This remains under the same conditions and pay rates as the public service. This has led to questions over the now perceived difference in the standing of the two regulators. The ONR will eventually be responsible for determining the suitability of one or more sites for a GDF, selected during MRWS Stage 4, assuming that the current process gets that far.

Historically, one can speculate that if the outcome of the Planning Inquiry had been in favour of Nirex's appeal, the RCF would have gone ahead, to be followed by development of a repository which would be in existence today. Questions arise over the powers and influence of the regulators in this process, for the following reasons:

1. It is not clear to what extent the regulator can determine whether a particular region or area is intrinsically unsuitable. Its powers appear to be limited to site-specific issues.
2. The safety case depends upon data and edited results supplied by the developer to the regulator.
3. There is a risk that if the regulator does not have the time or means to examine the safety case in depth, errors of assessment can be made.
4. In such a case as 4, the regulator is little more than a technical reviewer of the type outlined in section 5.3 above.

There is also concern that although regulators insist they are independent they are also in the position of having to facilitate, as much as possible, government policy. This can lead to decisions being made, on the balance of risks, which might not otherwise be made in an open and critical analysis.

Reason 1 above means that the ONR today has no say in the fact that sites may be chosen within West Cumbria, an area shown to be intrinsically unsuitable by the Planning Inquiry. It is noteworthy that Nirex, the appellant at the 1995-96 Inquiry, tried to prevent the HMIP Inspector from giving evidence on radioactive waste management policy and scientific matters (McDonald 1996, para. 1.10). In short, Nirex at the time was trying to circumscribe the HMIP Inspector's remit.

The situation today is little different; the ONR and the EA have very little power to question the overall validity or otherwise of the voluntarist over the geological approach decribed in the 2008 White Paper.

Reason 2 means that the regulator may not have the necessary resources to fully scrutinise and challenge the data and results that the developer may wish to supply to the regulator. The developer at Longlands Farm in the 1990s was Nirex; in future the GDF will be developd by a site licensee company (SLC) of the NDA (Defra 2008, p. 26). An SLC is generally, in effect, a profit-making company, one of whose main interests is in generating profits for its shareholders.

Since the Radioactive Waste Management Directorate (RWMD) of the NDA, which is to be the developer, is not yet a fully formed SLC, questions must be asked about its future role and objectives. It is understood that the SLC in this case is being developed to allow for 'normal' regulatory control over the repository construction and operations. Iniitally it will not follow the usual private SLC model.

The NDA currently operates subject to government policy, and will remain the 'controlling mind' of any SLC which operates a repository; this leads to questions over possible financial implications for the SLC. If the NDA continues to control the SLC's budget, which it is believed it will do, this could impact on its operations through budget restraints.

In theory, all of this, while it remains in government hands, will be subject to parliamentary accountability (albeit at arms length), and health and environmental safety should remain its primary remit. In the long term, however, it is possible that the SLC itself could be privatised, or that the repository could be transferred to a private company. Such a company might be much less willing to release inconvenient or contrary information.

There needs to be demonstrable and open systems in place to show that:

- The regulator can delve deeply into any part of the safety case,
- This is done truly independently, and
- The money is available for this work.

Unfortunately as both the NDA/RMWD, the EA and ONR are all now subject to government budgetary constraints, there is a risk that regulatory oversight – despite good intentions – will not be as thorough as the public expect and deserve

Reason 3 means that the regulator may be restricted in how far it can go into all aspects of a safety case; for example, re-running predictive groundwater flow models using different assumptions from the developer.

5.9.2 CoRWM

CoRWM (2011b), to which I had sent my April 2011 paper on West Cumbria (Smythe 2011b) eventually provided a short letter of reponse. Some of the statements in this letter call for analysis. Firstly, CoRWM has stated that its role is:

> "*to scrutinise and advise on Government and NDA preparations and plans for the ... deep geological disposal of higher activity radioactive waste*."

followed by a *non sequitur*:

> "*It is, therefore, not appropriate for us to comment on the specifics of the scientific case you build to support your views and conclusions*."

If it is indeed CoRWM's task to *scrutinise* – that is 'examine or inspect closely or thoroughly' – then surely the science (or lack thereof) behind the current MRWS process is precisely what CoRWM should be examining closely. The letter continues:

> "*there is presently no credible scientific case to support the contention that **all** of West Cumbria is geologically unsuitable*" [emphasis in original]

repeating what it said in an earlier letter to MRWS (CoRWM 2011a), written before receipt of my report, and concluding:

> "*Our view is that,* ***at this stage in the MRWS siting process****, it is not known whether or not there are suitable geologies in West Cumbria.*" [my emphasis]

I have highlighted part of the revealing clause above, which appears to indicate that CoRWM has not fully examined the geology. It risks giving what appears to be a blanket approval to the MRWS process of its current approach to geology. CoRWM appears to be willing to wait until (it asserts) that which "*is not known*" might be known. It is not clear how CORWM might square suitable or unsuitable geology with the voluntarism approach – and how it will respond if suitable geology is found in an area where the 'community' is not willing to proceed - or indeed *vice-versa*. CoRWM is going to ignore any possibly inconvenient facts ("*it is not known*") until such time as the geology comes to be considered within a politically-driven ('voluntarist') approach. This is another example of agnotology in operation.

The letter defines how CoRWM arrives at its judgment on West Cumbria:

> "*Our collective understanding is based on the expertise and experience of CoRWM members in appropriate areas of geoscience, including but not limited to hydrogeology, engineering geology, structural geology and mapping, and geochemistry, as well as members' expertise in and understanding of radioactive waste issues. This collective understanding we refer to is informed both by members' scrutiny and review of an extensive range of published literature, reports, workshop papers and briefing documents relevant to geosphere characterisation, and also by their attendance at national and international meetings on the subject. Our collective understanding, therefore, is independent and based on international experience and practice.*"

I concur entirely with CoRWM's view of its collective expertise as expressed above, but nevertheless the West Cumbrian geological issue must be addressed by evidence-based argument. To date, CoRWM has not undertaken this work.

5.9.3 Funding for genuinely independent review and regulation

The nuclear waste industry appears to misunderstands what academic peer review comprises; this has been discussed in section 5.3 above. In view of the importance of getting the disposal process right - as opposed merely to presenting a safety case which satisfies regulators and politicians in the coming decade or two - there should be provided realistic levels of public funding for critical, independent analysis for those knowledgable in the various relevant fields to provide a challenge and examination of the process and proposals. This counterbalance is essential, not just in order that the 'right thing' be done, but also to enable public confidence in its views. This has to go beyond the regulators reviewing existing data and papers produced by the disposal agency. Funding should be provided for replication of modelling, for example, by groups which are *a priori* sceptical. Given that £3M has already been spent on process and public relations in West Cumbria, sums of a similar order of magnitude can and should be found to fund research groups. This issue is distinct from the industry commissioning research from universities or private agencies.

Such funding is already provided by legislation in Sweden and in Canada. In the UK the concerted and thoughtful opposition has had to be provided *pro bono* by independent specialists (as is the case with my own work), or by the NGOs.

It may be that the government does not wish opposing viewpoints to be heard, in case there is a repeat of Longlands Farm, that resulted in £400M being spent. Since then twenty years appear to have been wasted without much progress. But a more honest, as well as a more transparent route, might be to follow the example of other countries, and to provide adequate funding for those who seek to criticise the science and other aspects of the proposal at each stage.

5.9.4 Lack of criteria for regulation

Irrespective of the problems of regulation and external review mentioned above, the current MRWS process presents no truly clear geological criteria against which a safety case can be judged.

The search processes both in the 1970s and 1980s both started with clear geological criteria to be met. In the 1980s they included, for example, the geological environments as defined by Chapman *et al.* (1986). The criteria were ignored or manipulated in arriving at Longlands Farm as the preferred site, but at least they were stated in advance.

Today we have the so-called 'volunteering' of a 'community', but 'community' is not defined, as shown in section 5.2 above. The whole process is at risk of being open to manipulation by council subgroups; in volunteering, one local council may be pitted against another, a larger district or regional council may 'trump' a smaller, and so on.

The NDA approach to defining a suitable host rock is devoid of real content (section 5.8 above). It is clearly no basis either for search or for subsequent regulation.

Lastly, international guidelines are ignored. So the MRWS process, if it goes any further, will be forced to make up criteria as it goes along, and with the hope that the regulator will approve each stage. It is in no-one's interest for this process to continue in its present form.

5.10 Evidence for predetermination

I have alluded to the possibility that the entire process for finding a suitable site for HLW is directed at a return to the Sellafield area, or somewhere else in West Cumbria. Here is a short summary of the principal events, most of which I have discussed in various places above, which lend credence to this view:

- 1997: dismissal of Nirex's appeal against refusal of planning permission to construct an RCF at Longlands Farm.
- 1997-98: completion and publication of 'Nirex 97' by Nirex.
- 1997-2001: BNFL/Pangea venture to find a world site for HLW; scientifically a sound idea but politically unacceptable.
- 2000 (c.): removal of all primary documentation from the Nirex website relating to the Planning Inquiry.
- 2001: Defra (2001) consultation paper 'Managing radioactive waste safely' published.
- 2003: creation of CoRWM.
- 2004: Nirex introduces the idea of 'voluntarism'to CoRWM.
- 2005: Nirex claims that:
    - Sellafield is potentially suitable.

  - the BGS supports the claim that Sellafield is potentially suitable.
  - that voluntarism has worked in other countries.
- 2006: CoRWM's final report recommends geological disposal, with siting based on the principle of voluntarism.
- 2008: Defra white paper promotes CoRWM recommendations above.
- c.2007-09: Removal of the right to a public local inquiry in cases deemed to be 'national infrastructure'; replaced by the Infrastructure Planning Commission.
- 2009: The only volunteer communities are effectively Copeland and Allerdale, with Cumbria County Council involved as it has planning powers over waste and minerals.
- 2010: NDA analysis of host rock characteristics concludes, tautologically, that any suitable host rock will suffice.
- 2011: MRWS claims in a briefing note that the Inquiry did not categorically rule out Sellafield, and that 'important' technical advances have taken place since 1997.

After completion of the Nirex 97 set of documents, the NDA must have been expecting that it might return to West Cumbria to site a repository there. It is not unrealistic to say that there was an expectation in some quarters that at least one local council (Copeland) would volunteer. To the cynical eye it could appear that certain aspects of its activities amount to manipulation, in effect to 'a dirty tricks campaign', since it is based on presenting misleading or wrong information, or even untruths, to CoRWM, among others. These comprise principally:

- the notion of volunteerism itself;
- the falsehood that volunteerism has been applied successfully in other countries;
- the publication in 2005 of a misleading review of the 1980s site search;
- suppression of Inquiry documentation;
- a claim (later withdrawn) that had Nirex 97 been published in time, the outcome of the Inquiry would have been in Nirex's favour;
- the claim that the Longlands Farm site is still potentially suitable;
- the falsehood that the BGS supports this claim.

The government is still paying lip service to the notion that other 'communities' (i.e. councils) may yet volunteer to host a deep geological repository (DECC 2012a), but there is no sign of this becoming a reality. The government seems to have now given up on inviting other areas to consider taking part in the MRWS process; the fact that the Sellafield area volunteered early has probably served to dissuade other areas of the country from bothering to respond. In fact the early 'expression of interest' by the council area in which Sellafield is situated probably led many other areas to feel they had been let off the hook

6 CONCLUSIONS

6.1 Concerns to be addressed

1. The absence of any other district than West Cumbria presenting itself as a 'volunteer' is of concern, and brings into doubt the whole 'voluntarism'approach.

2. The history of the development of UK site search methodology since 1997 suggests that attempts to achieve the renewed choice of a potential site near Sellafield are being sought.

3. It is of grave concern that the government has already spent upwards of £3M on process in West Cumbria, when such public monies could have been more usefully spent on scientific research to find geologically promising localities.

4. It is of concern that HLW is to be placed in a repository, whereas the 1980s UK-wide search exercise was confined to ILW and LLW sites.

5. No substantive geological studies have been undertaken in the UK in the 15 years since 1997, the year of the Planning Inquiry determination.

6. It is of concern that the arguments presented by the Inquiry Inspector and accepted by the then Secretary of State appear to have been wilfully removed from public view and consideration.

7. The argument that proximity to Sellafield is an overriding consideration in locating a repository is spurious, as was pointed out by the Inspector.

8. The results and documentation of the 1995-96 Nirex Public Planning Inquiry at Cleator Moor have been removed from public accessibility via government portals.

9. Inasmuch as any reference by government departments or agencies is made to the aforesaid Planning Inquiry, the references are couched in terms of local details and difficulties, not in terms of the fundamental scientific problems which were uncovered.

10. The geology of West Cumbria is extremely well-understood even by the high UK standards of UK geological understanding; the pretence that 'we do not know enough' to rule out the area is not correct.

11. CoRWM must engage with the geological science, and not sit on the sidelines, as it appears to be doing, claiming that it does not know enough.

12. The reasons for the elimination of Stanford as a potentially suitable site need to be re-evaluated in the light of the Inquiry Inspector's comments about the flaws in the MADA process. This is important to fully understand this and future processes.

13. The topography of the Lake District is unique in global terms, in that no other country is searching or has searched for for a suitable waste repository site below the water

table in similar extreme topography.

14. Documentation is required for the allegation that the Mercia Mudstone Group is now considered by the BGS as a potentially suitable host rock.

15. It is of concern that the claim by the NDA that Longlands Farm is now “potentially suitable” is supported by the BGS, is evidently untrue.

16. The NDA analysis of geological suitability is inadequate and not fit for purpose.

17. Current international guidelines on repository site search are being ignored; it is of concern that the government is still referring only to the 1994 IAEA duidelines.

18. The alleged new openness and transparency by Nirex between 1997 and its assimilation into the NDA in 2006 was a dissimulation, as shown by the example of its 2005 paper on the history of site selection.

19. Arguments presented for the justification of a fresh look at the suitability of West Cumbria, viz. the developments of 3D seismic exploration methods, and the increase in computing capability since the mid 1990s, do not bear close examination.

20. The full 3D modelling of the Longlands Farm site discussed in Nirex 97 needs to be made publicly available for independent scrutiny; funding needs also to be provided for licensing of the appropriate software on which these models have been developed.

21. The peer review process as used by Nirex and NDA is inadequate; the government seems to misunderstand what the process entails.

22. Funding for genuinely independent review of waste disposal site science, and other aspects of the process, is not available in the UK, in contrast to other countries.

23. The allegation that other countries have ‘successfully’ found a suitable waste disposal site using community agreement as opposed to geological search should be withdrawn, as it is not strictly correct.

24. The influence of Nirex on the original CoRWM between its inception and final reporting is of concern.

25. The late appearance and subsequent rapid elevation of the principle of volunteerism in the development of CoRWM’s deliberations is not fully documented.

26. Defra has misled the public in implying that ‘voluntarism’ abroad has taken precedence over geological search criteria, whereas in all other countries the geology came first.

27. The definition by CoRWM and Defra of ‘community’ is inadequate both in socio-political and in geographical terms.

28. The BGS needs to explain why it is justified in not excluding certain areas from its preliminary screening criteria, on the unexplained basis that the entire rock column

from 200 m to 1000 m needs to be an aquifer for the exclusion to apply.

29. The BGS should reconsider its non-exclusion of the Eskdale granite as a potential geothermal resource; it is one of the three such principal granite batholiths in the UK considered to have such potential.

30. MRWS needs to provide proper documentation of the allegation by Dearlove (2011b) that the BGS does not believe that the Solway Basin has been sufficiently evaluated by oil industry exploration for it to be well enough understood in the context of a search for a repository.

31. The BGS needs to reconsider the exclusion criterion that only discovery wells serve to rule out a region on hydrocarbon resource grounds, since a given region may well be explored in future (i.e. both risk of intrusion and intent to discover resources).

32. The Nirex 97 groundwater flow modelling of faults in the Longlands Farm district, particularly in the sediments overlying the BVG, appears to have been manipulated to preserve a semblance of near-horizontal seaward flow, when an upwards flow to the surface is more likely and corroborated by recent water supply well drilling.

33. The assurance given by Nirex to CoRWM that the Sellafield modelling was sound should be withdrawn.

34. It is of concern that the ONR and the EA may not have sufficient resources to enable them to undertake truly independent assessments.

6.2 Final comments

There are too many factors against the search for a site in West Cumbria – the previous search history; the outcome of the Planning Inquiry, the geology and hydrogeology, the international view, the unique but dubious search methodology adopted, and the strong suspicion, backed by evidence, that the entire consultative approach is predetermined on returning to that area.

My analysis of the geology and hydrogeology uses all available information. If the BGS (or any other agent) is asked to undertake the Stage 4 desk study it will reach the same conclusion – that West Cumbria is unsuitable for hosting a nuclear waste repository. My work has, in effect, short-circuited the MRWS process by doing the Stage 4 desk review. But if the government persists in moving to Stage 4 it can only succeed in furthering the search if it circumscribes the remit given to the BGS, for example, along the lines of ‘within the partnership area not already excluded, please tell us where the most likely areas are for siting a repository’ – a remit that many believe does not allow the answer ‘nowhere’. The BGS will likely come up with an area such as the Eskdale granite, for example, and will propose a borehole or two. We are then on the slippery slope towards an unsuitable site. It will then be very difficult for the BGS to turn round at a later date and say, ‘West Cumbria is in fact unsuitable, as our previous researches have shown’. In this, and in many other major projects, the more money which is spent, the harder it is for those concerned, particularly the leading proponents and supporters, to then acknowledge they may be wrong in their assumptions. The very fact that a return to Longlands Farm is even contemplated, after the expenditure of £400M, is an example.

The rational way forward is for the government to drop any idea of trying to find a waste repository site in West Cumbria. The voluntarist approach may have yielded a false sense of rapid and relatively untroubled progress, but this will end sooner or later.

Lastly, we owe it to future generations not to try to site a repository in such an unsuitable region. We must not allow hubris – whether of national or local politicians, or of the civil nuclear engineer – to cloud the overriding fact that the geology and hydrogeology are unsuitable.

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APPENDIX A

PIEDA initial list of 537 sites

Compiled by David Smythe

January 2011

Notes

PIEDA was the consultancy running the selection process in 1988-1989.
Ex-AOS means (large) area outside search.
From the initial list below, reject lists A-F were progressively compiled after each sieving process.
List H is the final short-list of 4 sites (red) from the sieving.
Sellafield-B (which I have numbered 999) was introduced to the process during the 'suitability' sieving process, during which the 5 sites of list G (blue) were rejected.

No.	Site name	Category	List
1	Aberporth	Ex-AOS coastal	D
2	Abingdon	Inland	A
3	Achairn	Hard rock inland	D
4	Ailsa Craig	Small island	A
5	Alconbury	BUSC inland	D
6	Alderley Edge	Inland	A
7	Aldermaston	Inland	A
8	Aldershot	Ex-AOS inland	D
9	Altnabreac	Hard rock inland	H
10	Altnaharra	Ex-AOS inland	F
11	Ansells Farm, Fleet	Inland	A
12	Andover RAF	Inland	A
13	Anthorn	Sedim. coastal	D
14	Arborfield	Inland	A
15	Arncott Depot	Inland	A
16	Arpinge Firing Range	Coastal	A
17	Ascrib Islands	Small island	A
18	Ashchurch	Inland	A
19	Ashdown Forest	Inland	A
20	Aston Down	Inland	A
21	Auskerry	Small island	B
22	Balmedie Rifle Range	Hard rock coastal	C
23	Balta	Small island	A
24	Bampton Castle	Inland	A
25	Bardsey Island	Small island	A
26	Barford St John	Inland	A
27	Barkston Heath RAF	Small island	C
28	Barlow	Small island	C
29	Barnard Castle	Inland	A
30	Barnham Army Camp	Inland	A
31	Barnsfield	Inland	A
32	Barnsley	Inland	A
33	Barry Duddon	Ex-AOS coastal	D
34	Barton Rd, Camb	Inland	A
35	Barton Stacey	Ex-AOS inland	D
36	Bassingbourn	Inland	A
37	Bawdsey	Coastal	A
38	Bawtry RAF	Inland	A
39	Bearley	Inland	A
40	Beckingham Range	Small island	C
41	Bedford	BUSC inland	D
42	Beith	Inland	A
43	Benson RAF	Inland	A
44	Bentwaters	Inland	A
45	Berkeley	Ex-AOS coastal	D
46	Berneray	Small island	A
47	Berneray	Small island	B
48	Besford Airfield	Inland	A
49	Bicester	BUSC inland	D
50	Bigga	Small island	B
51	Billingham	Ex-AOS inland	B
52	Binbrook RAF	Inland	A
53	Blandford	Ex-AOS inland	D
54	Blyton Airfield	Sedim. inland	B
55	Bolsover	Inland	A
56	Bordon	Ex-AOS inland	D
57	Boreray	Small island	A
58	Boscombe Down	Ex-AOS inland	D
59	Boulser	Ex-AOS coastal	C
60	Bourne Wood	Sedim. inland	C
61	Bovington Camp	Ex-AOS inland	D
62	Bowes Moor	Inland	A
63	Bradwell	BUSC coastal	G
64	Bramcote	Inland	A
65	Bramley	Inland	A
66	Brampton RAF	Inland	A
67	Bramshot	Inland	A
68	Branston	Inland	A
69	Brawlbin	Hard rock inland	C
70	Brize Norton	Ex-AOS inland	D
71	Broadford	Sedim. inland	B
72	Brother Isle	Small island	A
73	Broughton Moor	Ex-AOS inland	D
74	Burghfield	Inland	A
75	Burn Airfield	Sedim. inland	D
76	Burtonwood	Inland	A
77	Caerwent	Ex-AOS inland	D
78	Calf of Eday	Small island	A
79	Calf of Man	Small island	A
80	Caltinish, S. Uist	Hard rock coastal	E
81	Camberley	Inland	A
82	Canna	Small island	A
83	Canterbury	Inland	A
84	Cape Wrath	Ex-AOS coastal	E
85	Capenhurst	Sedim. inland	D
86	Cara Island	Small island	A
87	Cardington RAF	Inland	A
88	Carlisle Depot	Sedim. inland	C
89	Carna	Small island	A
90	Castle Martin	Coastal	A
91	Catterick	Sedim. inland	D
92	Cava	Small island	B
93	Chalgrove	Inland	A
94	Chapelcross	Inland	A
95	Chatham	Coastal	A
96	Chelverston Afd	Inland	A
97	Chepstow College	Coastal	A
98	Chester Barracks	Sedim. inland	C
99	Chetwynd RAF	Inland	A
100	Chicksands USAF	Inland	A
101	Chilmark	Inland	A
102	Chilwell	Inland	A
103	Chipping Warden	Inland	A
104	Chivenor	Ex-AOS coastal	D
105	Church Fenton	Sedim. inland	C
106	Clardon Hill	Hard rock coastal	B
107	Colchester Barracks	BUSC inland	E

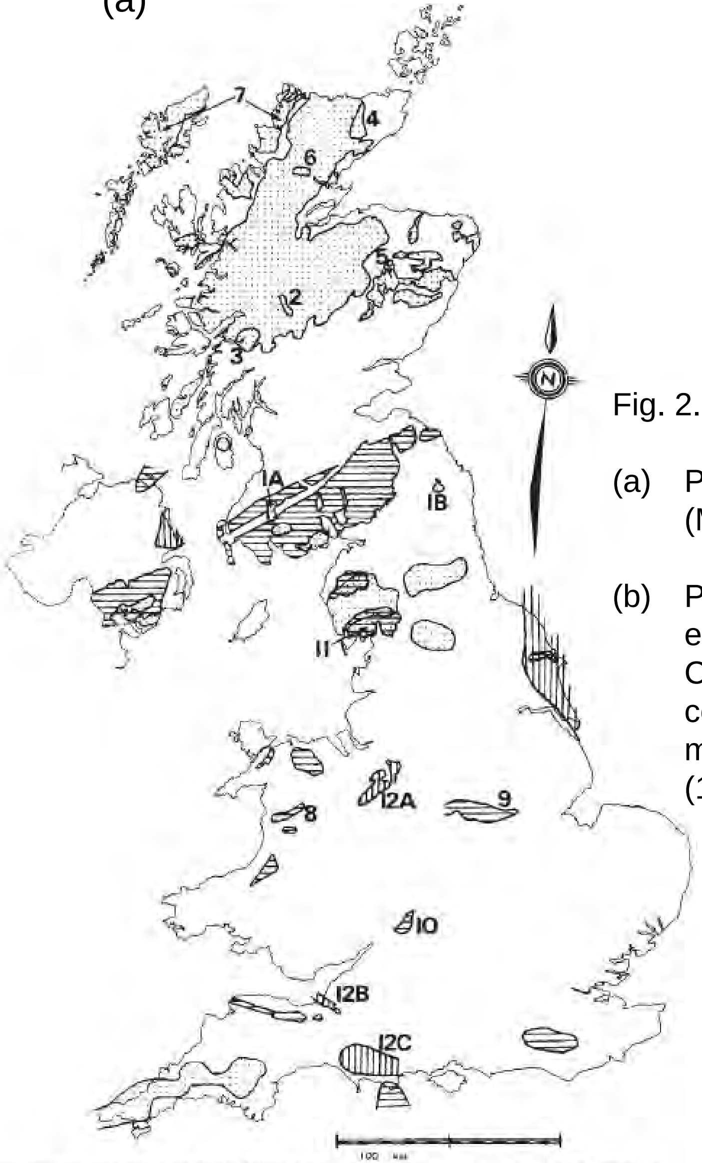
108	Colchester Ranges	BUSC inland	E
109	Colerne	Inland	A
110	Coll	Small island	B
111	Colonsay	Small island	B
112	Coltishall RAF	Sedim. inland	C
113	Coningsby RAF	Sedim. inland	C
114	Connah’s Quay	Ex-AOS coastal	D
115	Copinsay	Small island	A
116	Cosford	Inland	A
117	Cotgrave Wolds	Inland	A
118	Cottam	Ex-AOS inland	C
119	Cottesmore	Ex-AOS inland	E
120	Cowden RAF Range	Sedim. inland	E
121	Cranwell RAF	Sedim. inland	E
122	Credenhill	Inland	A
123	Crickhowell	Inland	A
124	Cricklade	Inland	A
125	Crimond Airfield	Hard rock coastal	E
126	Crookham	Ex-AOS inland	D
127	Croughton USAF	Inland	A
128	Crowlin Islands	Small island	A
129	Culbin Forest	Hard rock coastal	D
130	Culdrose	Inland	A
131	Culham	Inland	A
132	Dartmoor	Inland	A
133	Davidstow Moor	Ex-AOS inland	D
134	Dean Hill	Inland	A
135	Denver	Ex-AOS inland	C
136	Derby	Inland	A
137	Devizes Barracks	Inland	A
138	Didcot	Ex-AOS inland	C
139	Digby	Sedim. inland	C
140	Dinton	Inland	A
141	Dishforth	Inland	A
142	Donna Nook	Sedim. inland	F
143	Donnington	Inland	A
144	Dounreay	Hard rock coastal	H
145	Driffield	Sedim. inland	C
146	Drigg	Sedim. coastal	E
147	Droitwich	Inland	A
148	Druridge Bay	Ex-AOS coastal	D
149	Dungeness	Ex-AOS coastal	E
150	Dunkeswell	Inland	A
151	Dunnet Forest	Hard rock coastal	B
152	Dyke	Hard rock inland	E
153	East Moor Afd	Sedim. inland	B
154	East Yelland	Ex-AOS coastal	C
155	Eastlays	Inland	A
156	Eastriggs	Ex-AOS coastal	D
157	Edlesborough	Inland	A
158	Eigg	Small island	A
159	Eilean Dubh Mor	Small island	A
160	Eiean Mor	Small island	A
161	Eilean nan Ron	Small island	A
162	Eilean Trodday	Small island	A
163	Elsham Wold	Sedim. inland	B
164	Elstead	Inland	A
165	Elstow	Ex-AOS inland	C
166	Elvington	Sedim. inland	C
167	Ensay	Small island	A
168	Eorsa	Small island	A
169	Eriskay	Small island	A
170	Ernesettle	Inland	A
171	Eskmeals	Coastal	A
172	Eynhallow	Small island	A
173	Fairford	Inland	A
174	Fara	Small island	A
175	Faray	Small island	B
176	Fareham	Inland	A
177	Farnborough 1	Inland	A
178	Farnborough 2	Inland	A
179	Farnborough 3	Inland	A
180	Farne Islands	Small island	A
181	Farthingloe	Coastal	A
182	Fauld	Inland	A
183	Feldon	Ex-AOS inland	D
184	Feltwell	Inland	A
185	Ferrybridge	Ex-AOS inland	C
186	Filton	Inland	A
187	Fingrinhoe	BUSC inland	E
188	Finningley	Inland	A
189	Fladda-Cuain	Small island	A
190	Flannan Islands	Small island	B
191	Flat Holm	Small island	A
192	Flixborough	Sedim. inland	B
193	Forest Moor	Inland	A
194	Fort George	Hard rock coastal	C
195	Foula	Small island	A
196	Fradley Airfield	Inland	A
197	Fuday	Small island	G
198	Fulbeck Airfield	Sedim. inland	C
199	Fylindales	Inland	A
200	Gairsay	Small island	A
201	Garvellachs	Small island	A
202	Gasker	Small island	A
203	Gaydon Airfield	Inland	A
204	Gedling	Inland	A
205	Gigha	Small island	A
206	Goldington	Inland	A
207	Gometra	Small island	A
208	Gosport RN yard	Coastal	A
209	Grafham	Inland	A
210	Grantham	Sedim. inland	C
211	Gravesend	Coastal	A
212	Great Fen	BUSC inland	E
213	Greatworth RAF	Inland	A
214	Greenham Common	Ex-AOS inland	D
215	Gruinard island	Small island	A

216	Halsary	Hard rock inland	D
217	Halton RAF	Inland	A
218	Hams Hall	Ex-AOS inland	C
219	Hardwicke	Inland	A
220	Harlosh Island	Small island	A
221	Harrogate	Inland	A
222	Hart	Inland	A
223	Hartlepool	Inland	A
224	Hartlepool	Ex-AOS coastal	C
225	Harwell	Inland	A
226	Hascosay	Small island	A
227	Havering	Inland	A
228	Henlow	Inland	A
229	Heysham	Ex-AOS coastal	D
230	High Marnham	Sedim. inland	D
231	High Wycombe	Inland	A
232	Hildasay	Small island	A
233	Hilton	Inland	A
234	Hinkley Point	Ex-AOS coastal	D
235	Holbeach	Sedim. inland	E
236	Holcombe Moor	Inland	A
237	Holm of Huip	Small island	A
238	Holyhead	Hard rock coastal	D
239	Honington	Inland	A
240	Houndstone Camp	Inland	A
241	Hullavington Afd	Inland	A
242	Hunterston	Ex-AOS coastal	D
243	Hythe Army range	Coastal	A
244	Inch Kenneth	Small island	A
245	Inchmarnock	Small island	B
246	Innsworth	Inland	A
247	Insh Island	Small island	A
248	Inskip	Sedim. inland	C
249	Iona	Small island	A
250	Isay	Small island	B
251	Island of Danna	Small island	A
252	Island of Macaskin	Small island	A
253	Isle Martin	Small island	A
254	Isle of Ewe	Small island	A
255	Isle of May	Small island	A
256	Isle of Stroma	Small island	A
257	Isle Ristol	Small island	A
258	Isles of Scilly	Small island	A
259	Jura	Small island	A
260	Keadby	Sedim. inland	C
261	Keevil	Inland	A
262	Kemble	Inland	A
263	Kenilworth	Inland	A
264	Kerrera	Small island	A
265	Kibworth Rifle Range	Inland	A
266	Killegray	Small island	A
267	Killingholme	Sedim. coastal	G
268	Kineton	Ex-AOS inland	D
269	Kingsbury	Inland	A
270	Kingston upon Hull	Inland	A
271	Kinloss	Ex-AOS coastal	D
272	Kirkcudbright	Ex-AOS coastal	D
273	Kirknewton	Inland	A
274	Kirton in Lindsey	Sedim. inland	C
275	Laggan Bay, Islay	Ex-AOS inland	C
276	Lakenheath	BUSC inland	E
277	Lamba	Small island	A
278	Langbaurgh	Sedim. coastal	B
279	Langport	Inland	A
280	Lasham	Inland	A
281	Latimer	Inland	A
282	Laughton Forest	Sedim. inland	D
283	Lawford Heath	Inland	A
284	Leavesden Airfield	Inland	A
285	Leconfield	Sedim. inland	C
286	Lee on Solent RN sta	Coastal	A
287	Leeming RAF	Sedim. inland	D
288	Leuchars	Ex-AOS coastal	D
289	Levenseat Quarry	Inland	A
290	Lichfield	Inland	A
291	Lidlington	Inland	A
292	Lindholme RAF	Sedim. inland	B
293	Linga	Small island	A
294	Linga	Small island	A
295	Linga	Small island	A
296	Linga Holm	Small island	A
297	Linton on Ouse	Sedim. inland	C
298	Lismore	Small island	A
299	Little Colonsay	Small island	A
300	Little Cumbrae	Small island	A
301	Little Rissington	Inland	A
302	Little Staughton	Inland	A
303	Loch Fleet	Hard rock coastal	C
304	Lochaline	Ex-AOS coastal	B
305	Locking RAF	Inland	A
306	Long Marston Afd	Inland	A
307	Long Marston Depot	Inland	A
308	Longa Island	Small island	A
309	Longay	Small island	A
310	Longmoor	Ex-AOS inland	D
311	Longton	Sedim. inland	D
312	Lossie Forest	Hard rock coastal	D
313	Lossiemouth RAF	Hard rock inland	D
314	Loughborough	Inland	A
315	Luing	Small island	A
316	Lulworth	Ex-AOS coastal	D
317	Lundy	Small island	A
318	Lunga	Small island	A
319	Lydd Camp & Ranges	Ex-AOS coastal	E
320	Lyneham	Inland	A
321	Macrihanish	Ex-AOS coastal	D
322	March	Inland	A
323	Marchwood	Inland	A

324	Marham	BUSC inland	E
325	Martin Airfield	Sedim. inland	B
326	Meaford	Inland	A
327	Mealasta Island	Small island	A
328	Melton Mowbray	Inland	A
329	Meriden	Inland	A
330	Merrifield	Inland	A
331	Middle Wallop	Inland	A
332	Middlesbrough	Inland	A
333	Mildenhall	BUSC inland	E
334	Mingulay	Small island	B
335	Minley	Ex-AOS inland	D
336	Misson RAF Range	Sedim. inland	C
337	Molesworth Afd	Inland	A
338	Monarch Isles	Small island	A
339	Monks Fryston	Ex-AOS inland	C
340	Monks Park	Inland	A
341	Monkton Farley	Inland	A
342	Moorends Mine	Inland	A
343	Moreton on Lugg	Inland	A
344	Mormond Hill	Ex-AOS inland	C
345	Morrich More	Hard rock coastal	D
346	Mousa	Small island	B
347	Much Hoole	Sedim. inland	D
348	Muck	Small island	A
349	Muckle Green Holm	Small island	A
350	Muckle Skerry	Small island	B
351	Nave Island	Small island	A
352	Naver Forest	Ex-AOS inland	F
353	Nesscliff	Ex-AOS inland	D
354	Newborough Forest	Ex-AOS coastal	D
355	Newbury	Inland	A
356	Newton Airfield	Inland	A
357	Newton Covert Afd	Sedim. inland	B
358	Nocton	Sedim. inland	B
359	North Coates	Sedim. coastal	F
360	North Luffenham	Inland	A
361	North Rona	Small island	A
362	Norton Barracks	Inland	A
363	Norton Manor Camp	Inland	A
364	Nuneaton	Inland	A
365	Oakington	Inland	A
366	Odiham RAF	Inland	A
367	Ogborne St George	Inland	A
368	Oigh Sgeir	Small island	F
369	Old Dalby	Inland	A
370	Old Park Barracks	Inland	A
371	Old Sarum	Inland	A
372	Oldbury	Ex-AOS coastal	D
373	Ollerton	Sedim. inland	C
374	Orfordness	Coastal	A
375	Oronsay	Small island	A
376	Oronsay	Small island	B
377	Osgodby Moor	Sedim. inland	F
378	Ossington Afd	Sedim. inland	B
379	Otmoor	Inland	A
380	Otterburn	Ex-AOS inland	D
381	Ouston	Inland	A
382	Owston Ferry	Sedim. inland	C
383	Oxna	Small island	A
384	Pabay	Small island	B
385	Pabbay	Small island	B
386	Pabbay	Small island	B
387	Papa	Small island	A
388	Papa Little	Small island	A
389	Papa Stronsay	Small island	A
390	Pembrey	Ex-AOS coastal	D
391	Pendine	Ex-AOS coastal	D
392	Penhale	Ex-AOS coastal	D
393	Pershore Afd	Inland	A
394	Pontrilas	Inland	A
395	Portland	Coastal	A
396	Porton	Ex-AOS inland	D
397	Porton Down	Inland	A
398	Portreath	Ex-AOS coastal	D
399	Portsdown	Inland	A
400	Potton Island	BUSC coastal	G
401	Predannack	Coastal	A
402	Priest Island	Small island	A
403	Quedgeley	Inland	A
404	Raasay	Small island	D
405	Ramsey Island	Small island	A
406	Ratcliffe-on-Soar	Inland	A
407	Redford, Edinburgh	Inland	A
408	Rhum	Small island	A
409	Richborough	Inland	A
410	Ripon	Inland	A
411	Risley	Inland	A
412	Risley (1)	Inland	A
413	Risley (2)	Inland	A
414	Rona	Small island	B
415	Roseisle Forest	Hard rock coastal	D
416	Ross of Mull	Hard rock coastal	C
417	Rosyth	Ex-AOS coastal	D
418	Ruddington	Inland	A
419	Salford	Inland	A
420	Salisbury Plain	Ex-AOS inland	D
421	Samphrey	Small island	B
422	Sanda	Small island	B
423	Sandhurst	Inland	A
424	Sandray	Small island	G
425	Scalpay	Small island	B
426	Scampton RAF	Sedim. inland	C
427	Scarba	Small island	A
428	Scarp	Small island	A
429	Scoor	Ex-AOS coastal	D
430	Sculthorpe USAF	Sedim. inland	E
431	Sealand Range	Coastal	A

432	Seighford	Inland	A
433	Sellafield (-A)	Sedim. coastal	H
434	Sennybridge	Ex-AOS inland	D
435	Shawbury	Inland	A
436	Shellingford Afd	Inland	A
437	Shiant Islands	Small island	B
438	Shoeburyness	BUSC coastal	F
439	Shrivenham	Ex-AOS inland	C
440	Shuna	Small island	B
441	Shuna Island	Small island	A
442	Sizewell	BUSC coastal	E
443	Skokholm	Small island	A
444	Skomer	Small island	A
445	Slough	Inland	A
446	Soay	Small island	A
447	South Cerney	Inland	A
448	South Tyneside	Inland	A
449	Southwick	Inland	A
450	Spadeadam	Inland	A
451	Springfields	Sedim. inland	D
452	St Athans	Coastal	A
453	St Davids RAF	Inland	A
454	St Eval	Inland	A
455	St Kilda	Small island	A
456	St Leonards	Inland	A
457	St Mawgan	Ex-AOS coastal	D
458	Stanford	BUSC inland	H
459	Steep Holm	Small island	A
460	Stockton on Tees	Inland	A
461	Stradishall RAF	Inland	A
462	Strenshall Common	Sedim. inland	D
463	Summer isles	Small island	A
464	Summerfield	Inland	A
465	Swanton Morley RAF	Inland	A
466	Swinderby RAF	Sedim. inland	C
467	Switha	Small island	A
468	Swona	Small island	D
469	Swynnerton	Inland	A
470	Syerston RAF	Sedim. inland	C
471	Tangmere	Inland	A
472	Taransay	Small island	A
473	Tarner Island	Small island	A
474	Tern Hill Airfield	Inland	A
475	Texa	Small island	A
476	Theddlethorpe	Sedim. coastal	F
477	Tholthorpe Afd	Inland	A
478	Thorney Island	Coastal	A
479	Thurleigh Airfield	Inland	A
480	Tiree	Small island	A
481	Topcliffe	Sedim. inland	C
482	Torness	Ex-AOS coastal	D
483	Torpoint	Coastal	A
484	Trawsfynydd	Inland	A
485	Trecwn	Ex-AOS inland	D
486	Tregantle	Ex-AOS coastal	D
487	Treshnish	Small island	A
488	Ulva	Small island	A
489	Upavon	Inland	A
490	Upper Heyford	Ex-AOS inland	D
491	Upper Hulme	Inland	A
492	Upwood USAF	Inland	A
493	Urie Lingay	Small island	A
494	Vale Royal	Inland	A
495	Waddington	Sedim. inland	D
496	Wainfleet	Sedim. coastal	B
497	Waltham Abbey	Inland	A
498	Warcop	Ex-AOS inland	D
499	Waterbeach	Inland	A
500	Wattisham	BUSC inland	D
501	Watton RAF	Inland	A
502	Wedgnock	Inland	A
503	Weeton	Sedim. inland	C
504	Welford	Inland	A
505	Wellesbourne Afd	Inland	A
506	West Freugh	Ex-AOS coastal	D
507	West Islay	Ex-AOS coastal	E
508	West Linga	Small island	A
509	West Moors	Inland	A
510	Westcott	Inland	A
511	Weston-on-the-Green	Inland	A
512	Westwood	Inland	A
513	Wethersfield RAF	Inland	A
514	Wiay	Small island	A
515	Wigan	Inland	A
516	Wigsley	Sedim. inland	C
517	Willsworthy Ranges	Inland	A
518	Winchester	Inland	A
519	Winchester Range	Inland	A
520	Winfrith	Inland	A
521	Winslow Afd	Inland	A
522	Winterbourne Gunner	Inland	A
523	Wittering RAF	Inland	A
524	Wombleton Afd	Inland	A
525	Woodbridge USAF	Inland	A
526	Woodhall Spa	Sedim. inland	C
527	Woodvale RAF	Coastal	A
528	Workington	Inland	A
529	Worthy Down	Inland	A
530	Wrawby Moor Forset	Sedim. inland	C
531	Wroughton	Inland	A
532	Wylfa	Ex-AOS coastal	D
533	Wymeswold Afd	Inland	A
534	Wyton	BUSC inland	E
535	Yardley Chase	Inland	A
536	Yeading	Inland	A
537	Yeavilton	Inland	A
999	**Sellafield-B**	**Pseudo-BUSC**	

(a)



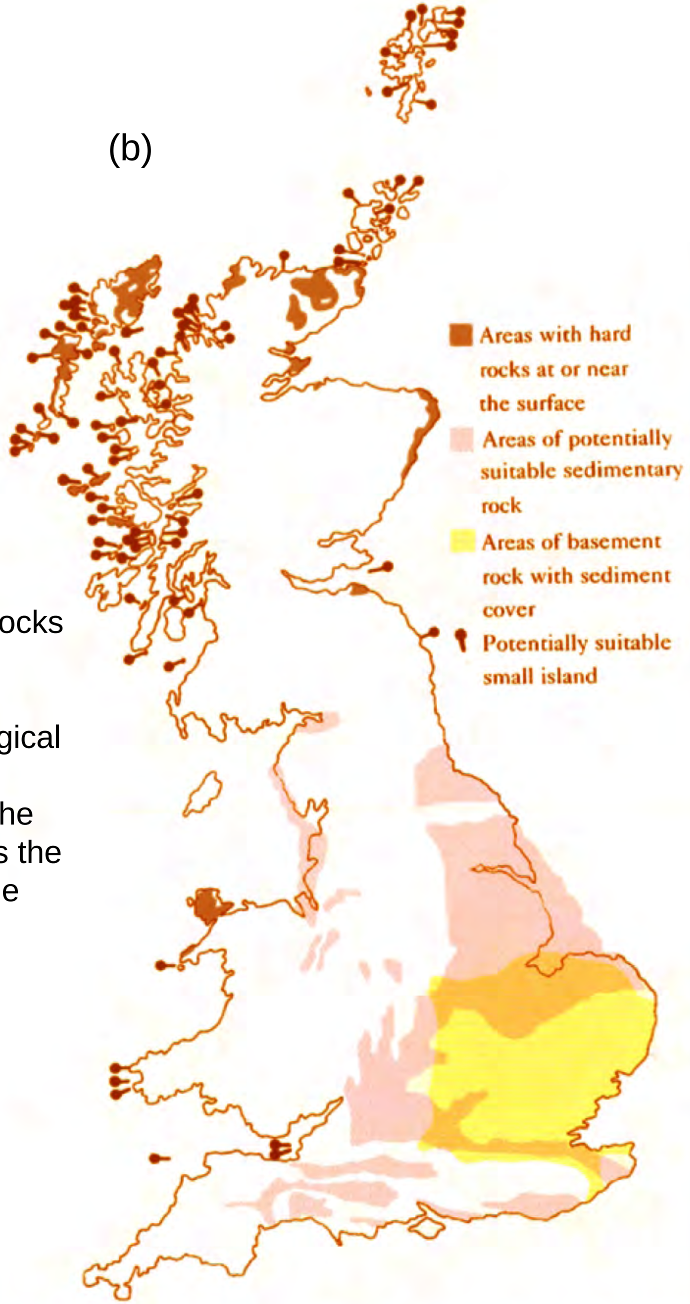
Map showing the distribution of rocks thought to meet the selection criteria and of those areas which have been selected for feasibility studies. Crystalline igneous and metamorphic rocks are stippled, argillaceous rocks are shown with horizontal lines and evaporites with vertical lines. The crystalline rocks include the postulated subsurface outcrops of the granites of northern and south-western England. No rock types meeting the criteria occur in the Shetland Islands.

Fig. 2.1.1.

(a) Potentially suitable host rocks (Mather *et al.* 1979)

(b) Potentially suitable geological environments, defined by Chapman *et al.* (1986). The colour image used here is the map reproduced by Michie (1998).

(b)



4 Geological environments considered to have potential for ILW repository development (after Nirex)

Geological cross-section through the coastal plain of Maryland, USA

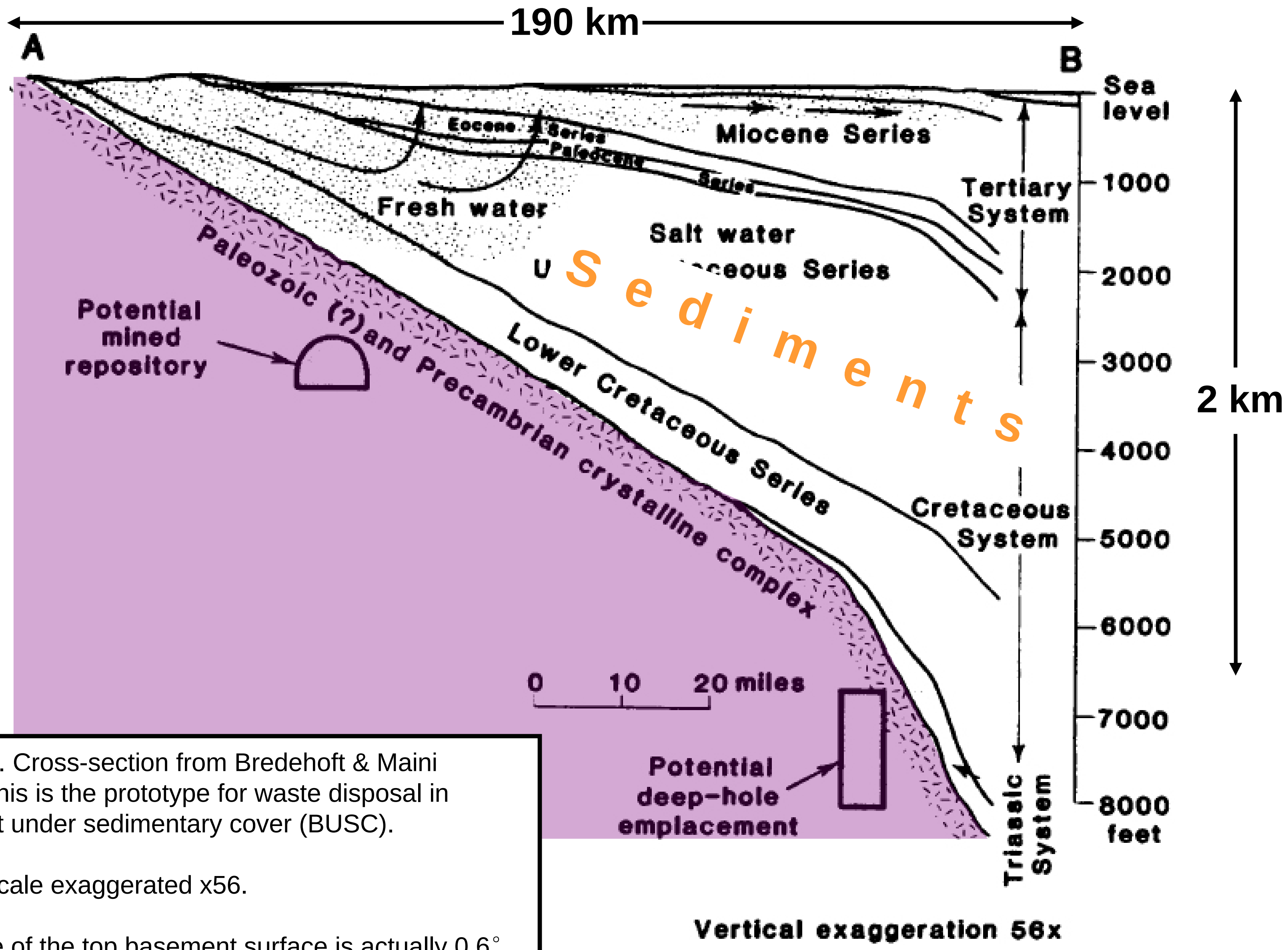
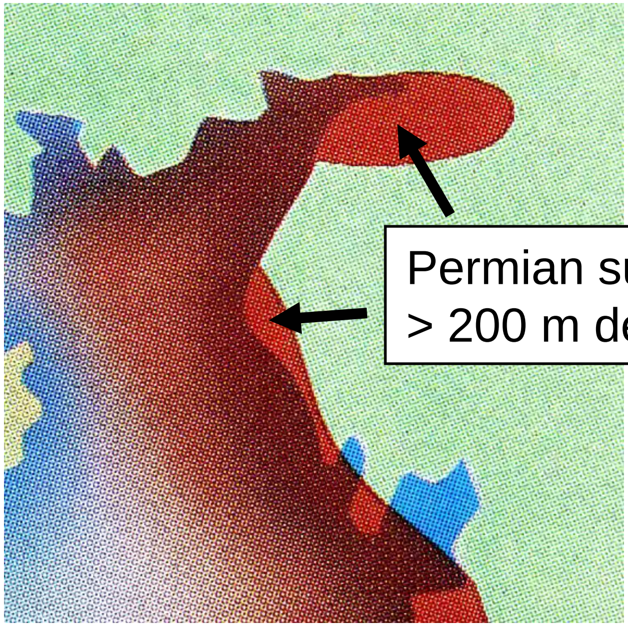


Fig. 2.1.2. Cross-section from Bredehoft & Maini (1981). This is the prototype for waste disposal in basement under sedimentary cover (BUSC).

Vertical scale exaggerated x56.

The slope of the top basement surface is actually 0.6°. Because of this very low gradient, water flow within it is almost stagnant.



Permian subcrop
> 200 m depth

🟥 Areas of ‘low relief terrain’ with hard rocks at or near surface

🟫 Areas of potentially suitable sedimentary formations

🟨 Area of low permeability basement with sediment cover

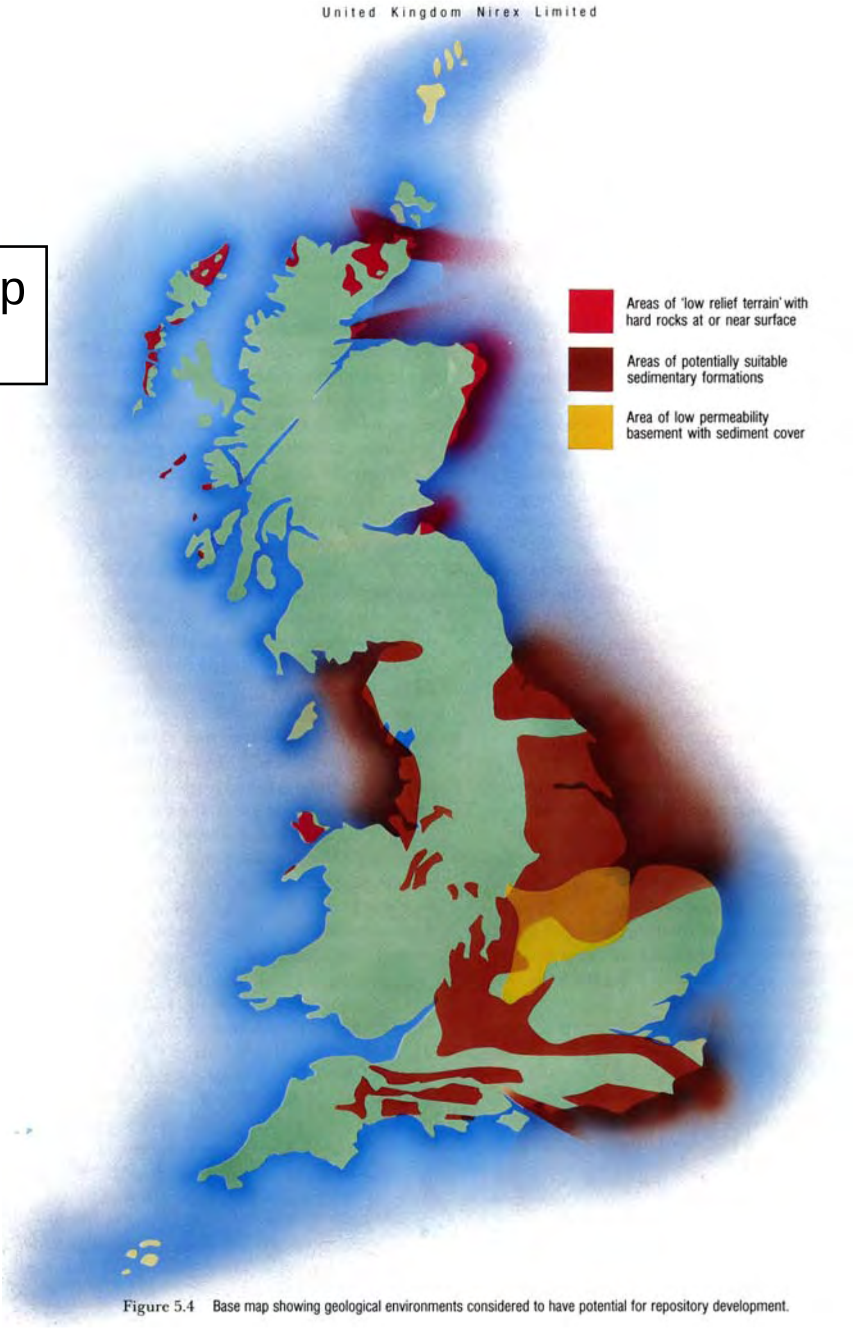
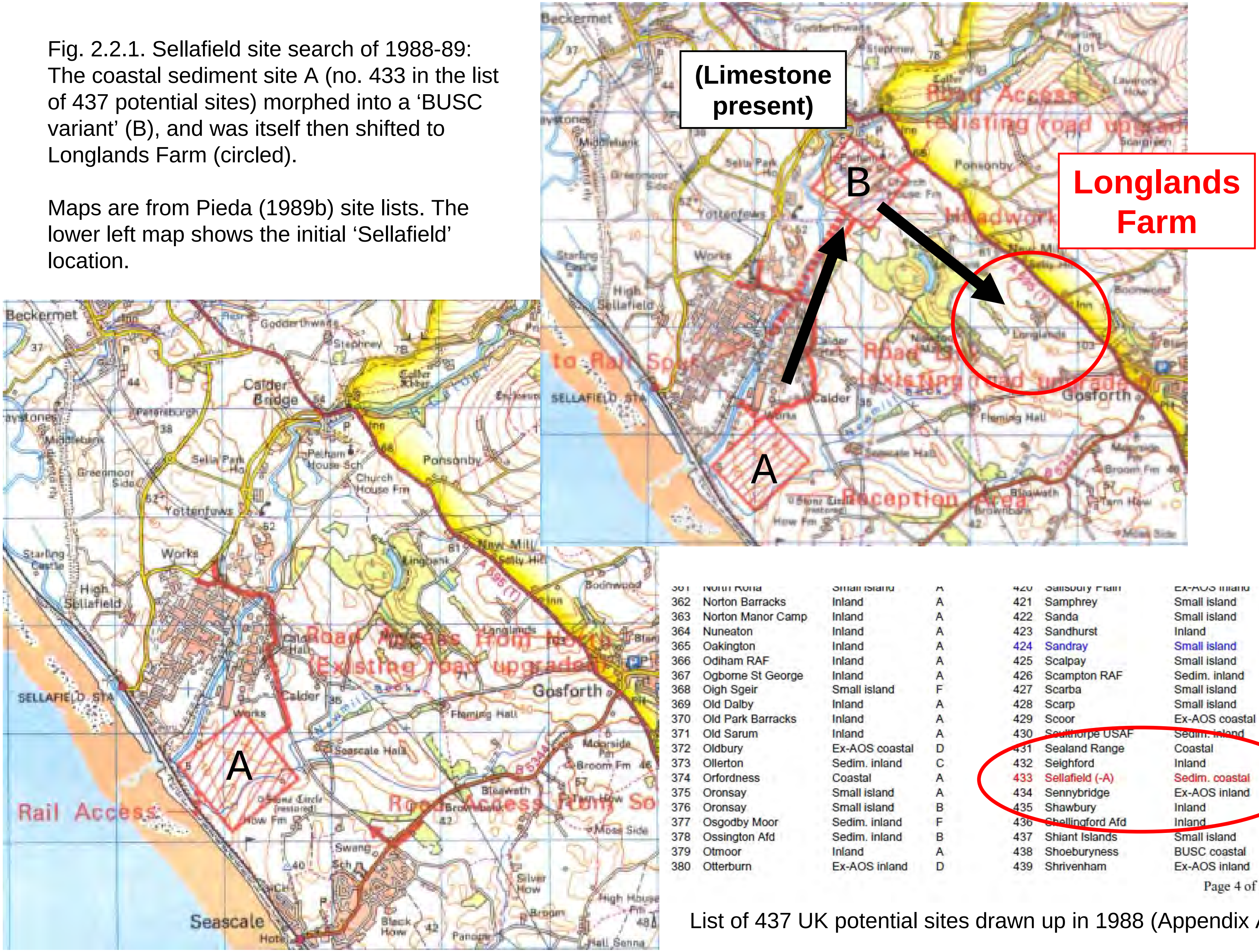


Figure 5.4 Base map showing geological environments considered to have potential for repository development.

Fig. 2.1.3. Main map: areas of potentially suitable geology identified by the BGS in the 1980s (Chapman *et al.* 1986) and re-published by Nirex (1987). The inset above shows Cumbria and the NE Irish Sea at an enlarged scale.

Fig. 2.2.1. Sellafield site search of 1988-89: The coastal sediment site A (no. 433 in the list of 437 potential sites) morphed into a 'BUSC variant' (B), and was itself then shifted to Longlands Farm (circled).

Maps are from Pieda (1989b) site lists. The lower left map shows the initial 'Sellafield' location.



361	North Rona	Small island	A
362	Norton Barracks	Inland	A
363	Norton Manor Camp	Inland	A
364	Nuneaton	Inland	A
365	Oakington	Inland	A
366	Odiham RAF	Inland	A
367	Ogborne St George	Inland	A
368	Oigh Sgeir	Small island	F
369	Old Dalby	Inland	A
370	Old Park Barracks	Inland	A
371	Old Sarum	Inland	A
372	Oldbury	Ex-AOS coastal	D
373	Ollerton	Sedim. inland	C
374	Orfordness	Coastal	A
375	Oronsay	Small island	A
376	Oronsay	Small island	B
377	Osgodby Moor	Sedim. inland	F
378	Ossington Afd	Sedim. inland	B
379	Otmoor	Inland	A
380	Otterburn	Ex-AOS inland	D
420	Salisbury Plain	Ex-AOS inland	D
421	Samphrey	Small island	B
422	Sanda	Small island	B
423	Sandhurst	Inland	A
424	Sandray	Small island	G
425	Scalpay	Small island	B
426	Scampton RAF	Sedim. inland	C
427	Scarba	Small island	A
428	Scarp	Small island	A
429	Scoor	Ex-AOS coastal	D
430	Sculthorpe USAF	Sedim. inland	E
431	Sealand Range	Coastal	A
432	Seighford	Inland	A
433	Sellafield (-A)	Sedim. coastal	H
434	Sennybridge	Ex-AOS inland	D
435	Shawbury	Inland	A
436	Shellingford Afd	Inland	A
437	Shiant Islands	Small island	B
438	Shoeburyness	BUSC coastal	F
439	Shrivenham	Ex-AOS inland	C

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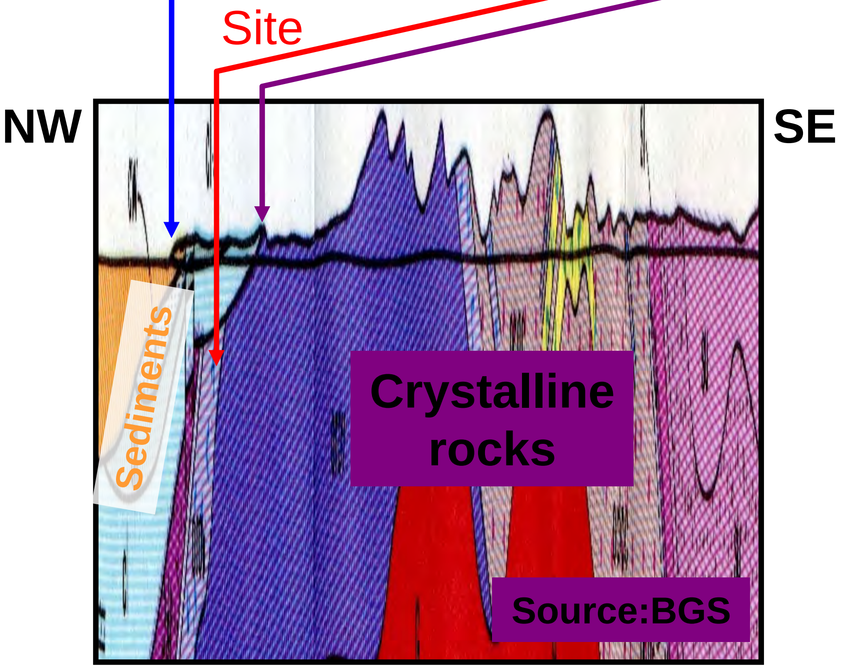
List of 437 UK potential sites drawn up in 1988 (Appendix A).

True BUSC cross-section (Fig. 2.2) mirrored (sea now on left) at V.E. x 10



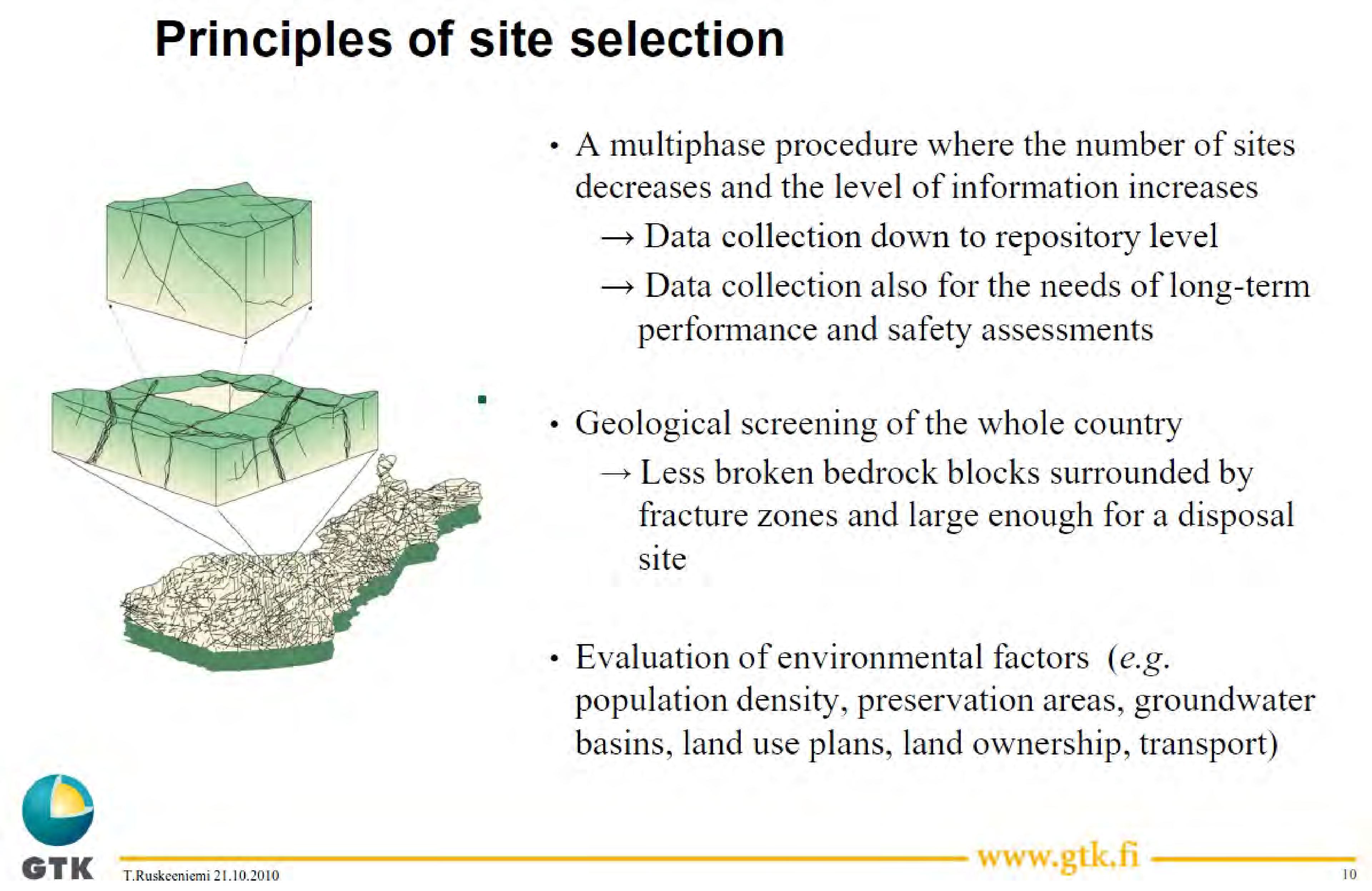
Geological cross-section from Windermere to the Solway. Same scales as the BUSC cross-section above.

Fig. 2.5. Flaws in the Cumbrian model compared to the true BUSC type:

- Horizontal scale compressed by x 20.
- Height of terrain within zone of interest higher by x 20.
- Dip (tilt) of the sedimentary layers higher by x 40.

So the relative proportions of BUSC are distorted by 20 x 20 = 400.

Result: the water flow patterns within West Cumbria are far too vigorous and complex – it is not a BUSC environment.



Principles of site selection

- A multiphase procedure where the number of sites decreases and the level of information increases
  - → Data collection down to repository level
  - → Data collection also for the needs of long-term performance and safety assessments
- Geological screening of the whole country
  - → Less broken bedrock blocks surrounded by fracture zones and large enough for a disposal site
- Evaluation of environmental factors (*e.g.* population density, preservation areas, groundwater basins, land use plans, land ownership, transport)

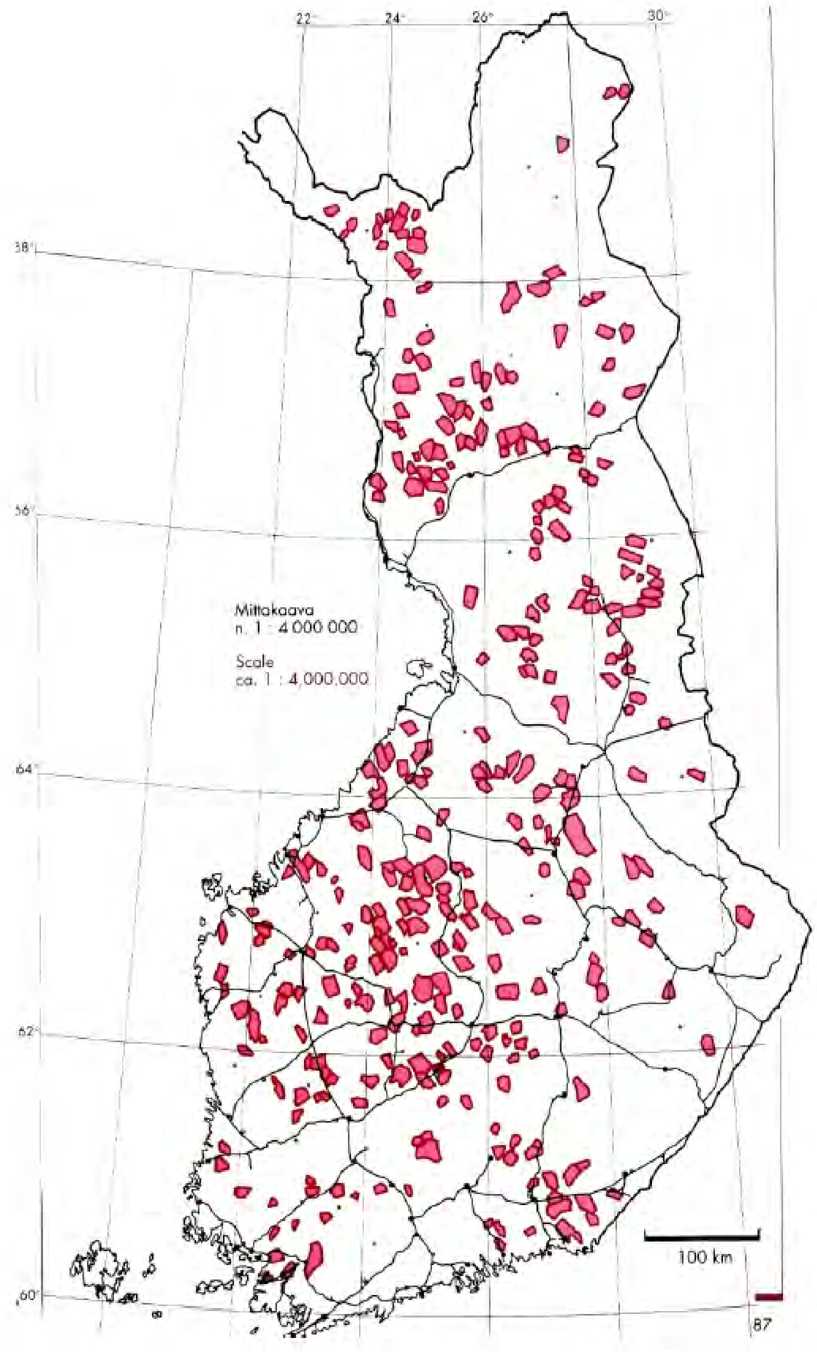
GTK

T.Ruskeeniemi 21.10.2010

www.gtk.fi

Fig. 3.6.1. Site search in Finland started by a systematic search of the whole country to find homogeneous blocks of rock (Ruskeeniemi and Paulamäki 2010).

Fig. 3.6.2. Site search in Finland: 327 regional bedrock blocks were identified (red areas) (Ruskeeniemi and Paulamäki 2010).



GTK

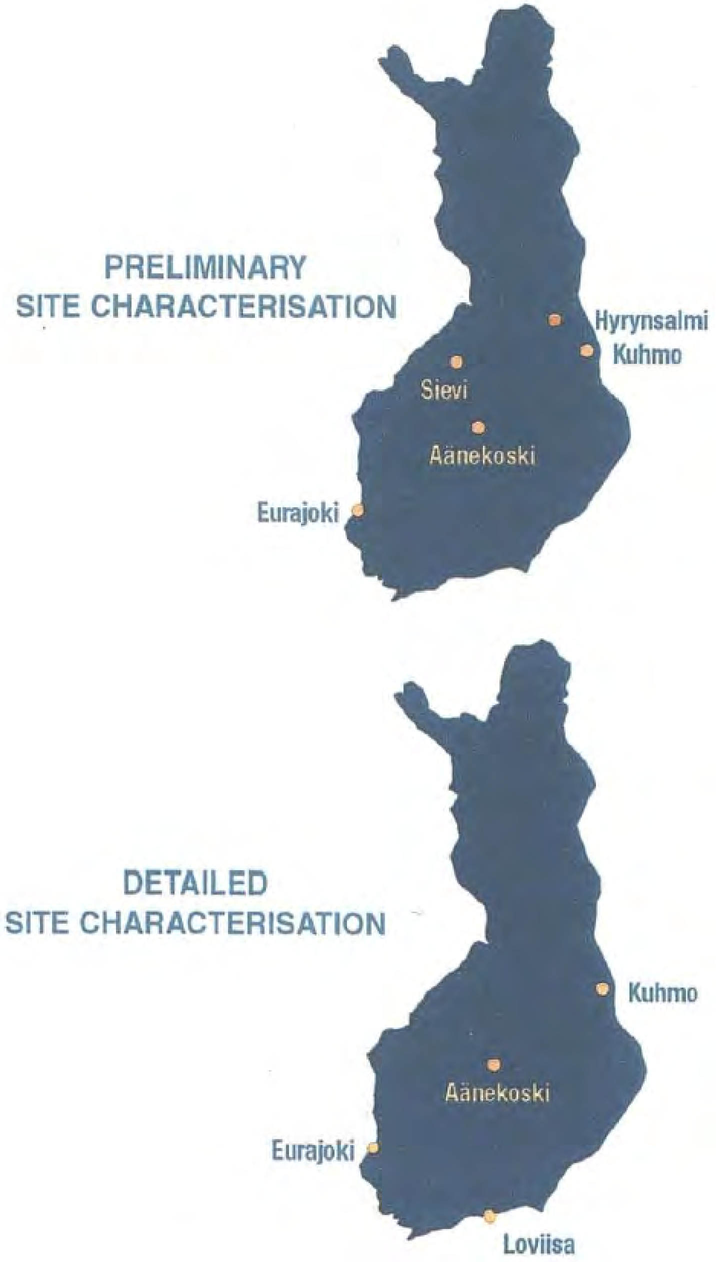


Fig. 3.6.3. Site search in Finland: the regional blocks were sieved down to five sites (upper map) which were subjected to site characterisation. Two sites were withdrawn, but a third added to give four sites (lower map). Municipal vetoes resulted in the withdrawal of the two most northerly sites. Olkiluoto in Eurajoki municipality was chosen in 2000 (Ruskeeniemi and Paulamäki 2010).

Fig. 3.6.4. Swedish staged site selection based on geology, but with:

- Local veto
- Government right to override the veto.

Stages 1-4 are discussed in the text. The finally chosen site (Forsmark) is ringed.

Note:
The geology of both Finland and Sweden is mostly ancient stable low relief hard rock.

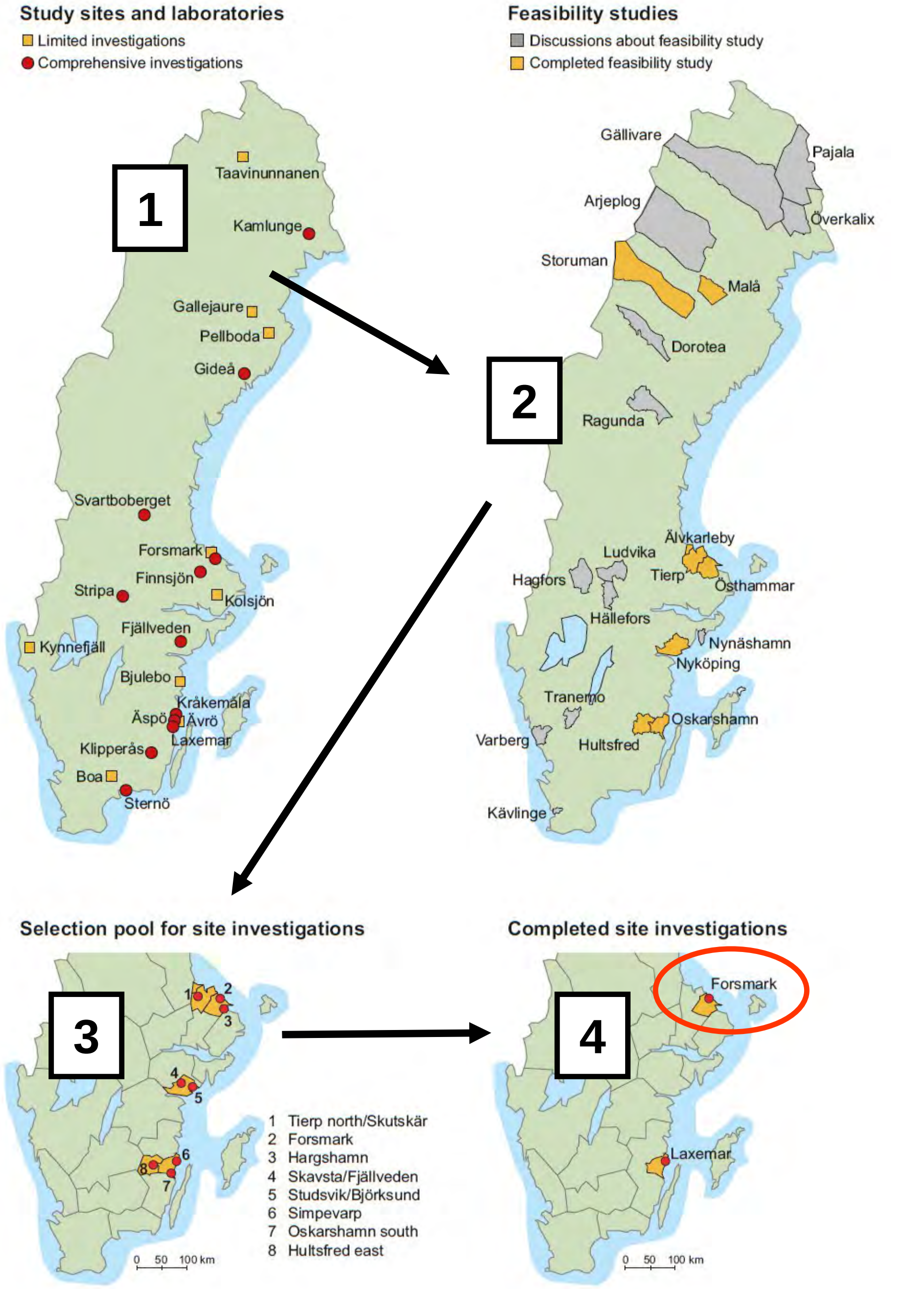


Figure 1-1. The siting process – an overview.

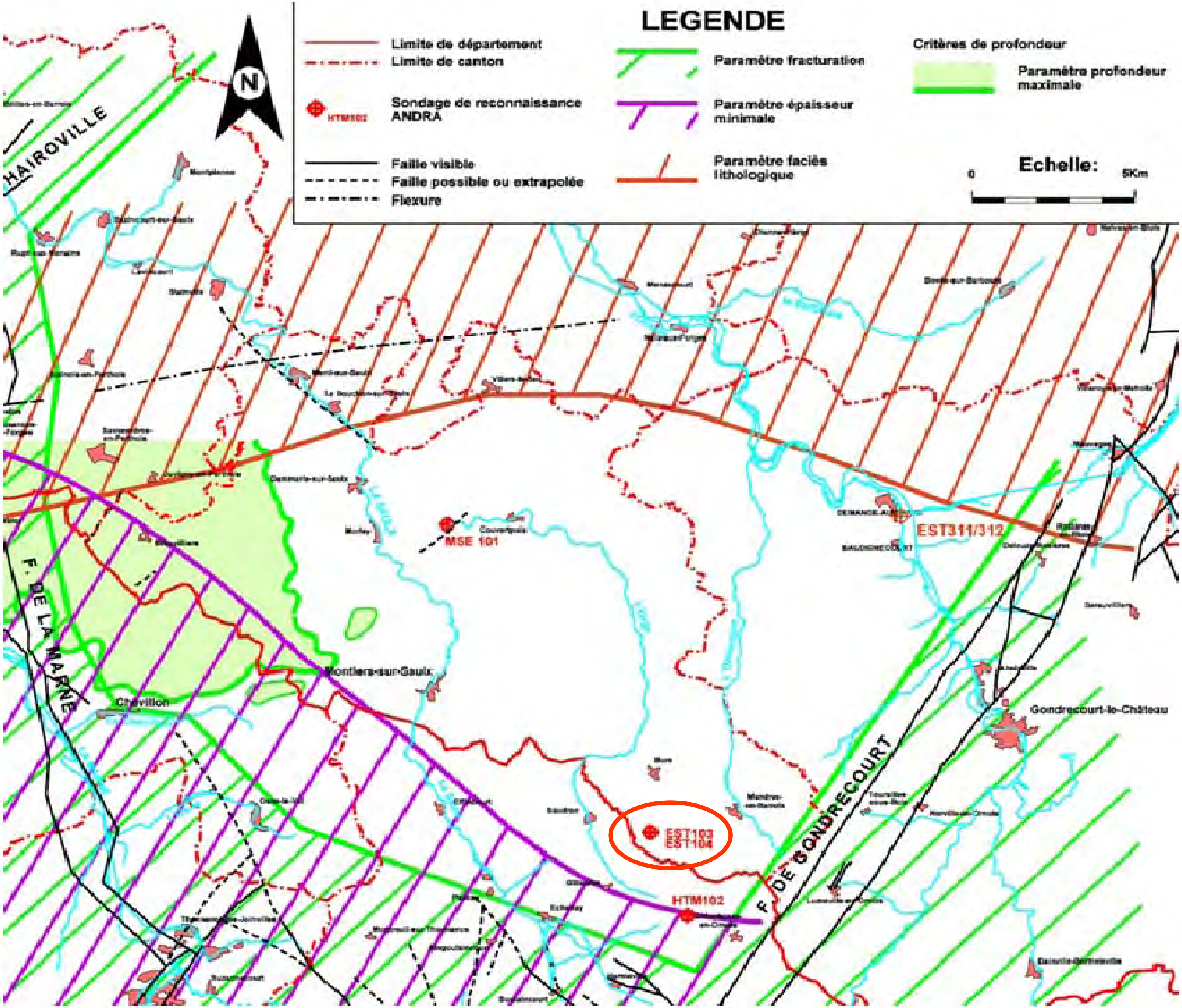


Fig. 3.6.5. The French URL at Bure (ringed). Search for a final deep repository site was extended throughout the triangular zone defined by geological limiting criteria: faulting to the east, lithology to the north, and minimum thickness to the south.

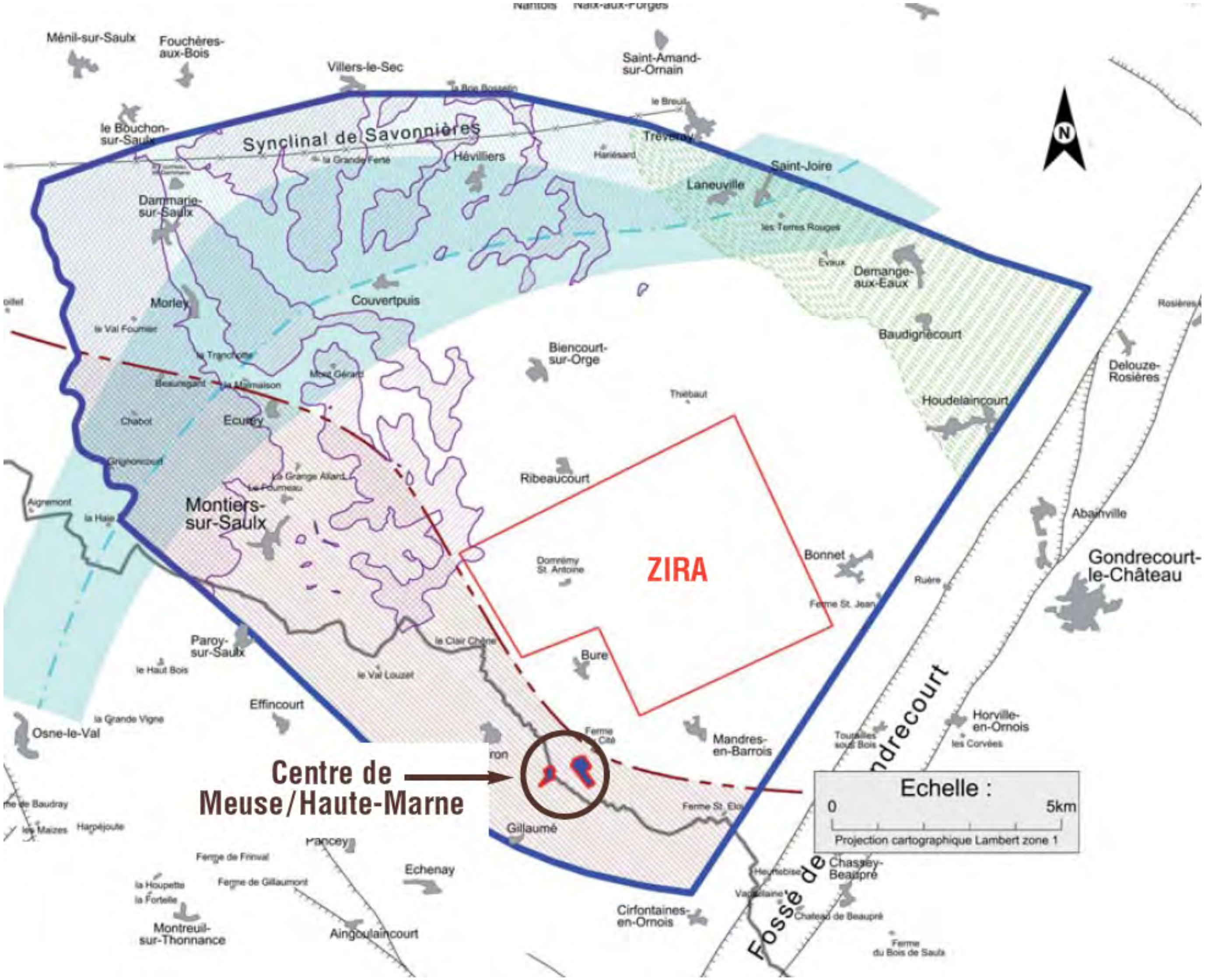


Fig. 3.6.6. The zone of interest (ZIRA) at Bure was defined in 2010.

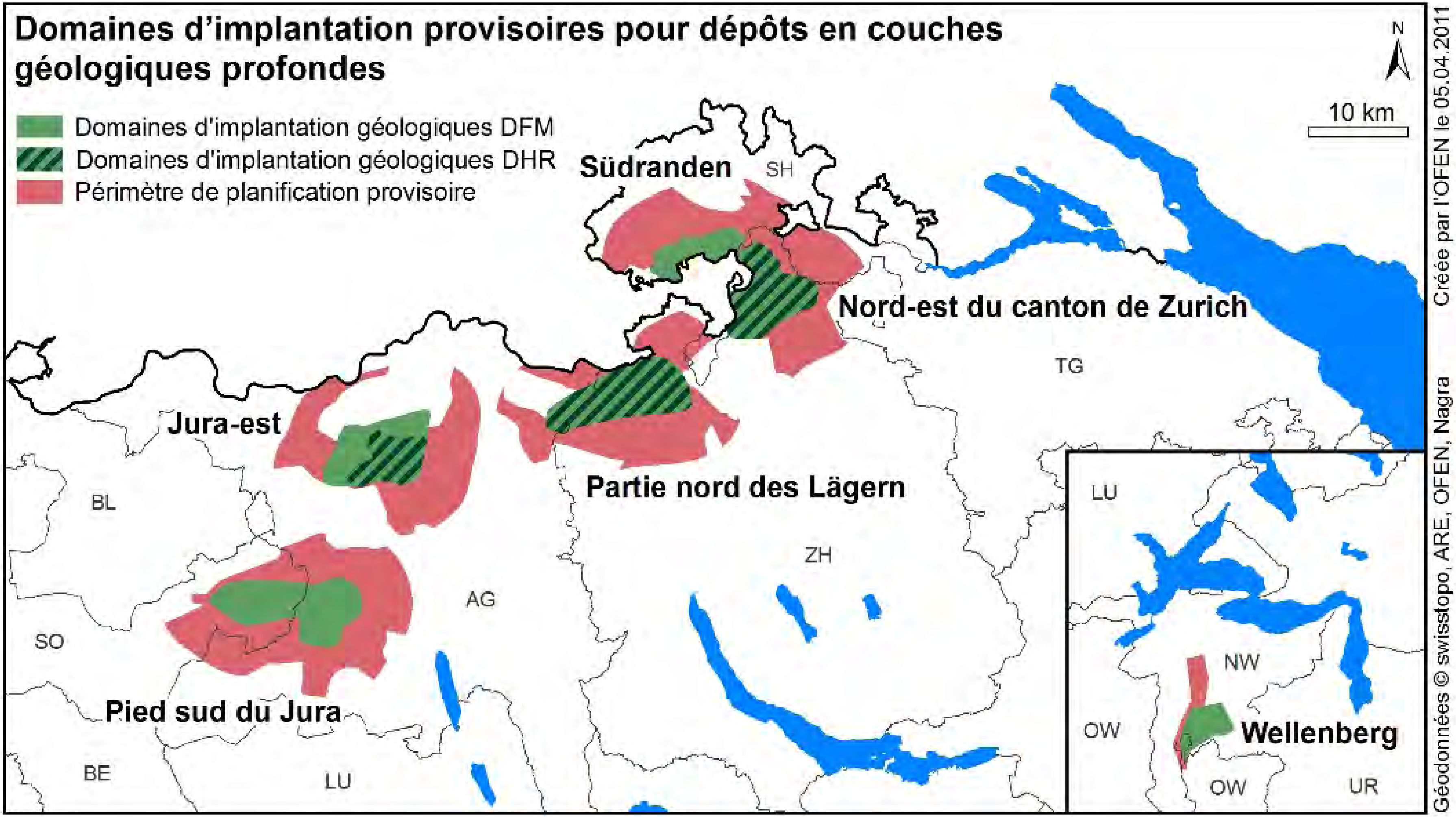


Fig. 3.6.7. Six proposed zones in Switzerland for HLW (DHR in key) and ILW (DFM in key). These zones have all been selected on geological criteria, not by ‘voluntarism’.

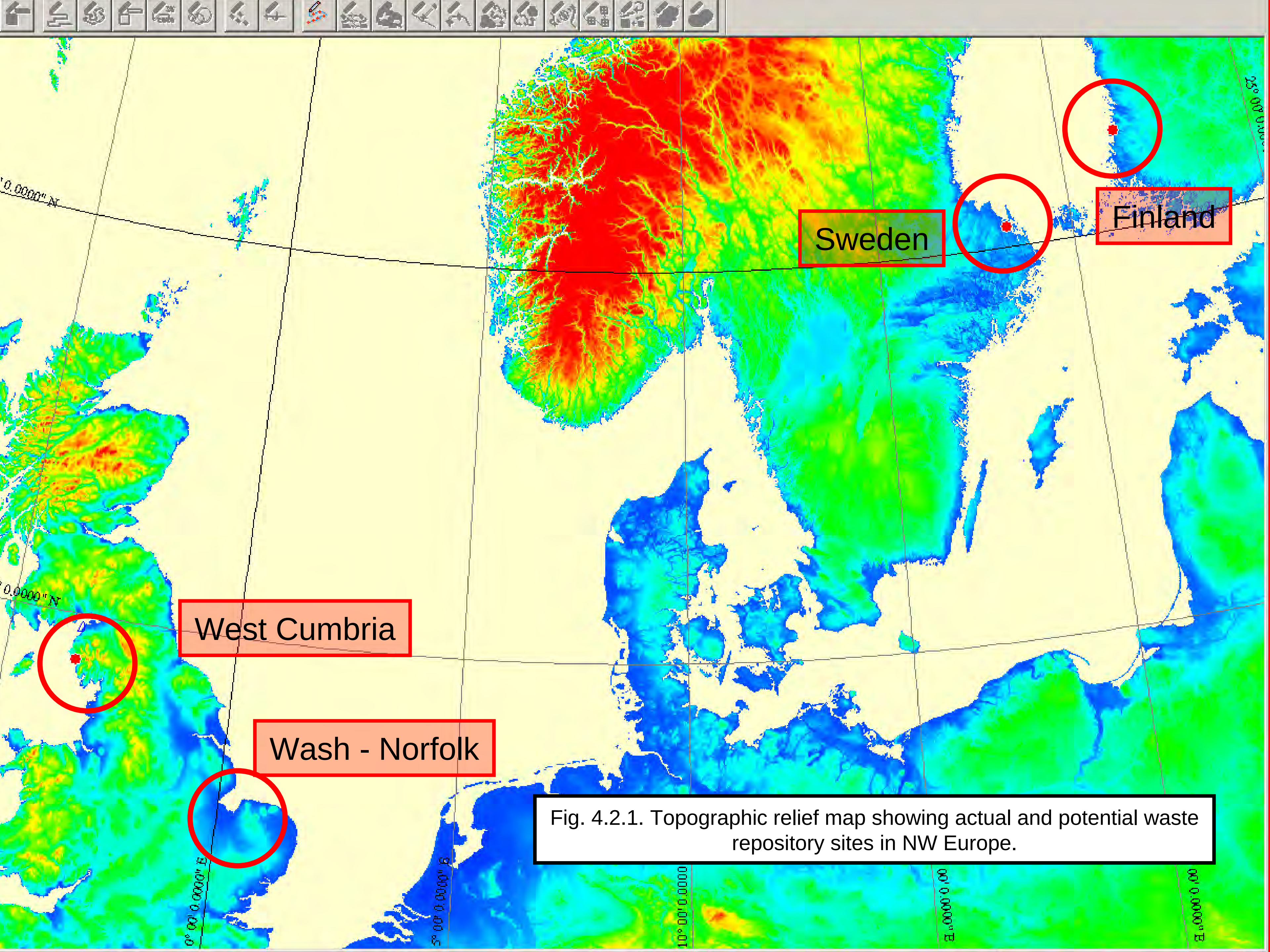


Fig. 4.2.1. Topographic relief map showing actual and potential waste repository sites in NW Europe.

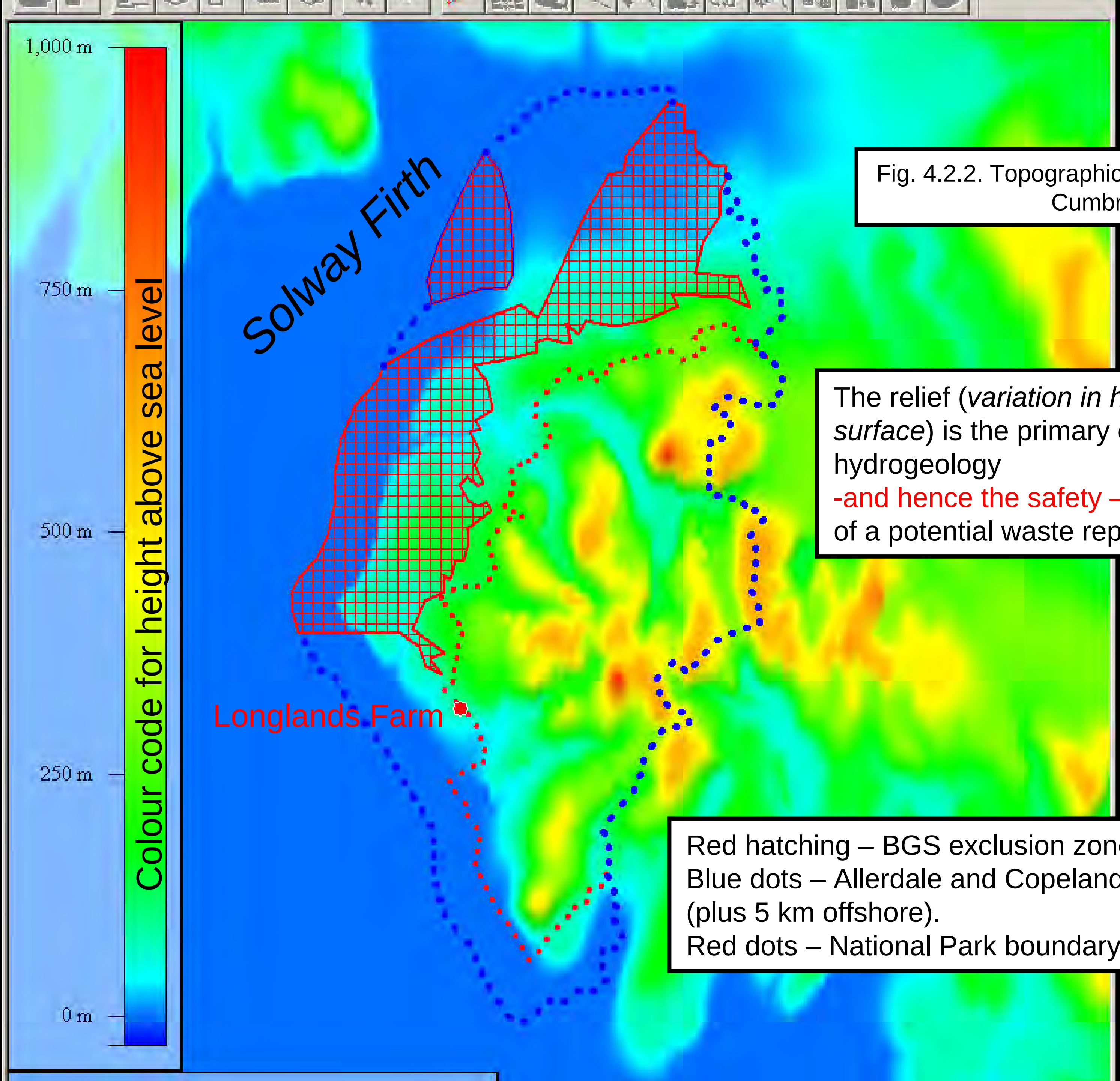
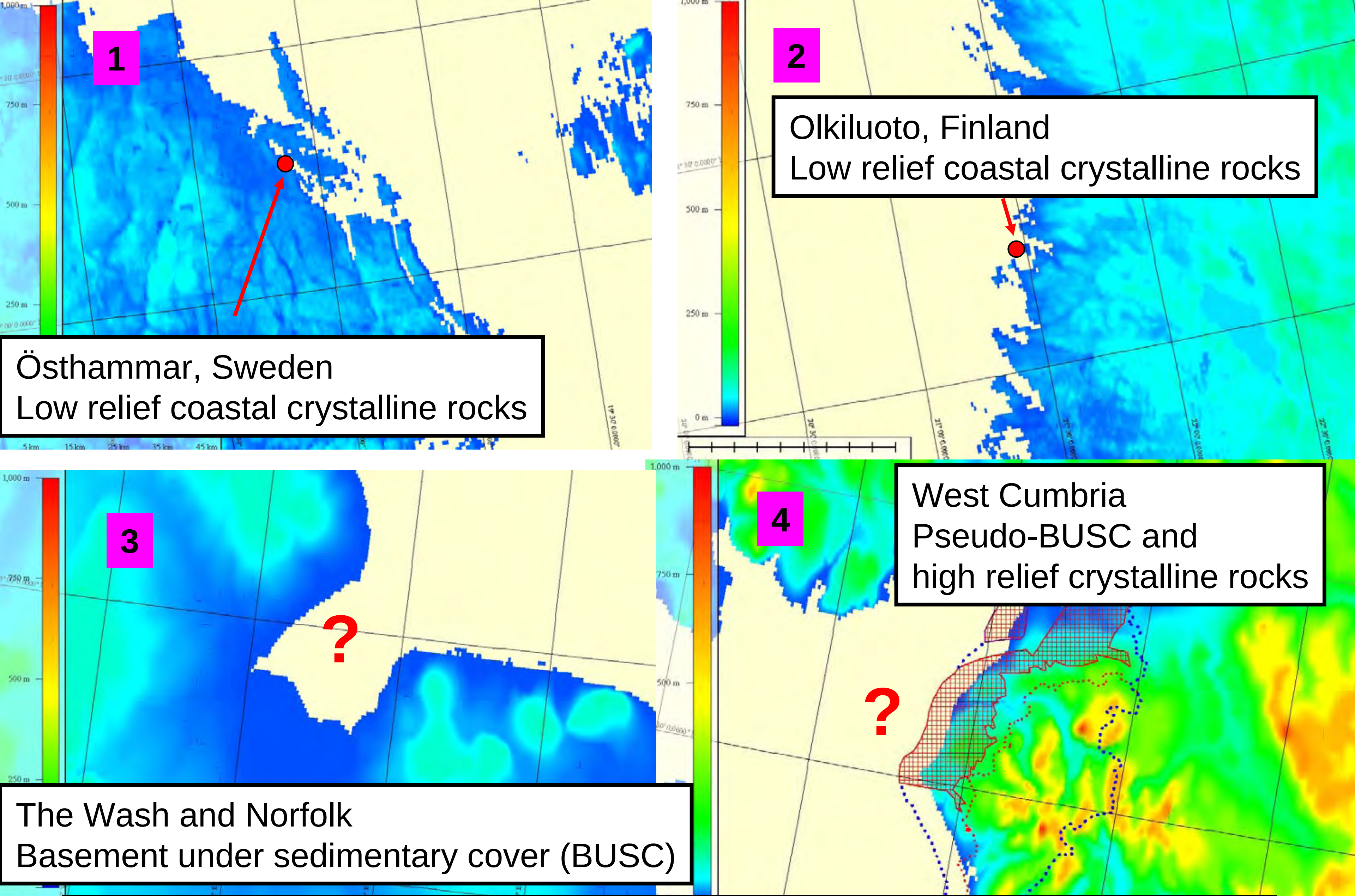


Fig. 4.2.2. Topographic relief map of West Cumbria.

The relief (*variation in height of the land surface*) is the primary control on the hydrogeology
-and hence the safety –
of a potential waste repository.

Red hatching – BGS exclusion zones.
Blue dots – Allerdale and Copeland district boundary (plus 5 km offshore).
Red dots – National Park boundary.



1

Östhammar, Sweden
Low relief coastal crystalline rocks

2

Olkiluoto, Finland
Low relief coastal crystalline rocks

3

The Wash and Norfolk
Basement under sedimentary cover (BUSC)

4

West Cumbria
Pseudo-BUSC and
high relief crystalline rocks

Fig. 4.2.3. Topographic relief of four actual and potential waste localities. The maps are at the same scale, and use the same colour code for height.

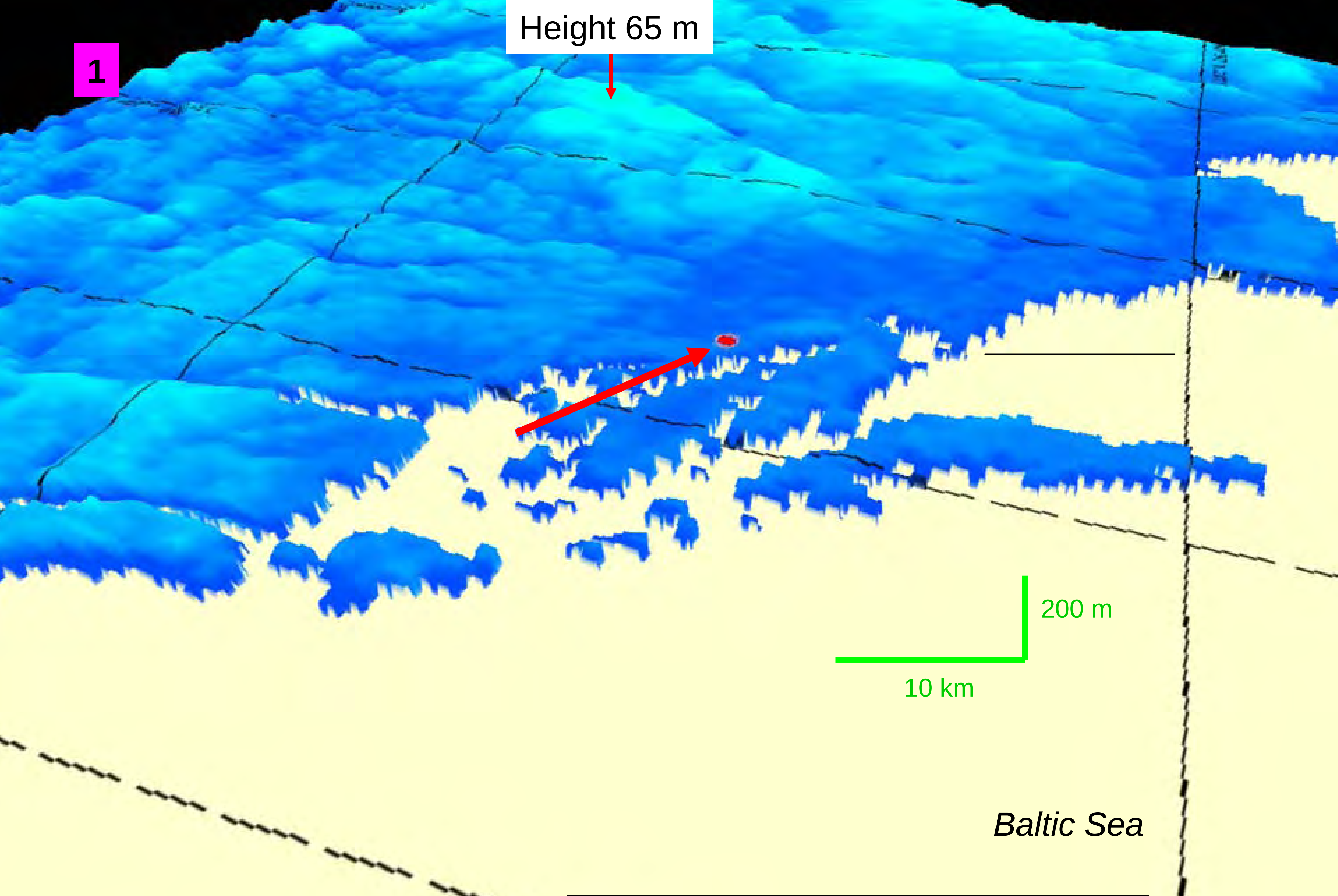


Fig. 4.2.4. Östhammar, Sweden.
Low relief coastal crystalline rocks

Perspective view looking west
Uniform scale and vertical exaggeration of relief

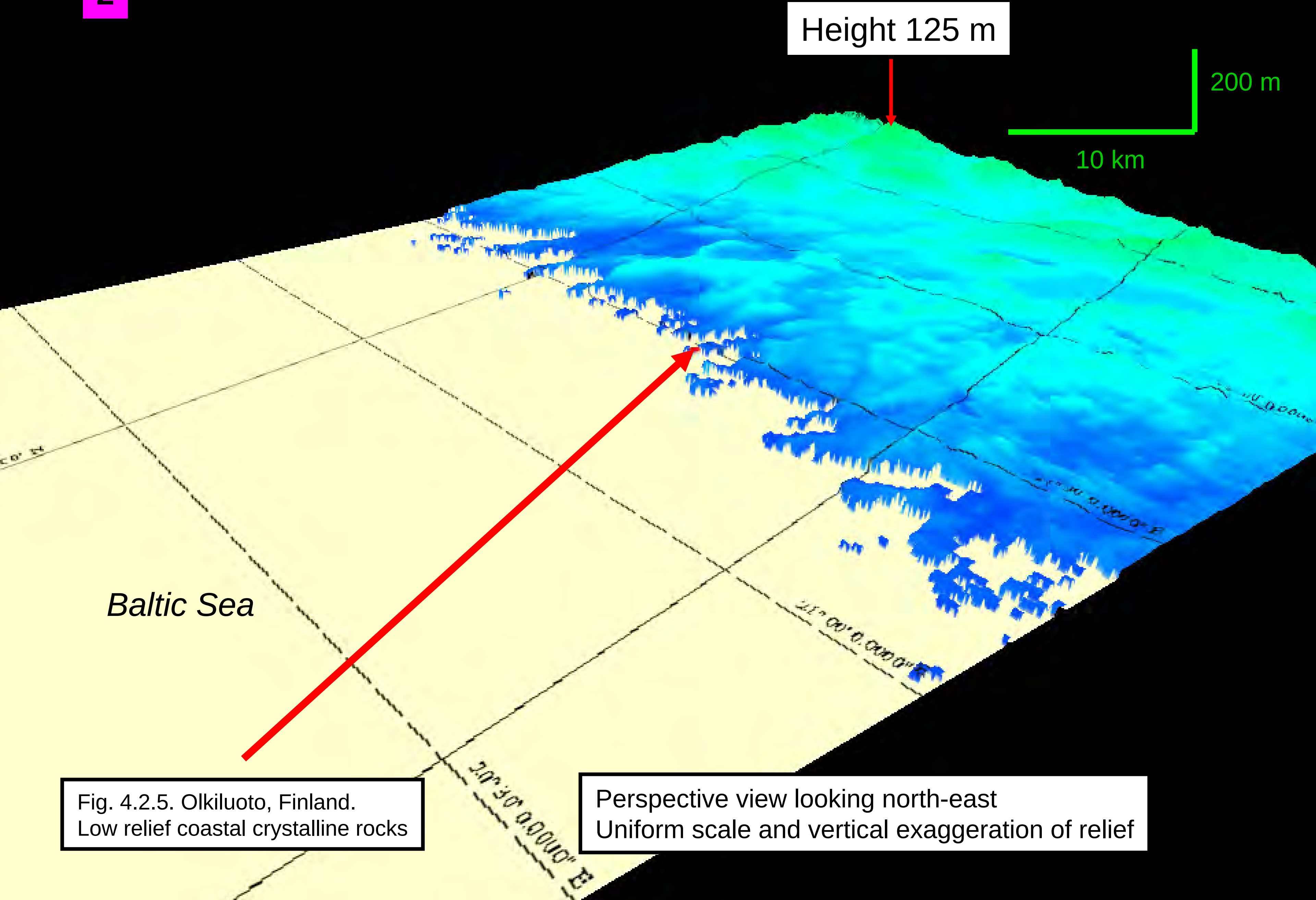


Fig. 4.2.5. Olkiluoto, Finland.
Low relief coastal crystalline rocks

Perspective view looking north-east
Uniform scale and vertical exaggeration of relief

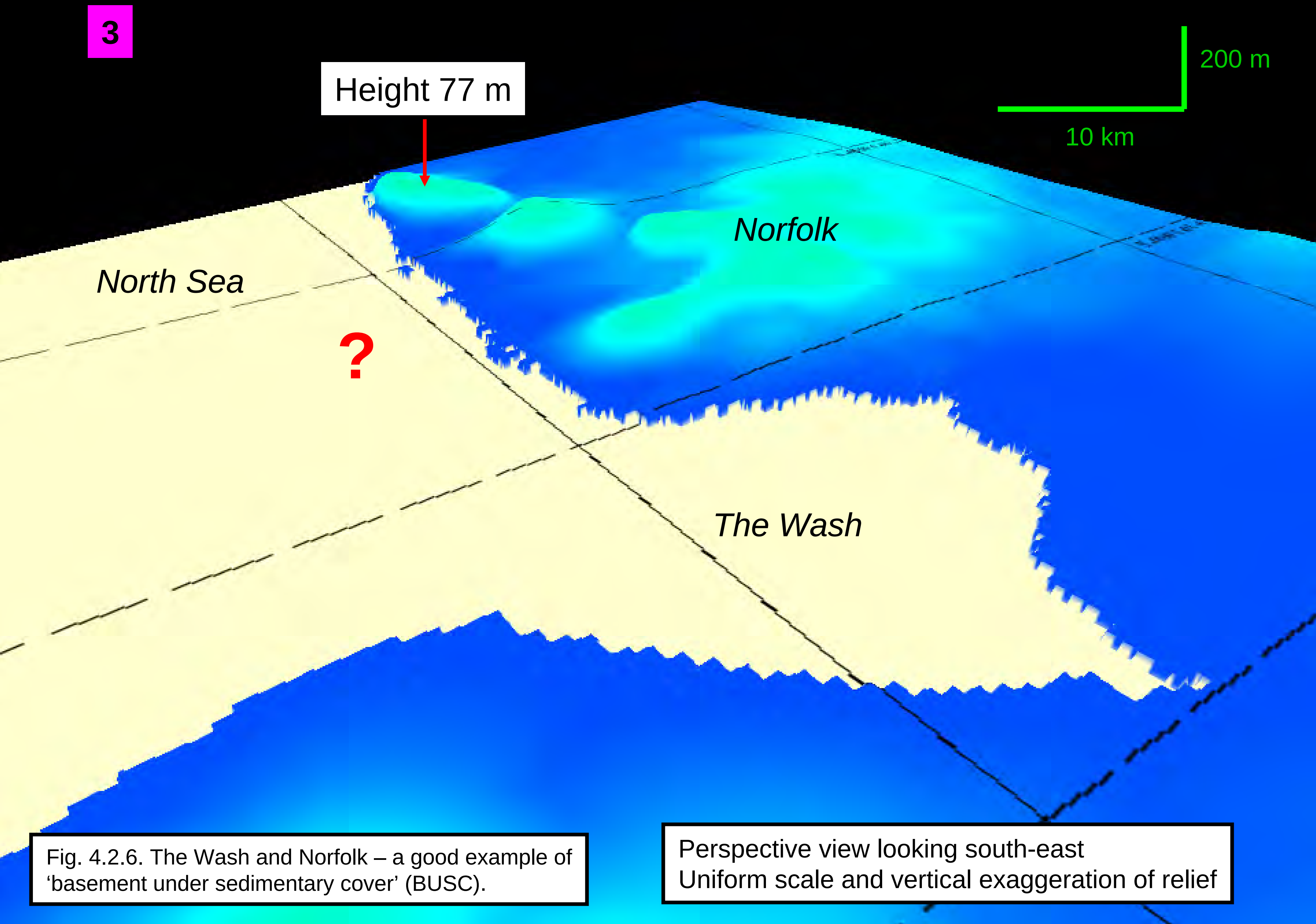


Fig. 4.2.6. The Wash and Norfolk – a good example of ‘basement under sedimentary cover’ (BUSC).

Perspective view looking south-east
Uniform scale and vertical exaggeration of relief

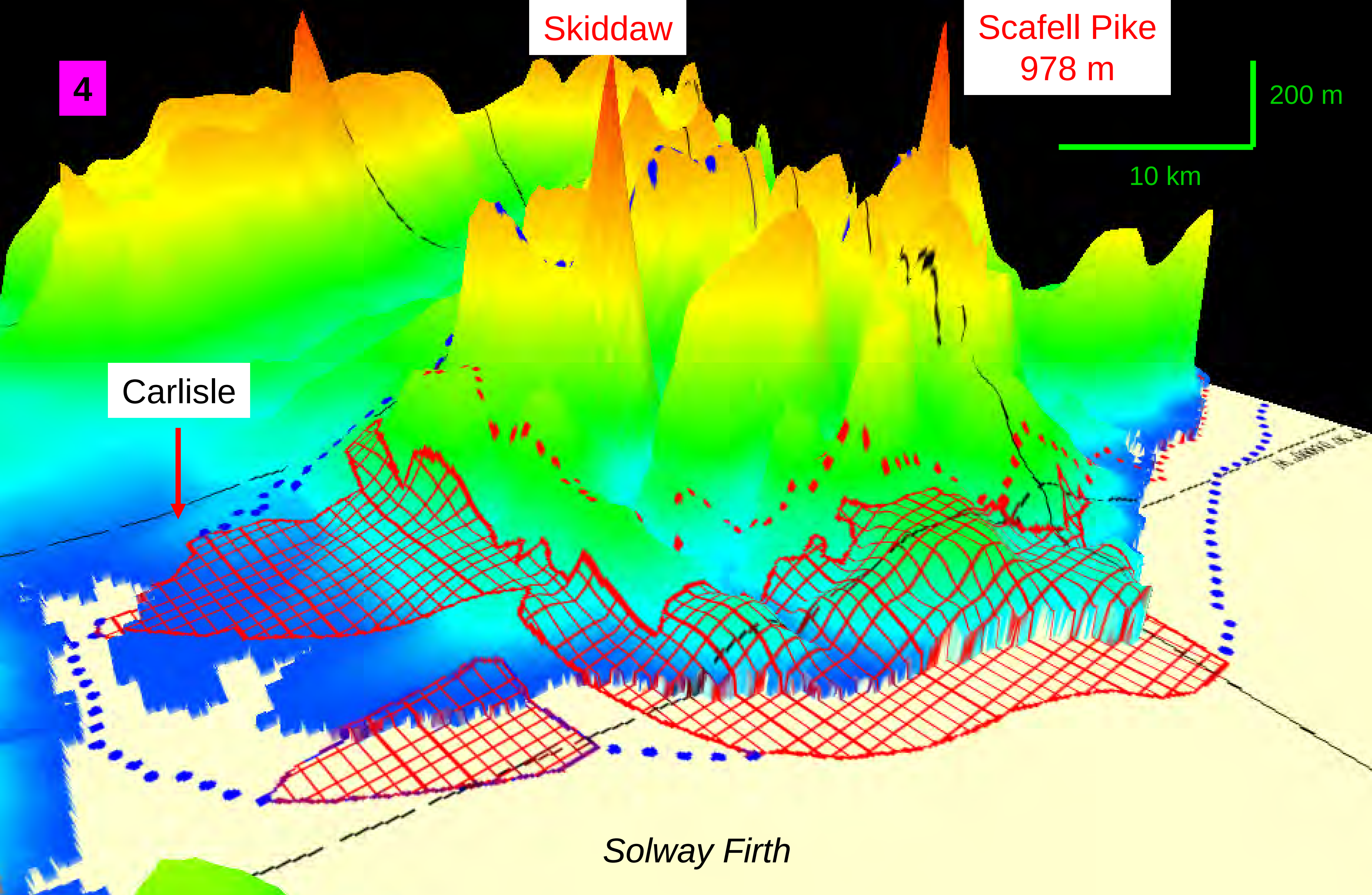


Fig. 4.2.7. West Cumbria :
Pseudo-BUSC and
high relief crystalline rocks.

Perspective view looking south-east
Uniform scale and same vertical exaggeration of relief as previous views

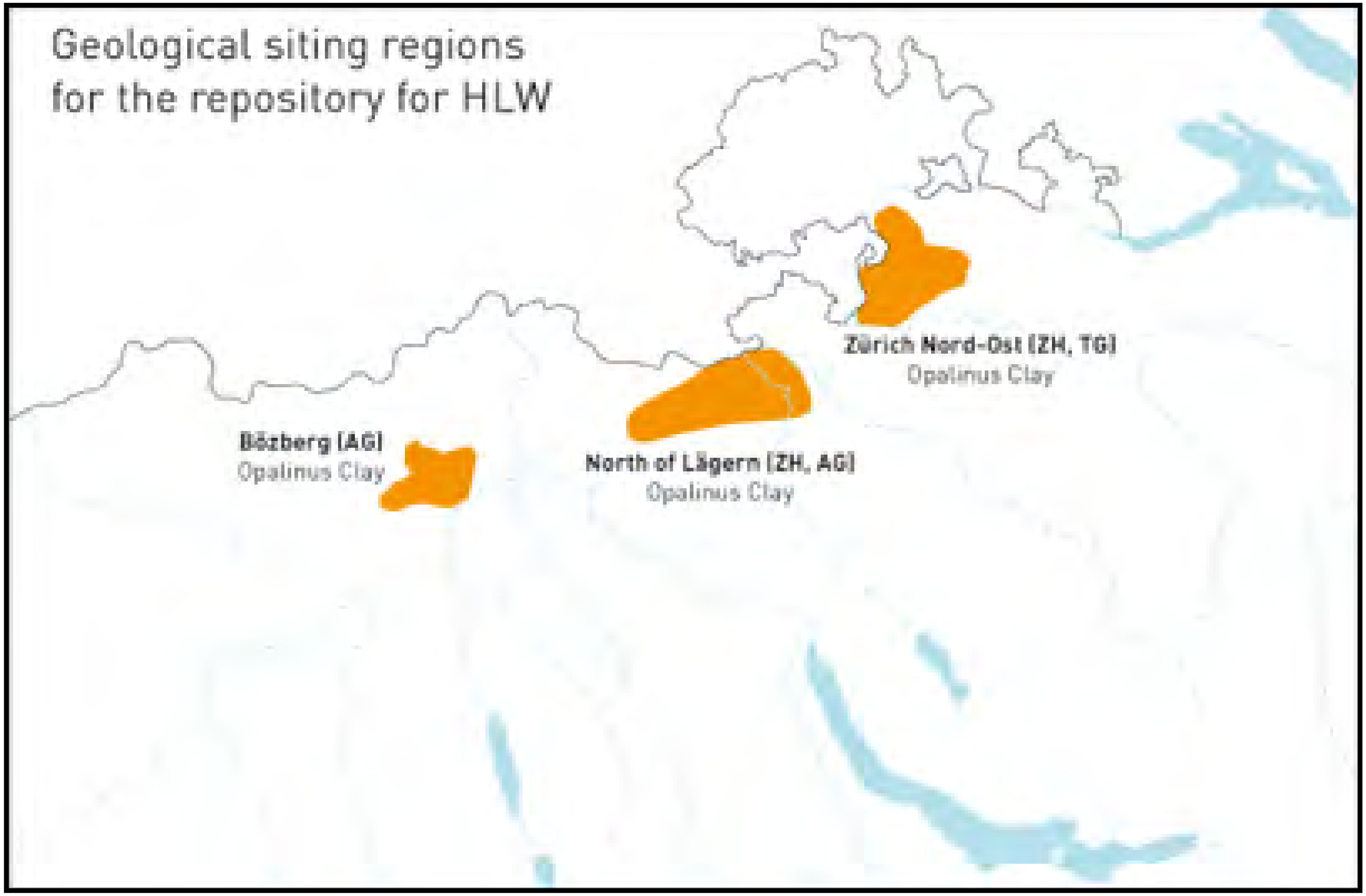
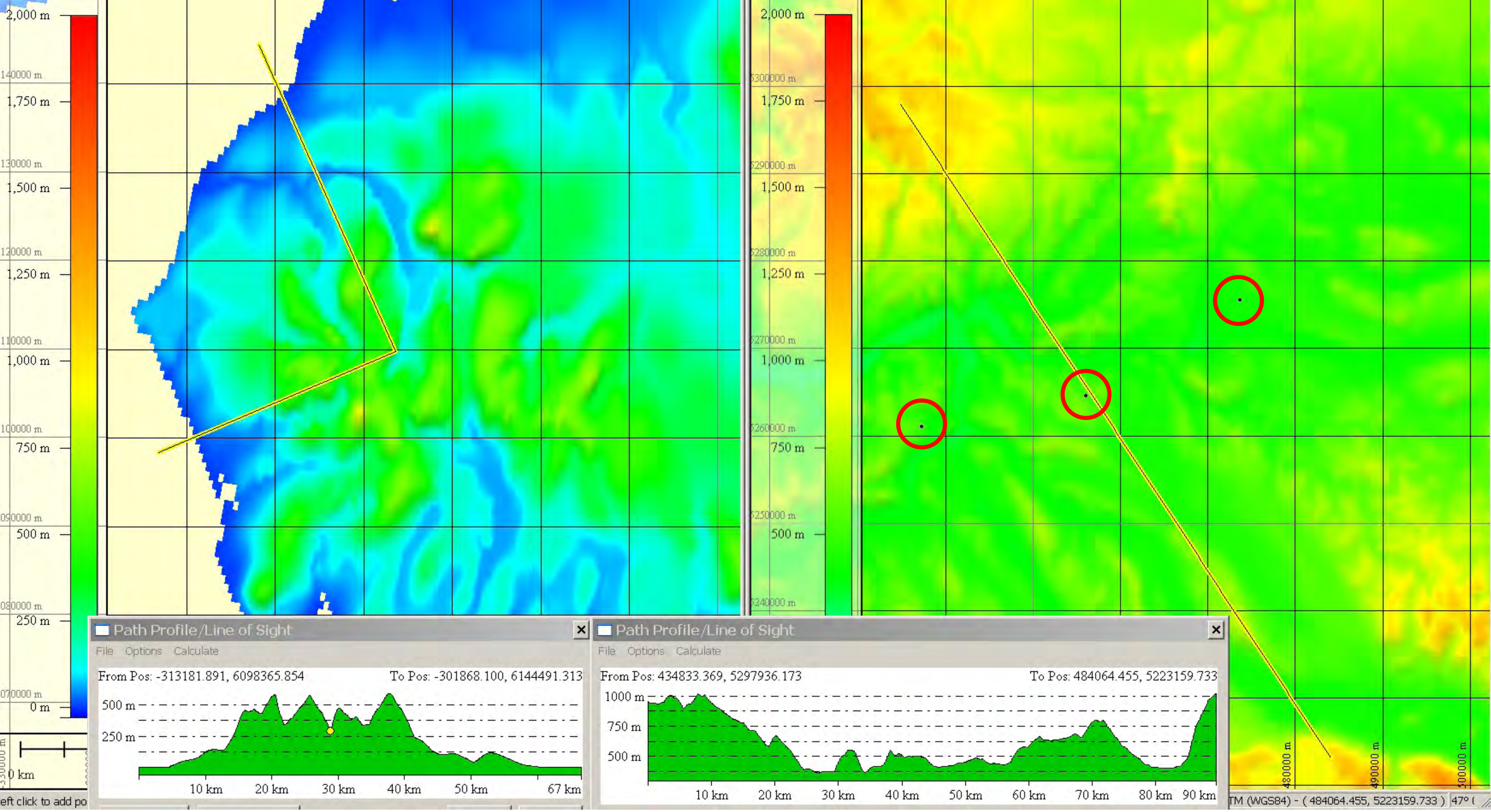


Fig. 4.2.8. Nagra map of the north of Switzerland, showing the three potential sites in buff colour. These three areas correspond to the zones shown in diagonal green and black stripes shown in Figure 3.6.7 above. The wiggly line is the border with Germany. All three sites are in Opalinus Clay.



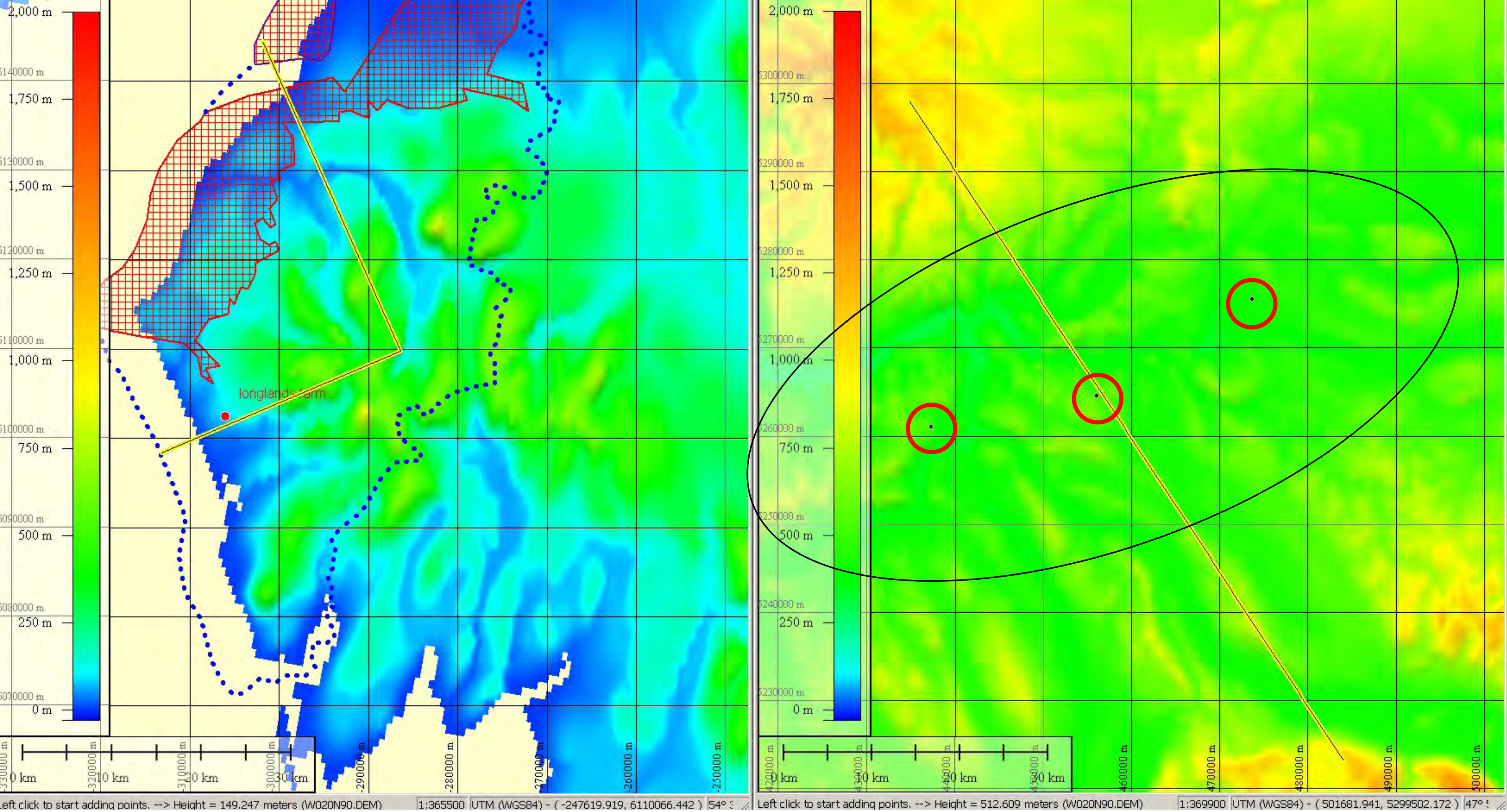
From Pos: -313181.891, 6098365.854 To Pos: -301868.100, 6144491.313

From Pos: 434833.369, 5297936.173 To Pos: 484064.455, 5223159.733

TM (WGS84) - (484064.455, 5223159.733) 47° (

Fig. 4.2.9. Topographic relief maps of West Cumbria (left) and northern Switzerland (right) at the same scale.

Grid squares are 10 km. The dogleg profile shown on the Cumbrian map runs from 5 km offshore through the former Sellafield potential repository zone, then turns NW to run along the BGS line of section through Cockermouth, finishing 5 km offshore.
The NW-SE profile on the Swiss map runs through the middle of the three potential high-level waste repository sites identified here (red circles mark the centre of each area).



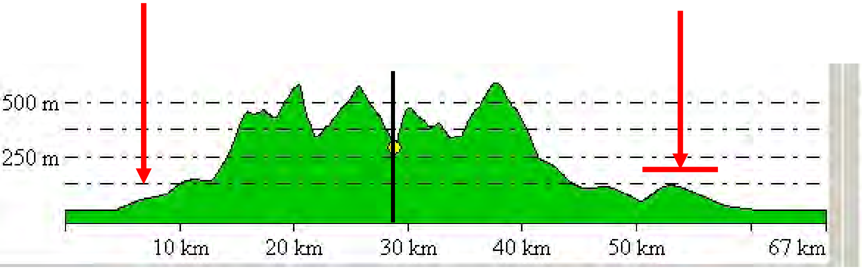
Left click to start adding points. --> Height = 149.247 meters (W020N90.DEM) | 1:365500 | UTM (WGS84) - (-247619.919, 6110066.442) | 54°

Left click to start adding points. --> Height = 512.609 meters (W020N90.DEM) | 1:369900 | UTM (WGS84) - (501681.941, 5299502.172) | 47°

Fig. 4.2.10. The 2000 sq km of available West Cumbria land, represented as an ellipse of around the same area on the Swiss map enclosing the three potential sites.

This shows that the relief variation within that ellipse is under 200 m, taken from any one of the three sites. This relief variation is a half or a quarter of the Cumbrian equivalent.

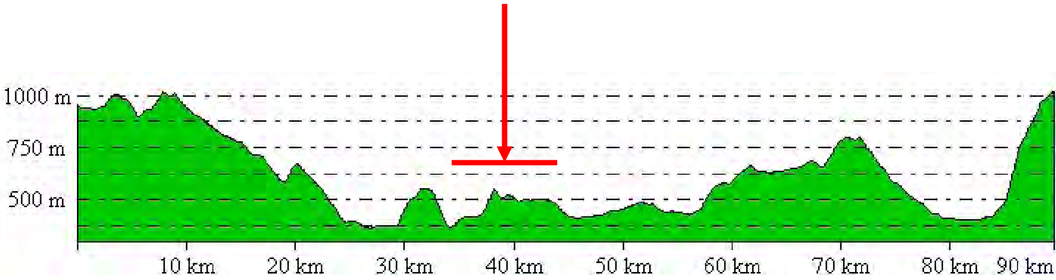
Note that the region outlined by the ellipse has similar topography to eastern England.



Longlands Farm

Limestone belt

West Cumbria



Three sites

Northern Switzerland

Fig. 4.2.11. The regional relief profiles show that potential sites in West Cumbria are much nearer the mountainous area than are the potential sites in Switzerland.

The West Cumbria dog-leg profile does not run through the highest peaks, which would add a further 300 m to the profile vertically, but is laid out to follow published Nirex geological profiles through Longlands Farm, the 1995 Potential Repository Zone, then to run NW along the cross-section published by the BGS.

So in Switzerland Nagra appears to have found three suitable sites within a strip of relatively gentle terrain about 50 km wide. In contrast, the lower flanks of the Cumbrian mountains available for a repository are only 10-15 km wide.

Fig. 4.3.1. Region, District and Site, as defined by Nirex in West Cumbria, from Nirex (1997b).

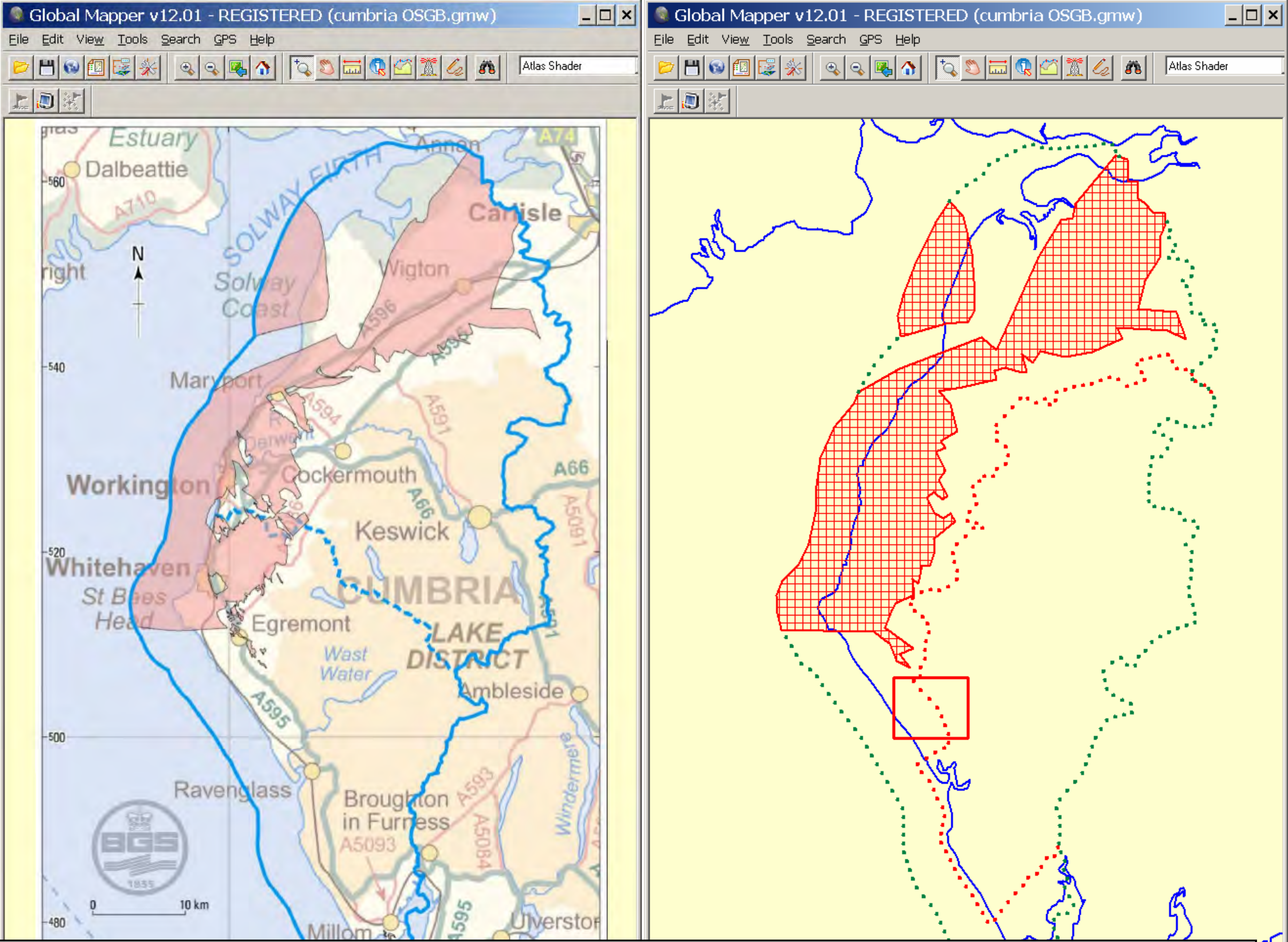
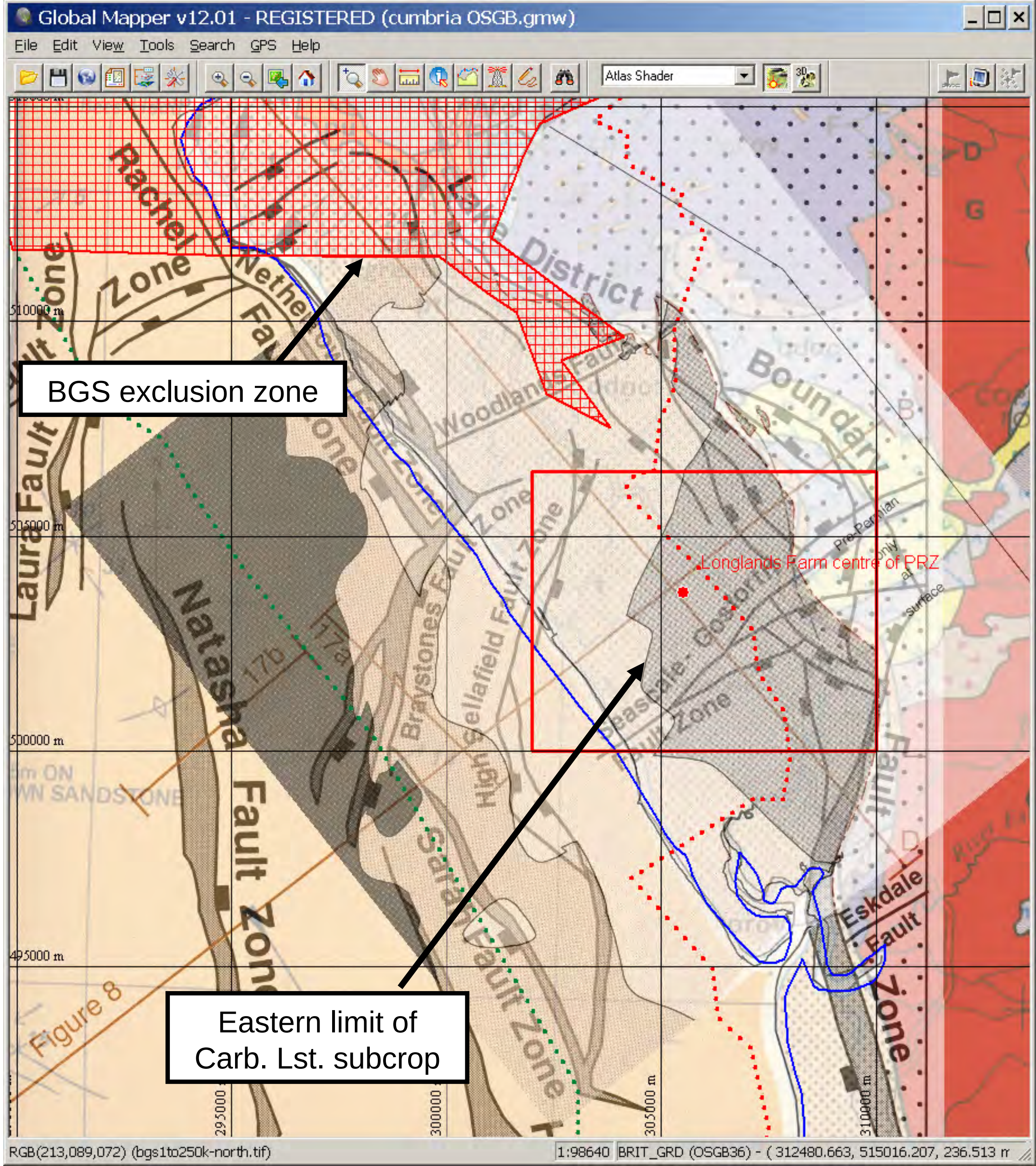


Fig. 4.3.2. Digitised outlines (right) compared with the BGS overview map (left). The green dotted outline is the area of Copeland and Allerdale District Councils; red dots show the National Park boundary within this area, and red square hatching shows the BGS exclusion areas. The Site rectangle (solid red outline) has been added from Figure 4.3.1.

Fig. 4.3.3. Geology and faulting around the Nirex site (red rectangle). Longlands Farm, site of the PRZ, is shown by the red dot. Red cross-hatching shows the southern margin of the BGS exclusion zone.



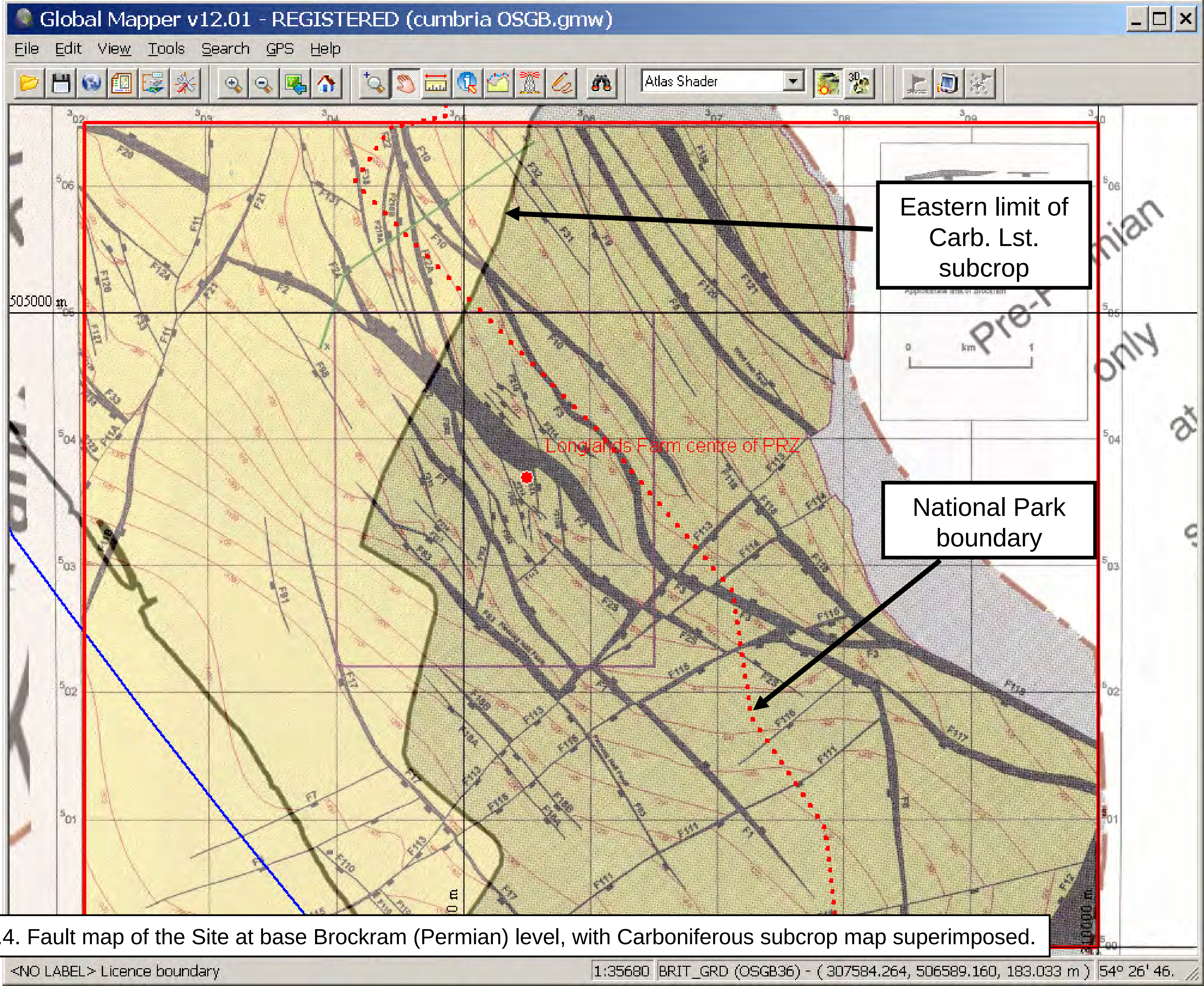
Longlands Farm centre of PRZ

BGS exclusion zone

Eastern limit of Carb. Lst. subcrop

RGB(213,089,072) (bgs1to250k-north.tif)

1:98640 BRIT_GRD (OSGB36) - (312480.663, 515016.207, 236.513 m



<NO LABEL> Licence boundary

1:35680 BRIT_GRD (OSGB36) - (307584.264, 506589.160, 183.033 m) 54° 26' 46.

Fig. 4.3.4. Fault map of the Site at base Brockram (Permian) level, with Carboniferous subcrop map superimposed.

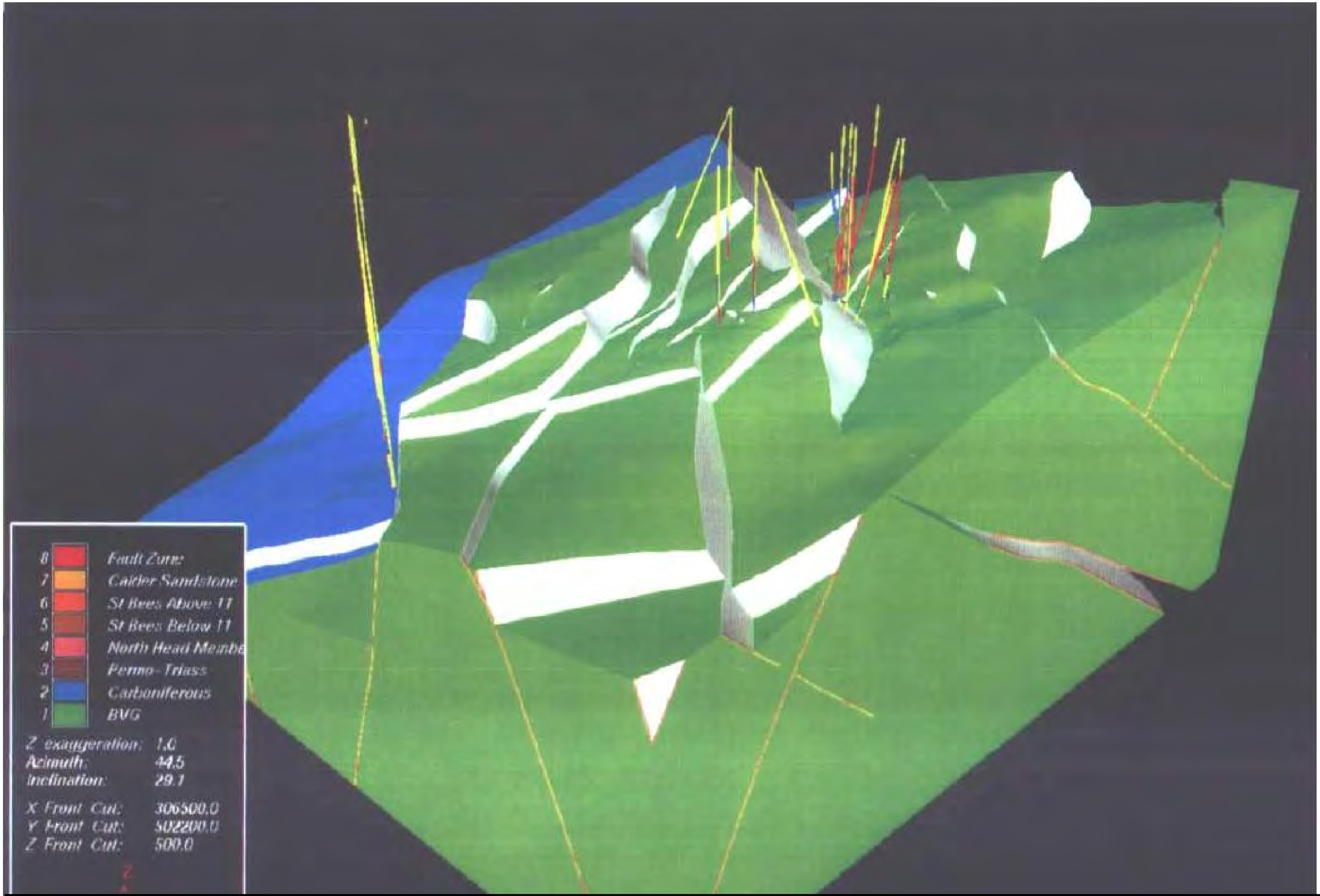
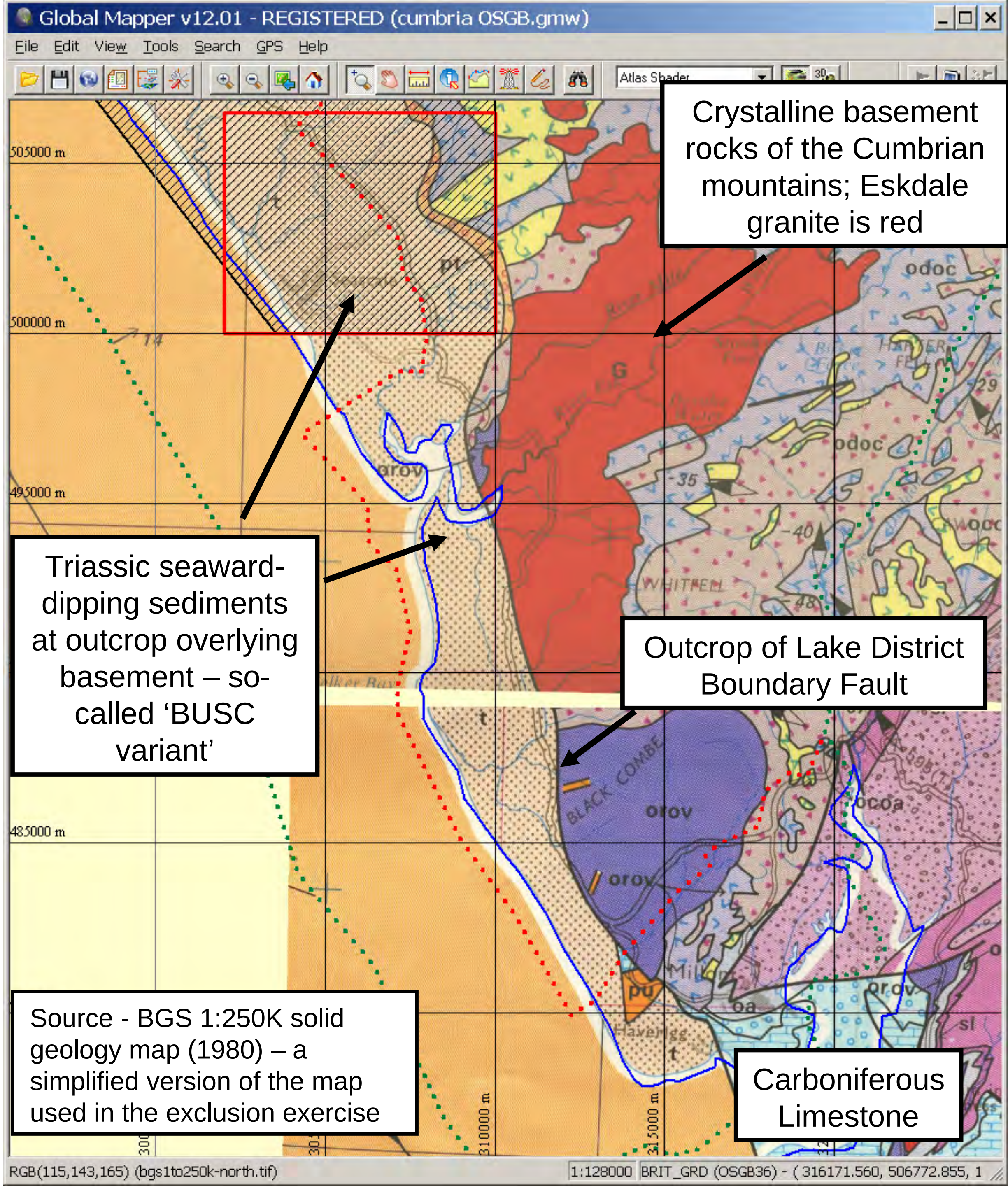


Fig. 4.3.5. Three-dimensional model of the structure at base Permo-Triassic of the PRZ (Nirex 1997f, fig. 14). The view is looking to the NW, and there is no vertical exaggeration. The Permo-Triassic has been removed to leave just the Carboniferous (blue) and repository host rock, the Borrowdale Volcanic Group (BVG – green). The sticks are the boreholes.



Crystalline basement rocks of the Cumbrian mountains; Eskdale granite is red

Triassic seaward-dipping sediments at outcrop overlying basement – so-called 'BUSC variant'

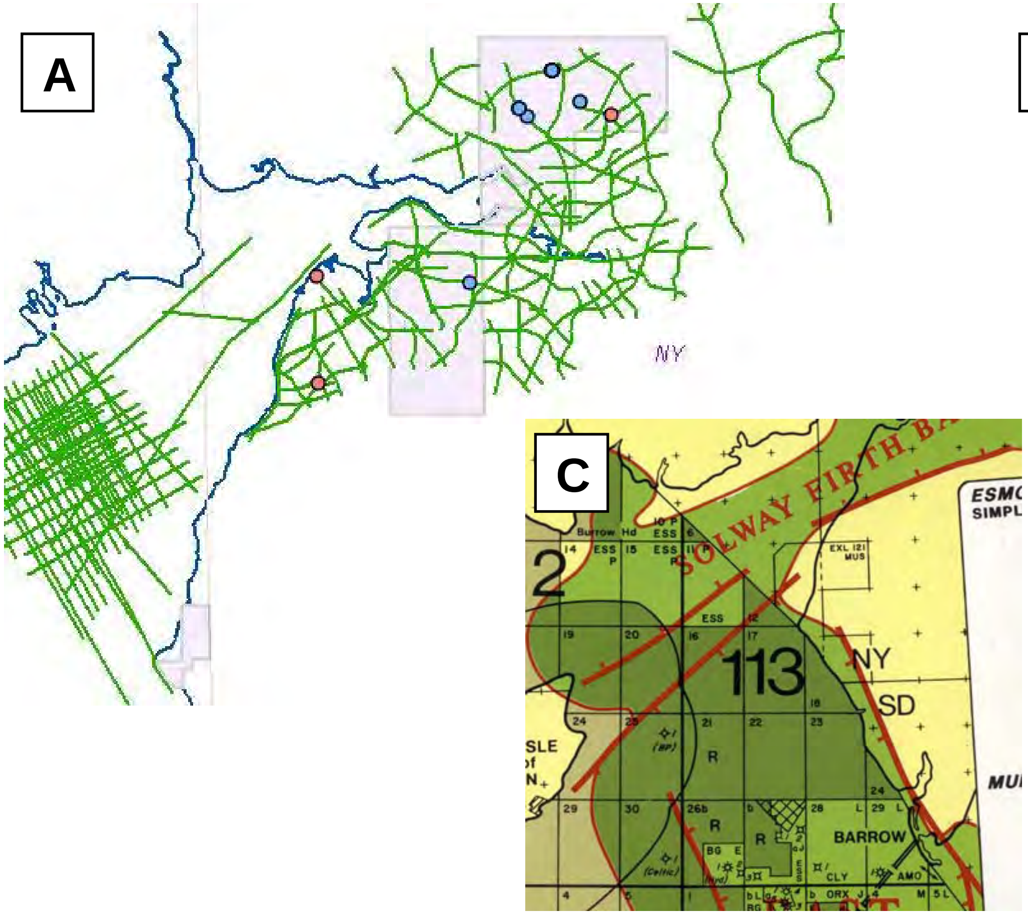
Outcrop of Lake District Boundary Fault

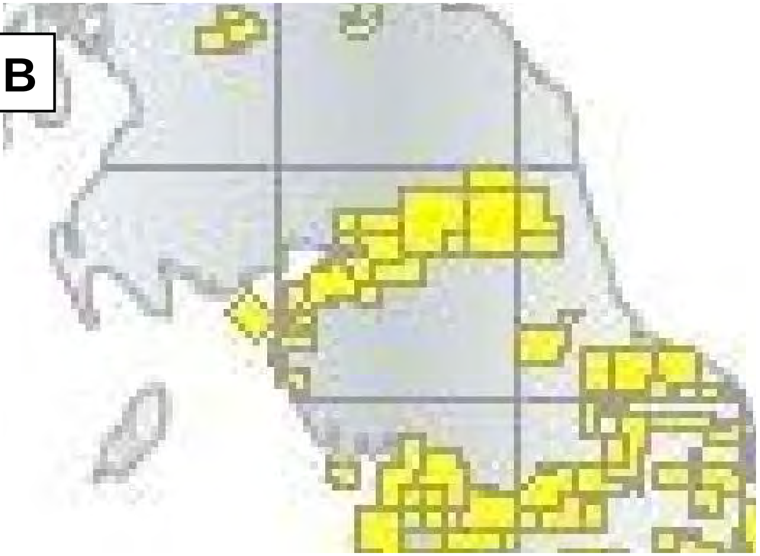
Source - BGS 1:250K solid geology map (1980) – a simplified version of the map used in the exclusion exercise

Carboniferous Limestone

```
RGB(115,143,165) (bgs1to250k-north.tif)        1:128000 BRIT_GRD (OSGB36) - ( 316171.560, 506772.855, 1
```

Fig. 4.3.6. Coastal geology south of the Site (red rectangle). In addition to the coastal sedimentary strip, the possibility of placing a site in the Eskdale granite is discussed.





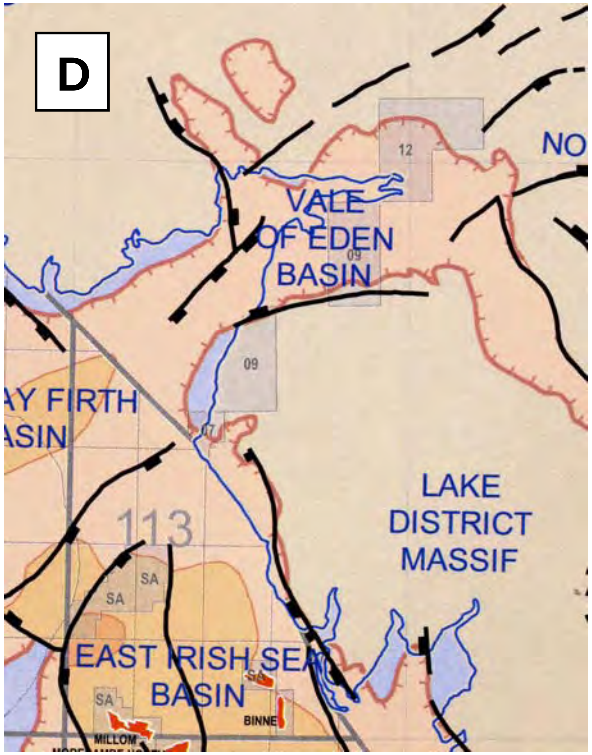
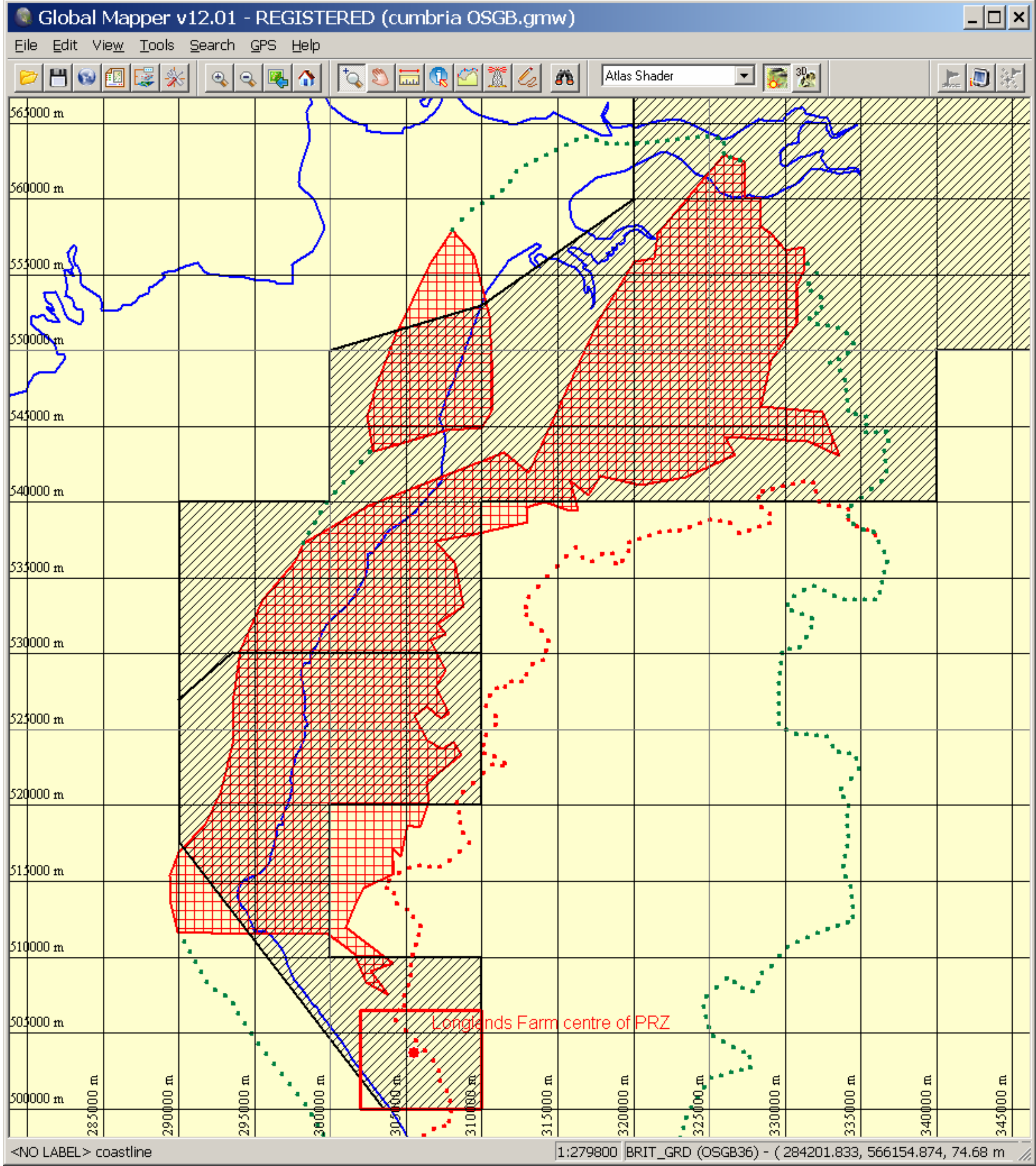


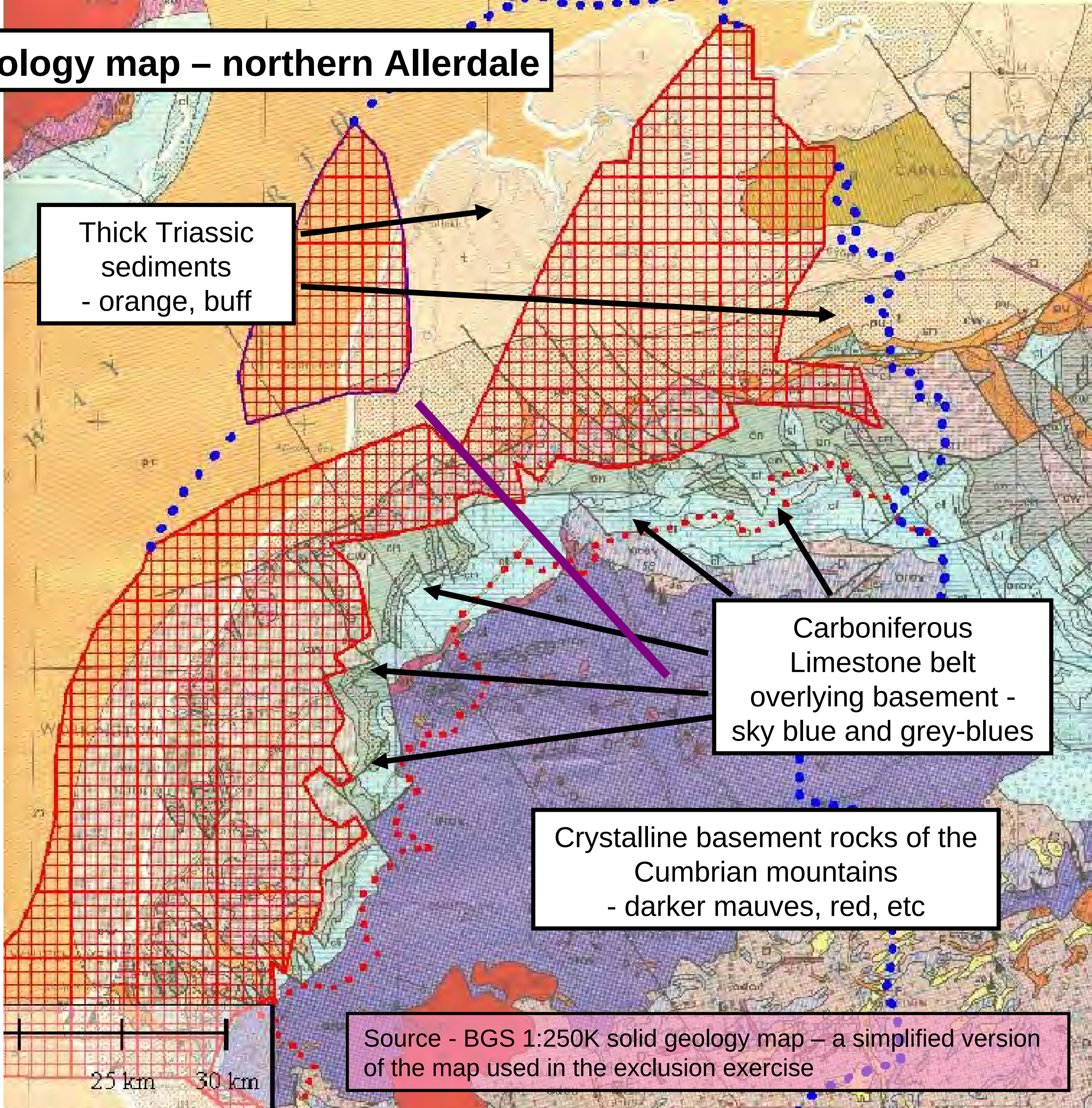
Fig. 4.4.1. Medley of maps showing exploration activity at different epochs in northern Allerdale.

A. DECC map (2011) showing available seismic profiles (green), exploration wells (red and blue dots) and current licensed areas (grey).
B. Historically licensed areas in the north of England (yellow).
C. PESGB map (1994) showing Mustang Resources exploration licence. extending south from Workington into the Sellafield Site quadrant.
D. PESGB map (2007) showing licences (grey).

Fig. 4.4.2. BGS exclusion area (red hatching) with the total area of former or current hydrocarbon exploration licences superimposed (diagonal ruling).



BGS 1:250,000 geology map – northern Allerdale



Thick Triassic sediments
- orange, buff

Carboniferous Limestone belt overlying basement - sky blue and grey-blues

Crystalline basement rocks of the Cumbrian mountains
- darker mauves, red, etc

Source - BGS 1:250K solid geology map – a simplified version of the map used in the exclusion exercise

Fig. 4.4.3. Guide to the geology of northern Allerdale. Purple line is the approximate location of the cross-section shown in the next but one diagram.

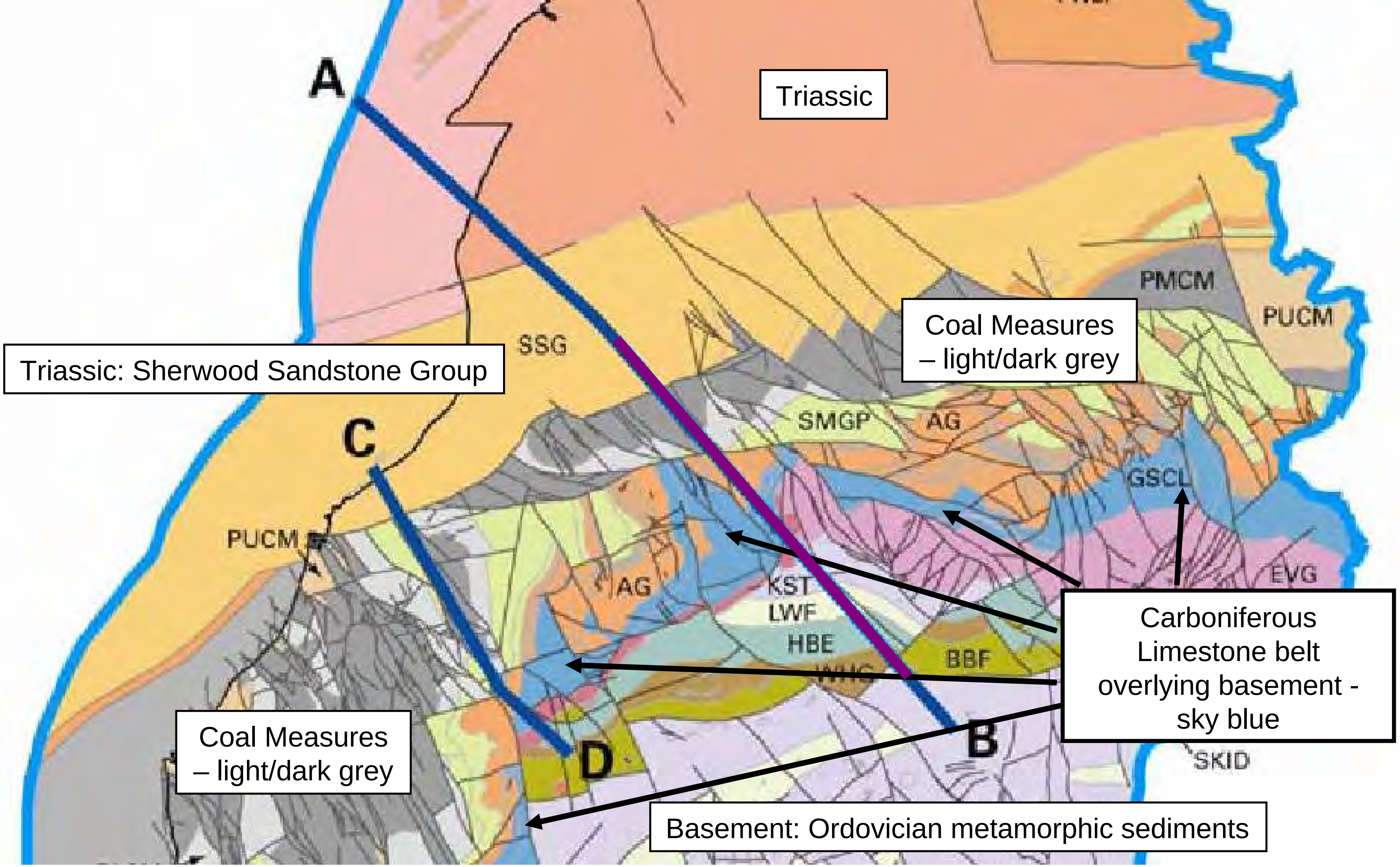
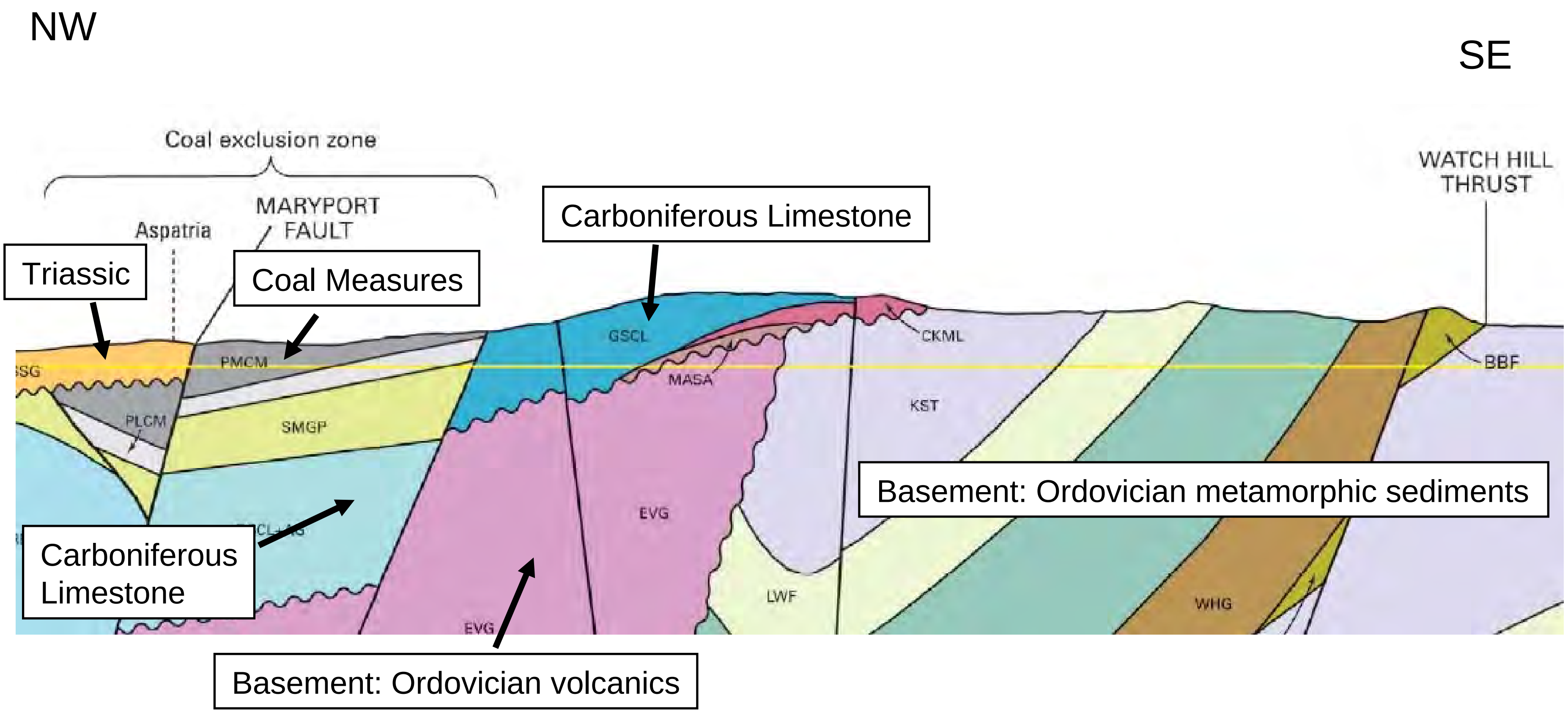


Fig. 4.4.4. Geology of northern Allerdale (extracted from the geology map of the BGS screening report (2010, fig. 8). The colour coding of the formations is somewhat different from that of the BGS 1:250,000 scale map used in the previous diagrams. A cross-section along the purple segment of line AB is shown in the next figure.



NW

SE

Triassic

Coal Measures

Carboniferous Limestone

Carboniferous Limestone

Basement: Ordovician metamorphic sediments

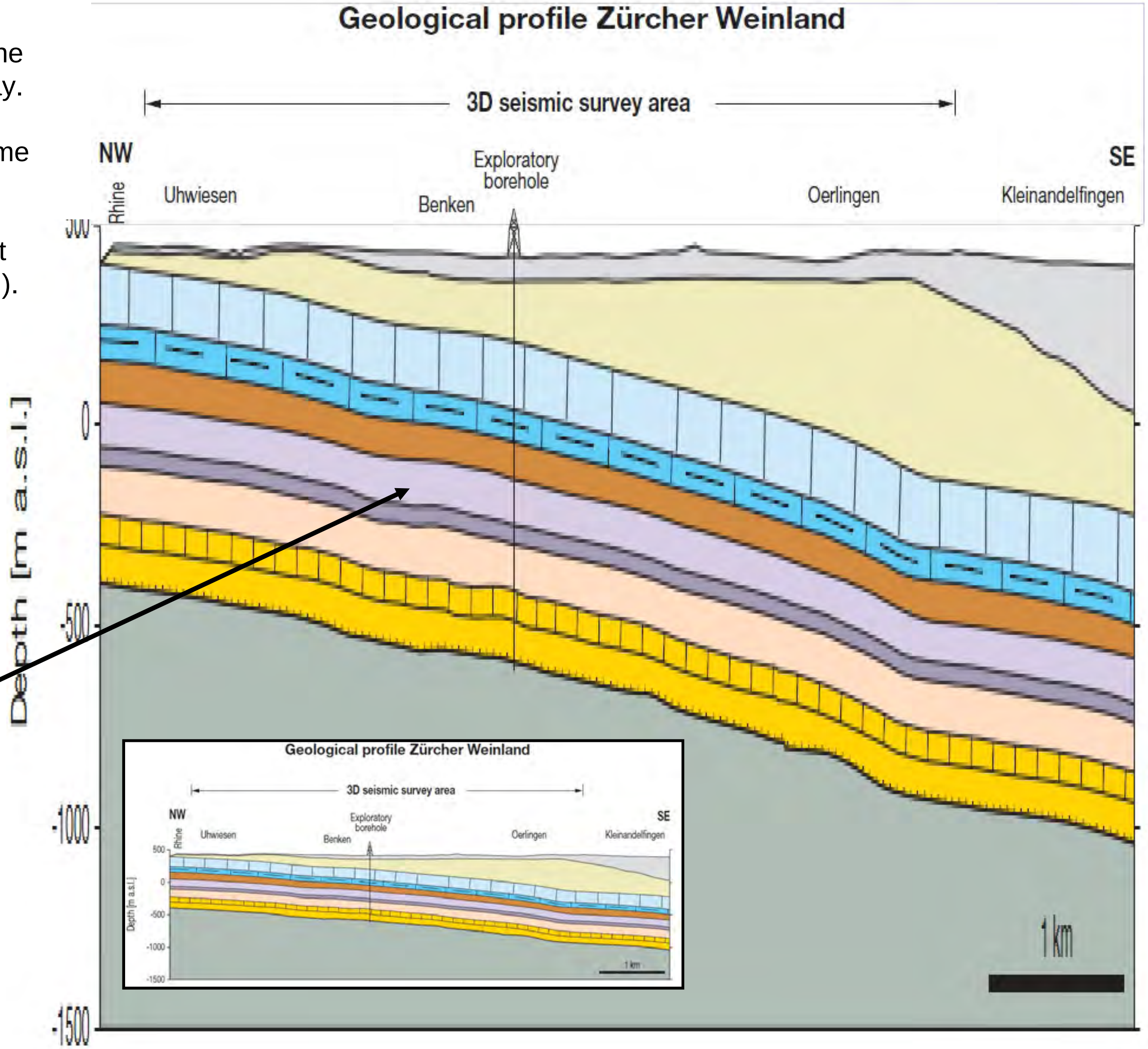
Basement: Ordovician volcanics

Fig. 4.4.5. Cross-section AB, extracted from BGS screening report [BGS 2010, fig. 9] (located in the two previous diagrams). Vertical scale 3x horizontal. Sea level – yellow line; base of section at 1500 m. Faults are denoted by solid lines, unconformities by wavy lines.

Fig. 4.4.6. Cross-section from the proposed Swiss HLW site, where the target host rock is the Opalinus Clay.

Vertical scale 3x horizontal, the same as the previous diagram.

The inset shows the same profile at true scale (no vertical exaggeration).



Quaternary

- ▭ Unconsolidated rock

Tertiary

- ▭ Lower Freshwater Molasse

Mesozoic

- ▭ Upper Malm (Kimmeridgian)
- ▭ Lower Malm (Oxfordian)
- ▭ Upper Dogger
- ▭ Opalinus Clay
- ▭ Liassic
- ▭ Keuper
- ▭ Upper Muschelkalk
- ▭ Middle and Lower Muschelkalk, Buntsandstein

Basement

- ▭ Crystalline / Permo-Carboniferous

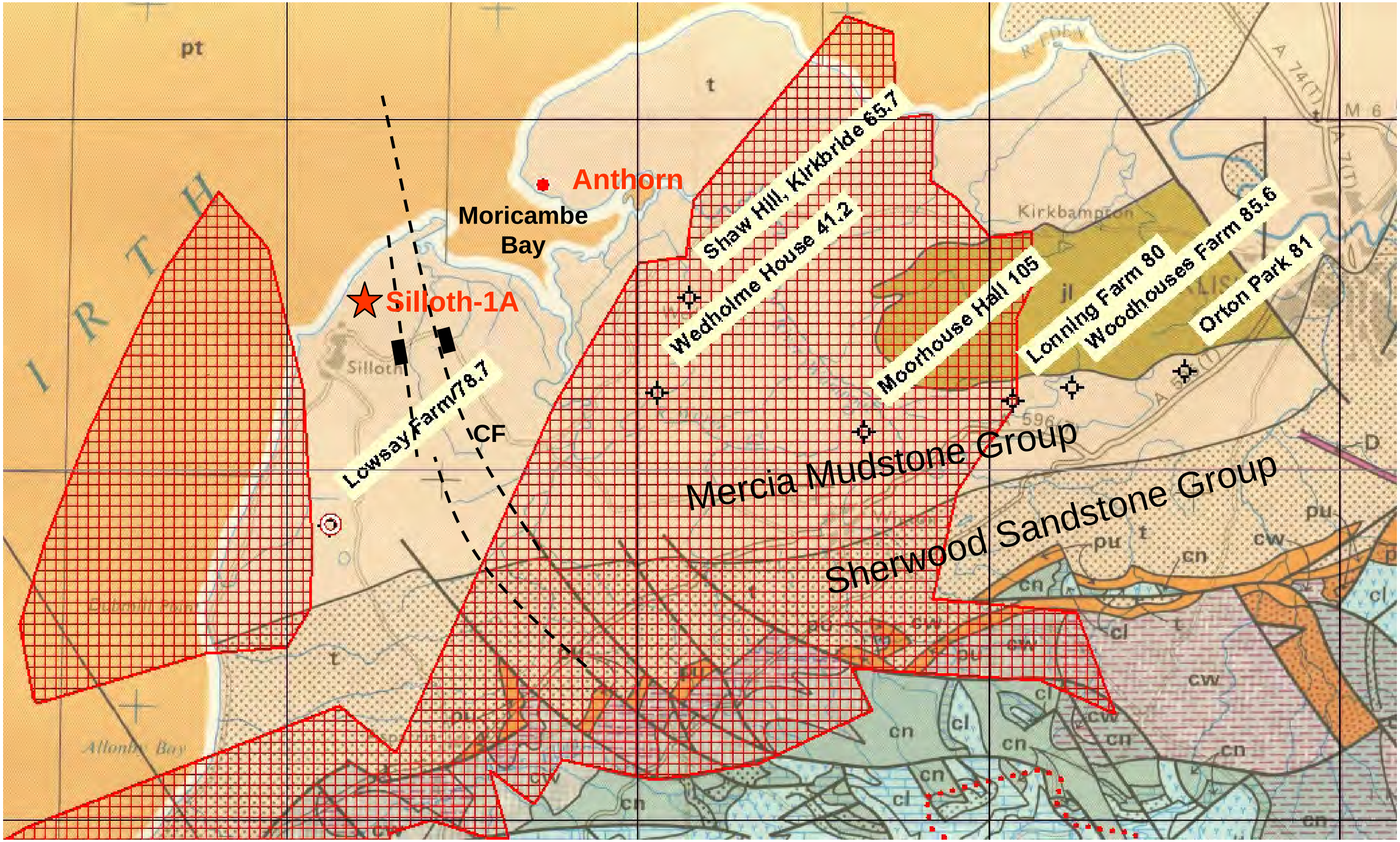


Fig. 4.7.1. Map of the northern Allerdale coastal plain, showing seven wells currently abstracting water from the Mercia Mudstone Group (MMG). Depths are given after the place names. BGS exclusion zones are shown in red cross-hatching. Geological basemap is the BGS 1:250K scale map Lake District Solid Geology, reprojected from UTM to OSGB grid. Buff colour is MMG; stippled buff is the Sherwood Sandstone Group. Anthorn is a potential repository site considered and rejected in the 1980s. Silloth-1A is an oil exploration well. The dashed lines are normal faults mapped in the subsurface with throws of the order of 100 m (Holliday et al. 2004); CF is the Crummock Fault.

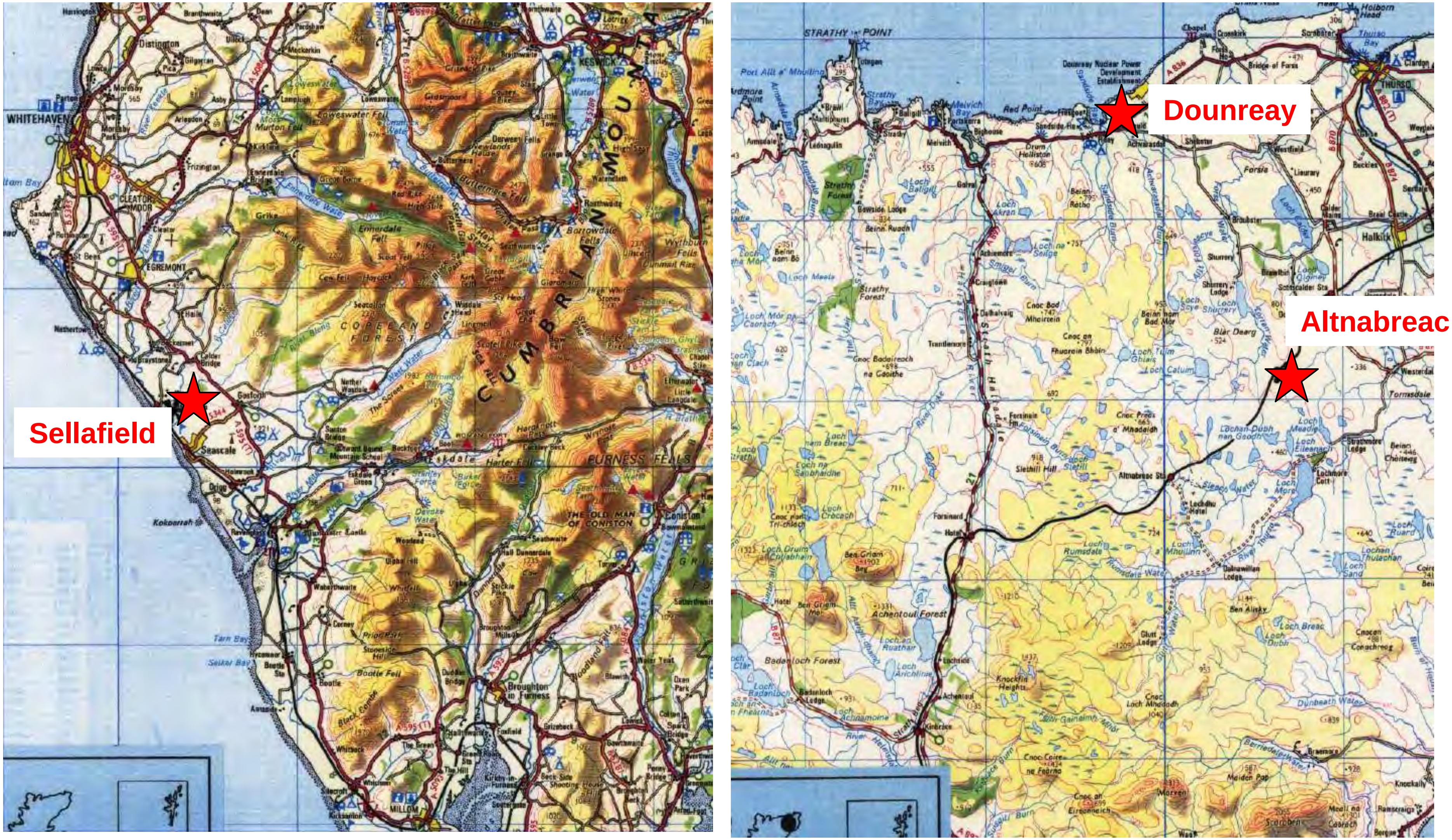


Fig. 4.8.1. Topography of Cumbria (left) and Sutherland (right) compared at the same scale. The latter is an area of low relief with two potential repository sites identified by the 1988 exercise, Altnabreac and Dounreay. Maps are taken from the Pieda site descriptions, and are shown at the same scale. The Sutherland sites are in areas of 'Hard rock with low relief'. In contrast, no hard rock location (e.g. Eskdale) can be found within the National Park area of Cumbria that has low relief.

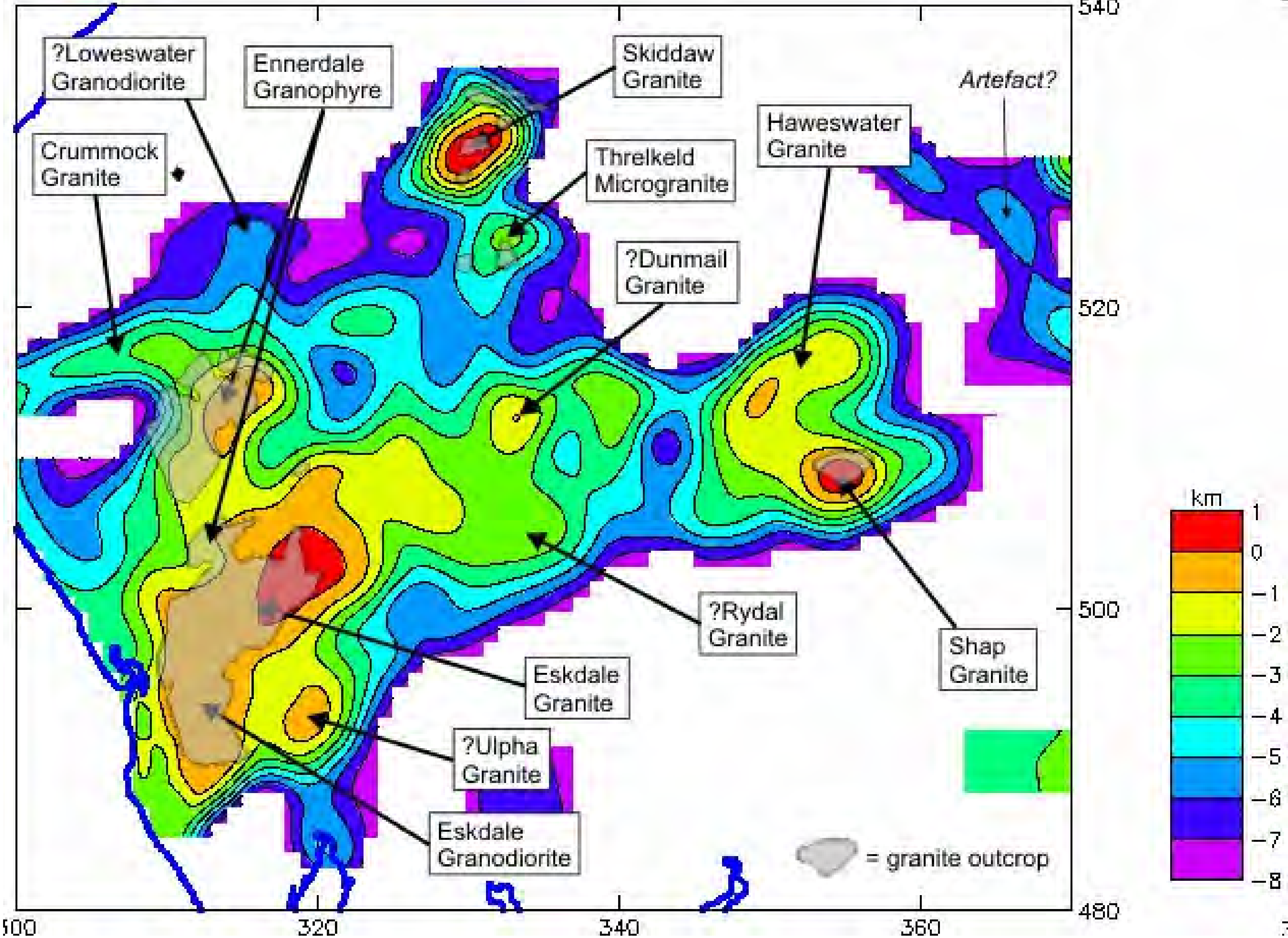


Fig. 4.8.2. Lake District: modelled depth of top of granite (relative to OD). From British Geological Survey (2006).

Fig. 4.8.3. 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 Kneller and Bell (1993).

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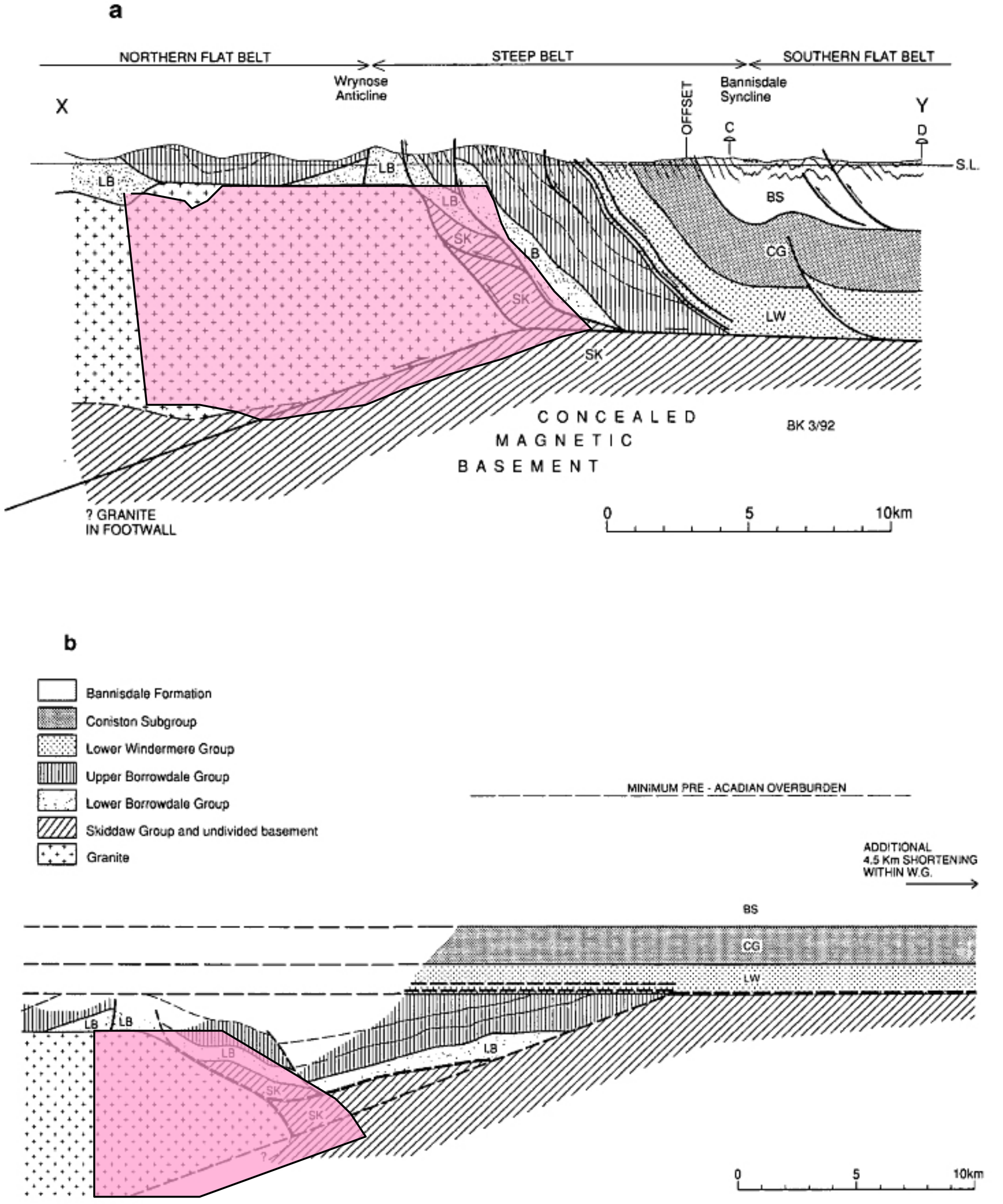


Figure 4. (a) Deep cross-section along the line shown on Figure 3. (b) Restored section. See text for discussion of construction and details of restoration. Upper Borrowdale Volcanic Group includes the Whorneyside Formation and above. Lower Windermere Group includes dominantly fine-grained late Caradoc (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.

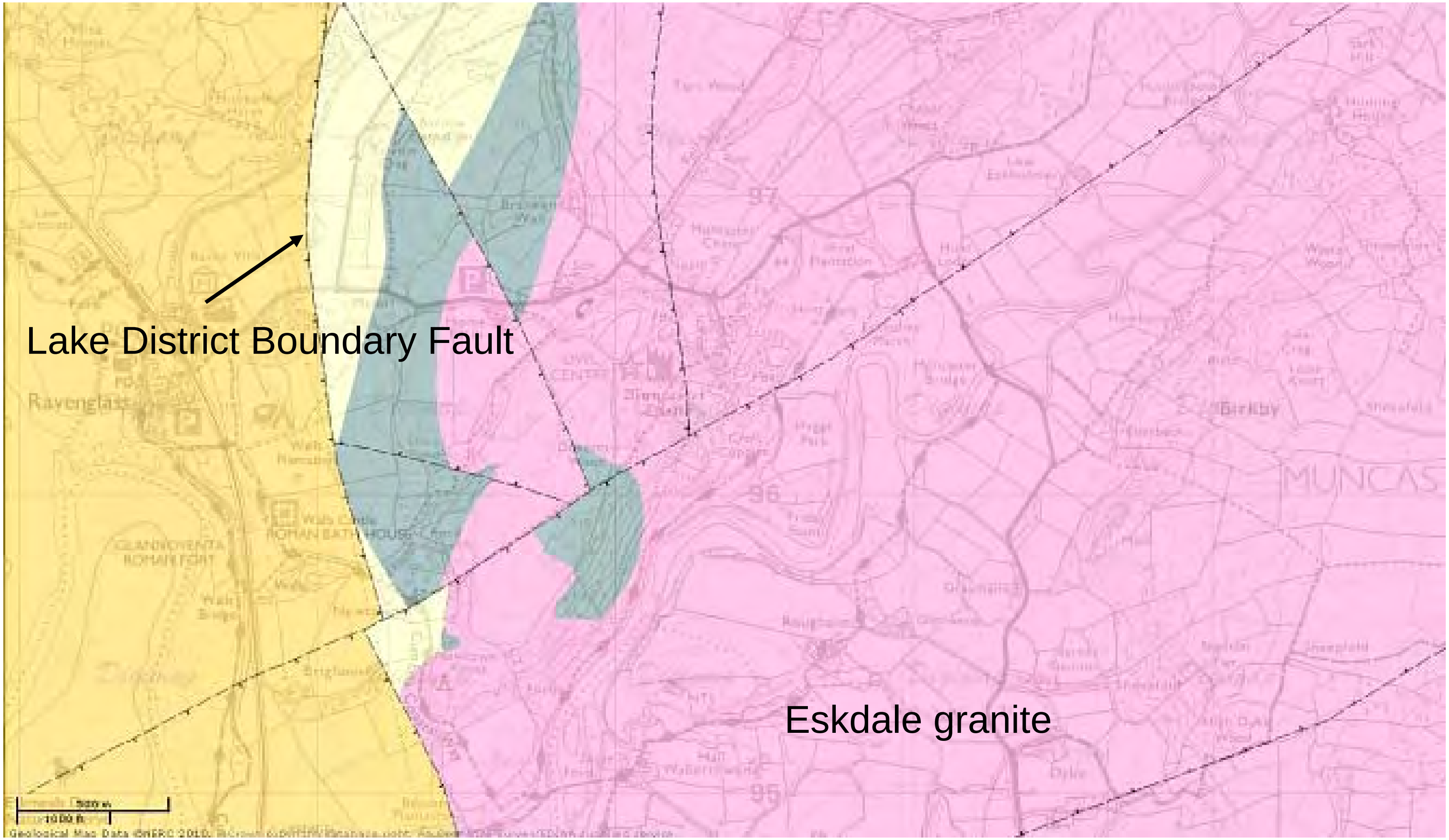


Fig. 4.8.4. Detail of the BGS solid geology map (1:50,000 scale) showing the outcrop of the Eskdale granite (pink). Faults are marked by dashed lines, with the tick-mark on the downthrown side.

‘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^2, the subsurface area required for a repository.

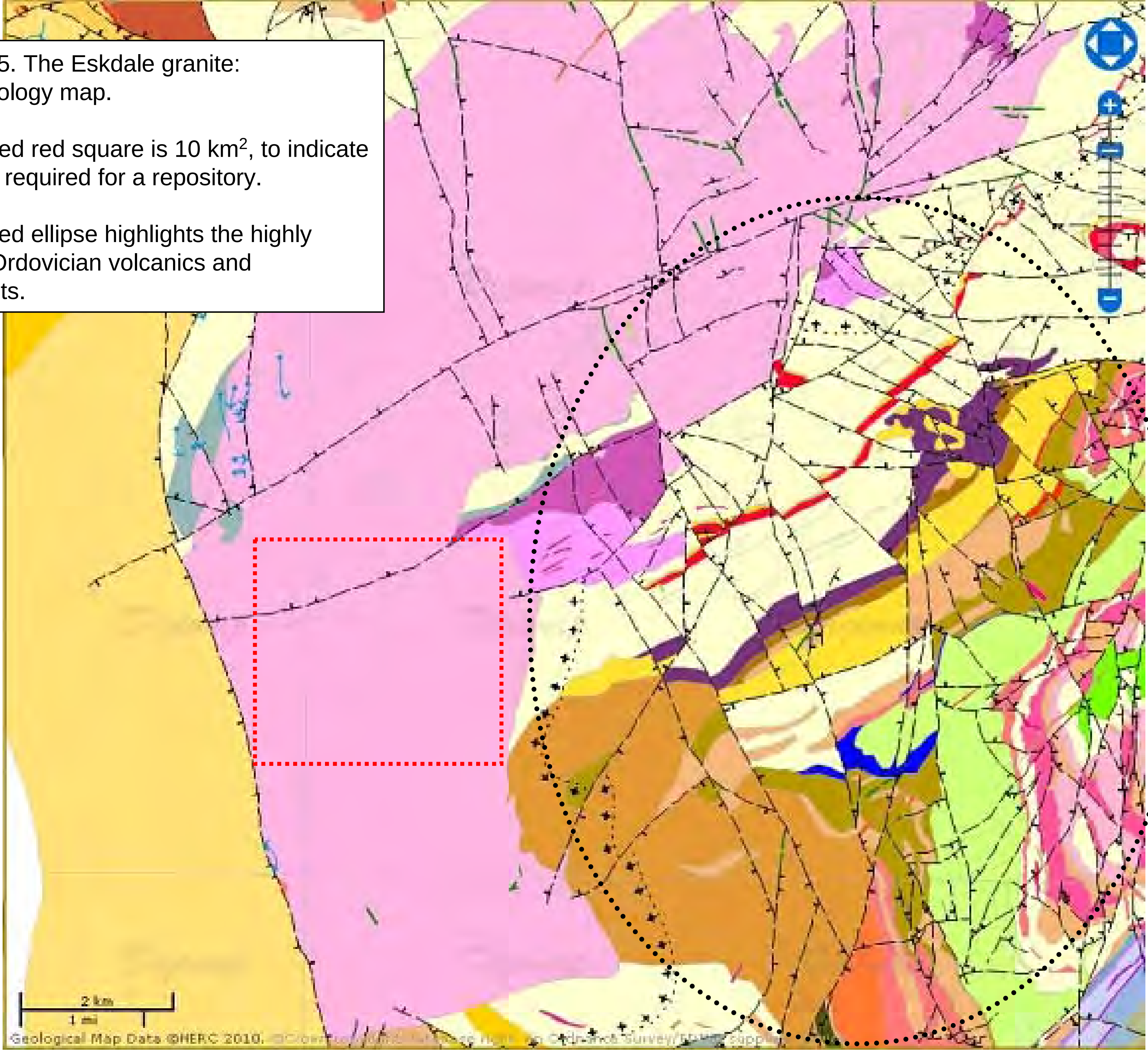


Fig. 4.8.5. The Eskdale granite:
Solid geology map.

The dotted red square is 10 km^2, to indicate the area required for a repository.

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

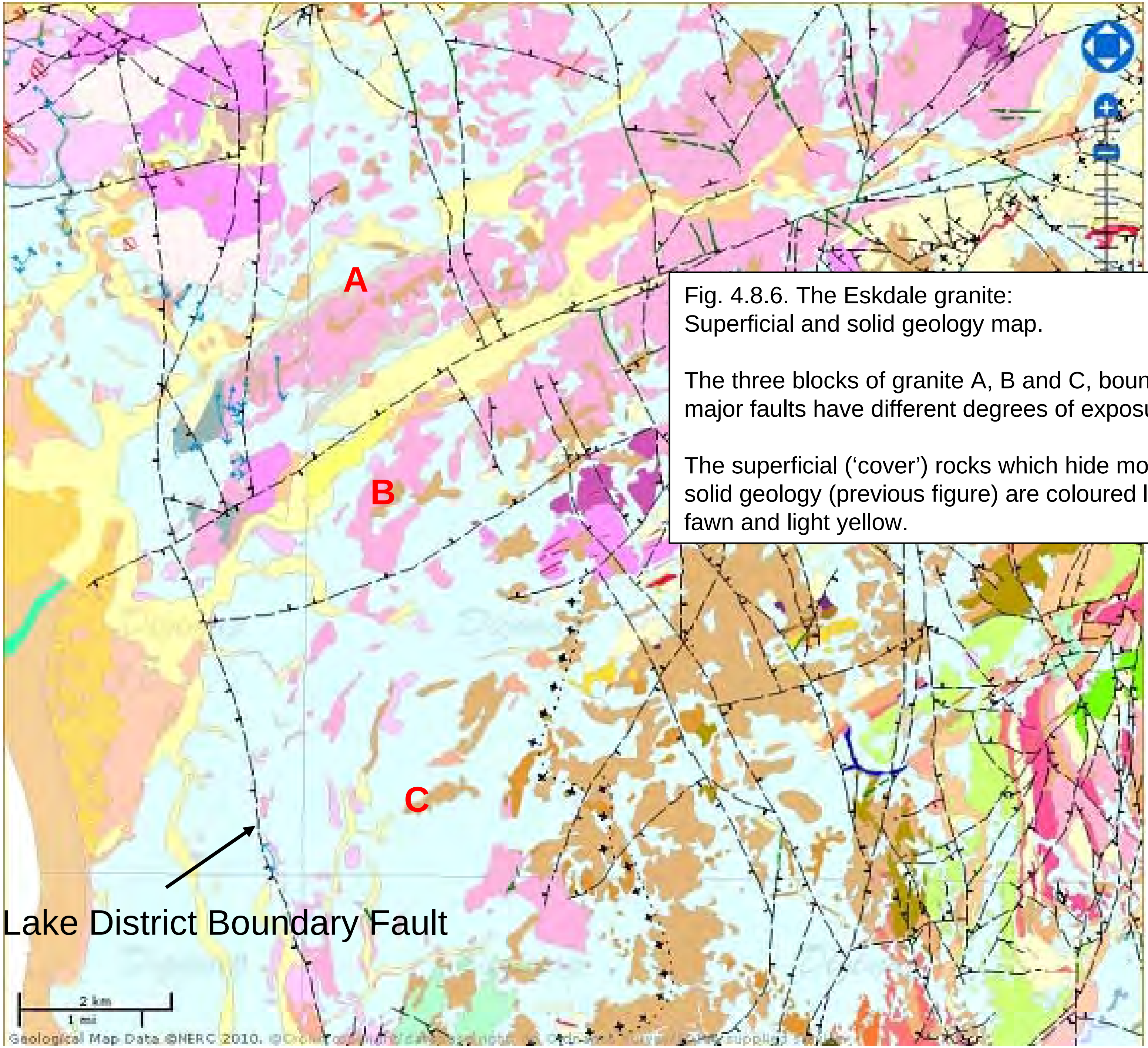


Fig. 4.8.6. The Eskdale granite:
Superficial and solid geology map.

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.

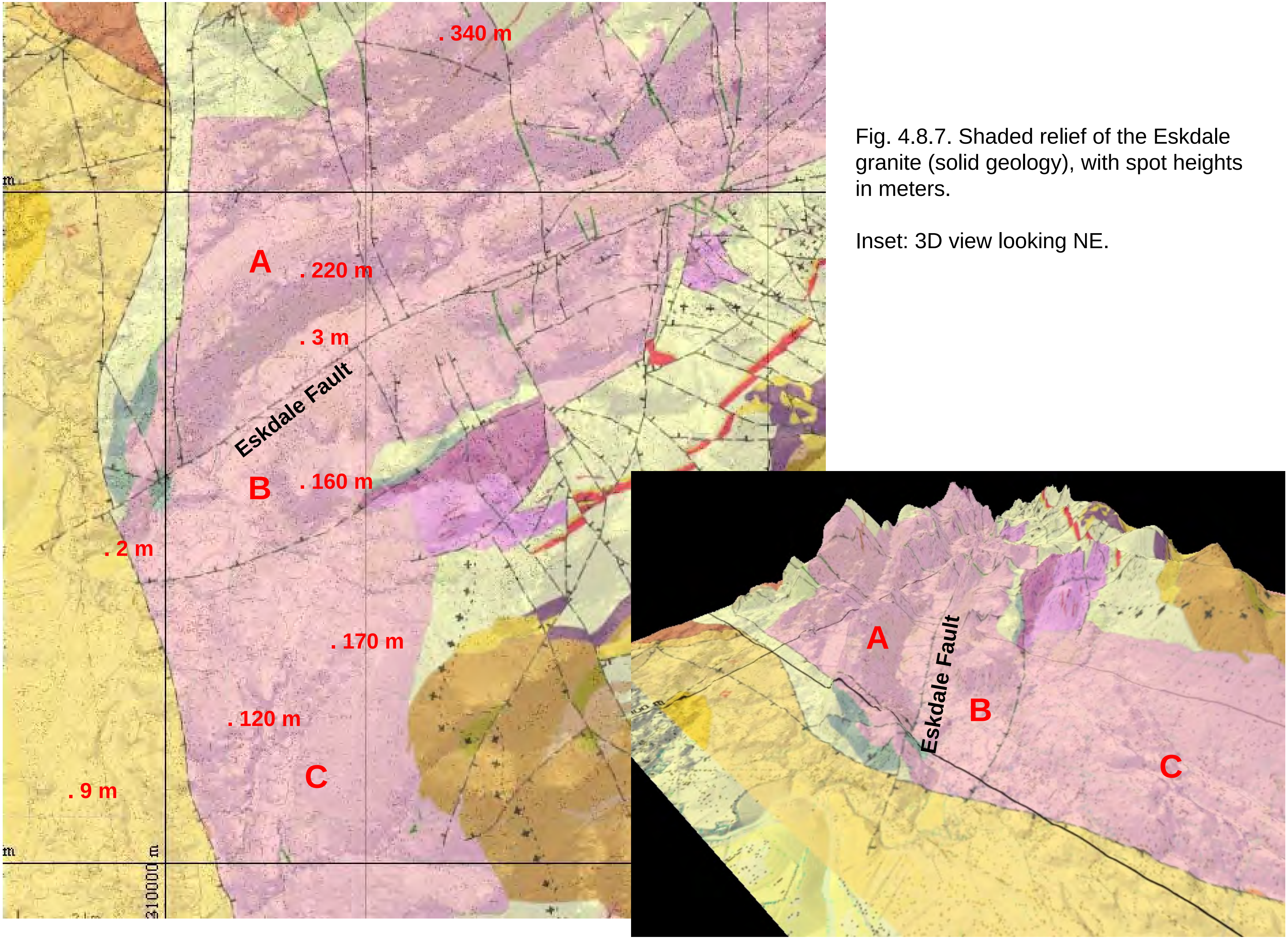


Fig. 4.8.7. Shaded relief of the Eskdale granite (solid geology), with spot heights in meters.

Inset: 3D view looking NE.

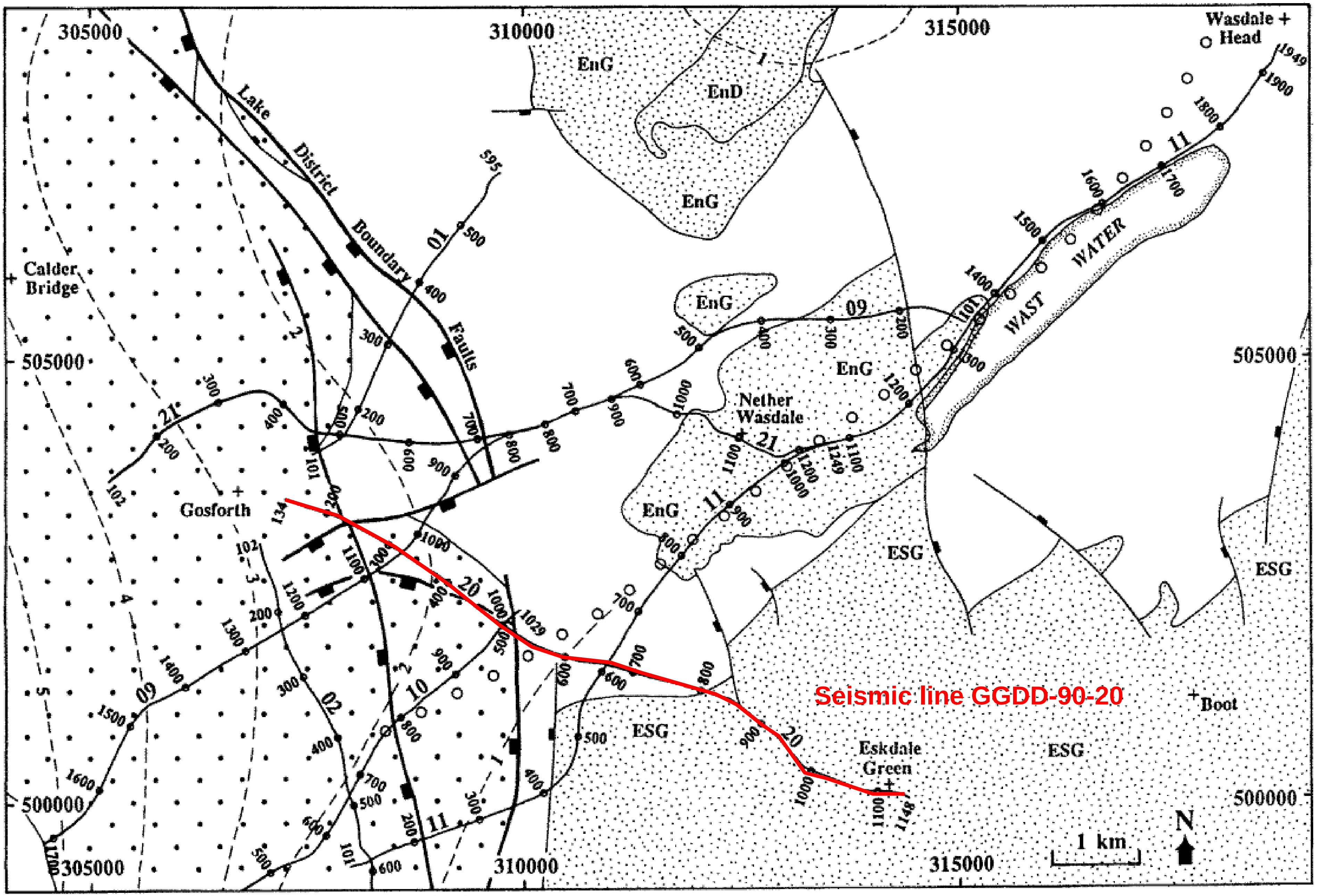


Fig. 4.8.8. Location of seismic reflection line GGDD-90-20 shown in the next figure.

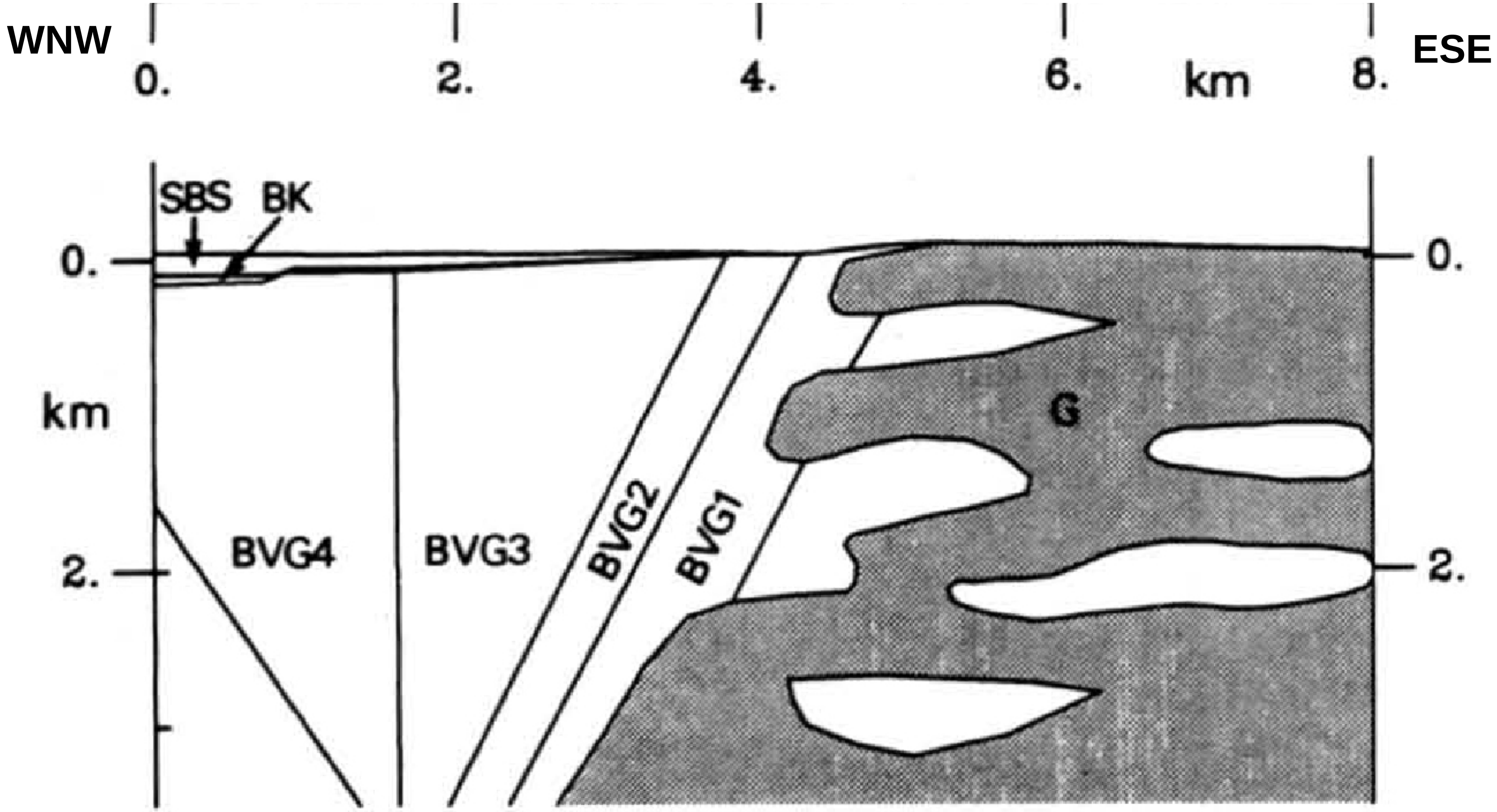


Fig. 4.8.9. Interpreted cross-section from Evans *et al.* 1994, fig. 14, along seismic line GDGG-90-20, showing the preferred model of the western edge of the Eskdale granite (G, shaded). BVG1-4 are Borrowdale Volcanic Group volumes with slightly different densities.

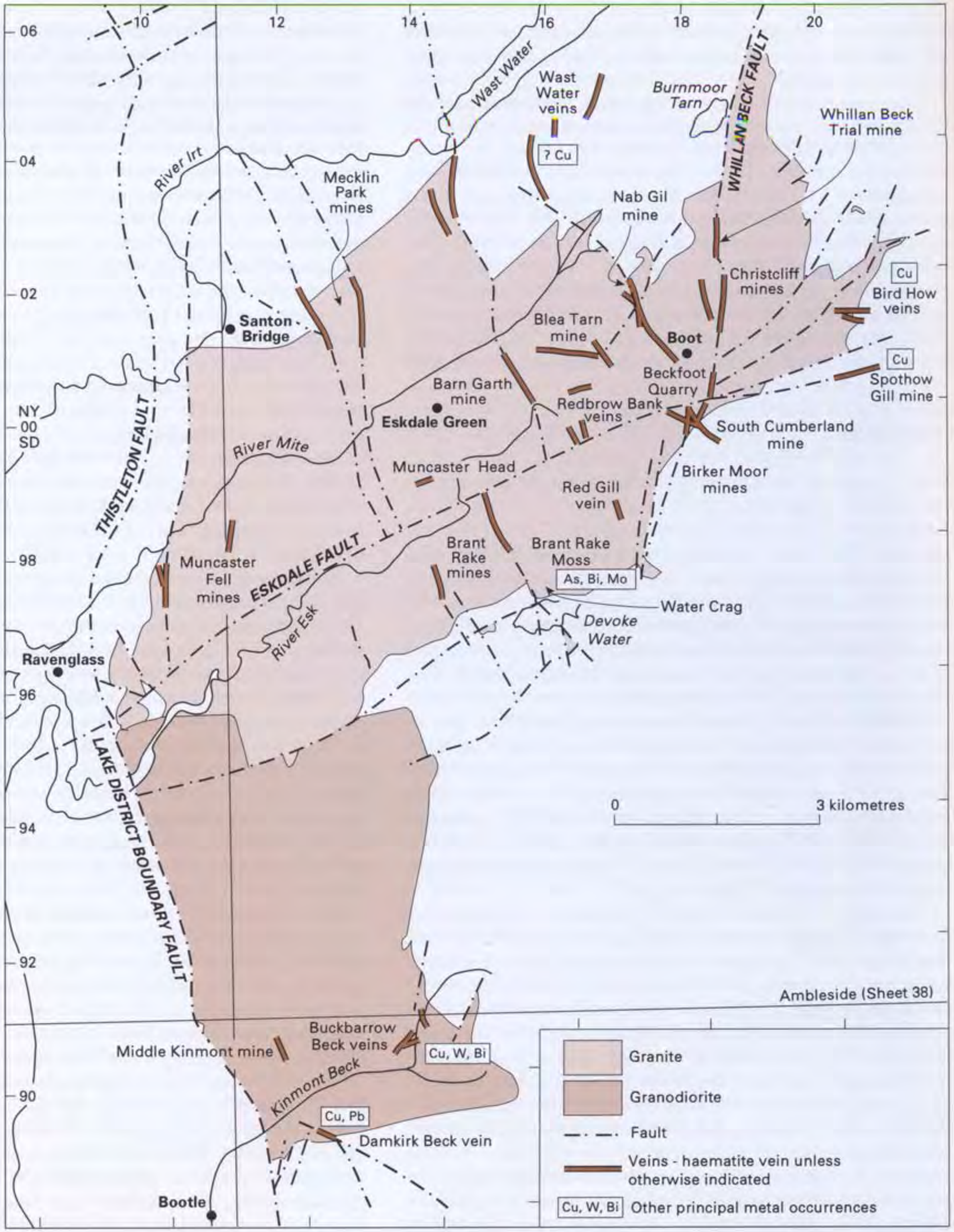


Fig. 4.8.10. Haematite veins of the Eskdale granite. From BGS memoir, *Geology of the Ambleside District*, fig. 66 (Millward *et al.* 2000).

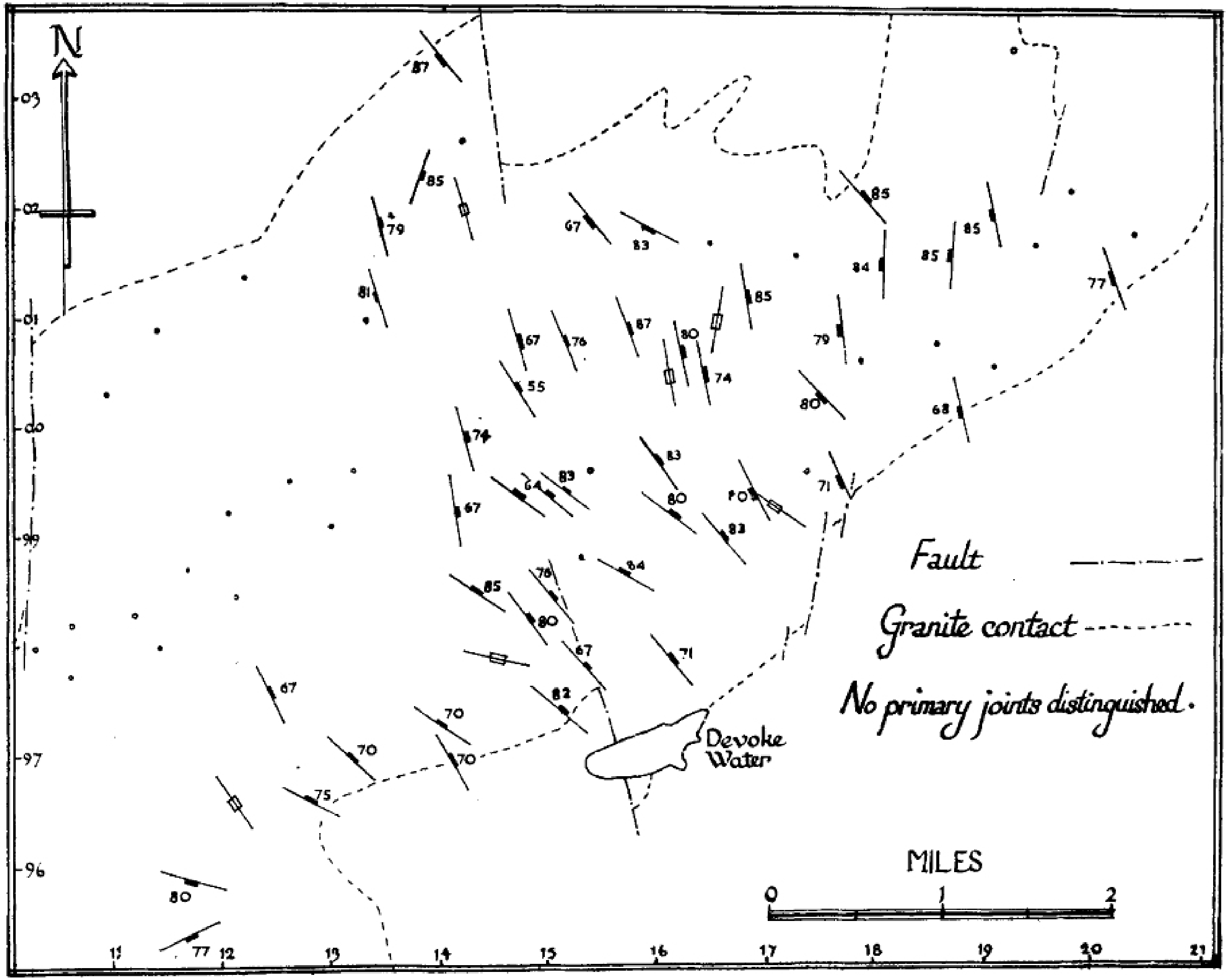


FIG. 3.—Possible primary granite joints.

Fig. 4.8.11. Primary tension joints mapped over the NE part of the Eskdale granite (Firman 1960).

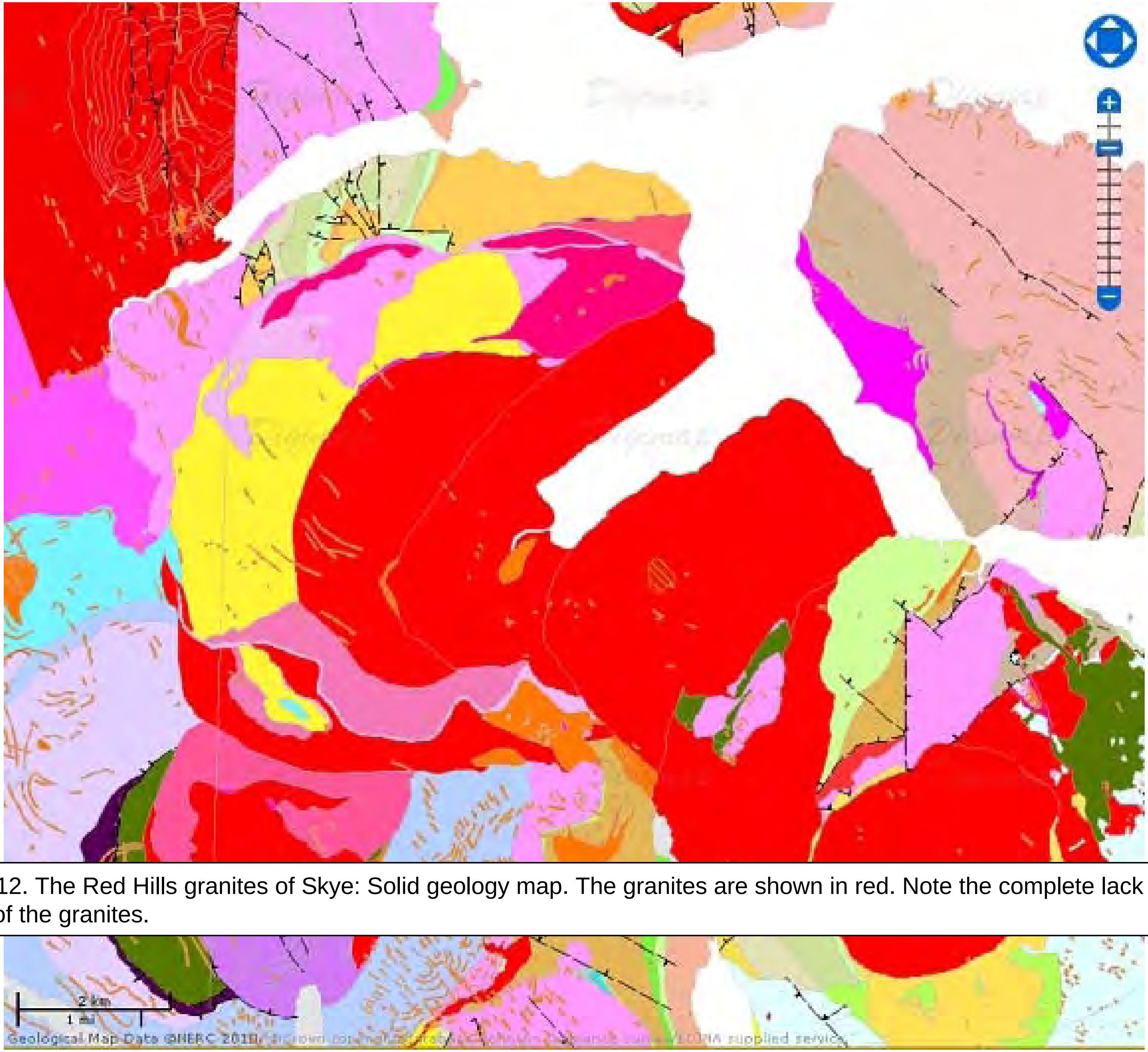


Fig. 4.8.12. The Red Hills granites of Skye: Solid geology map. The granites are shown in red. Note the complete lack of faulting of the granites.

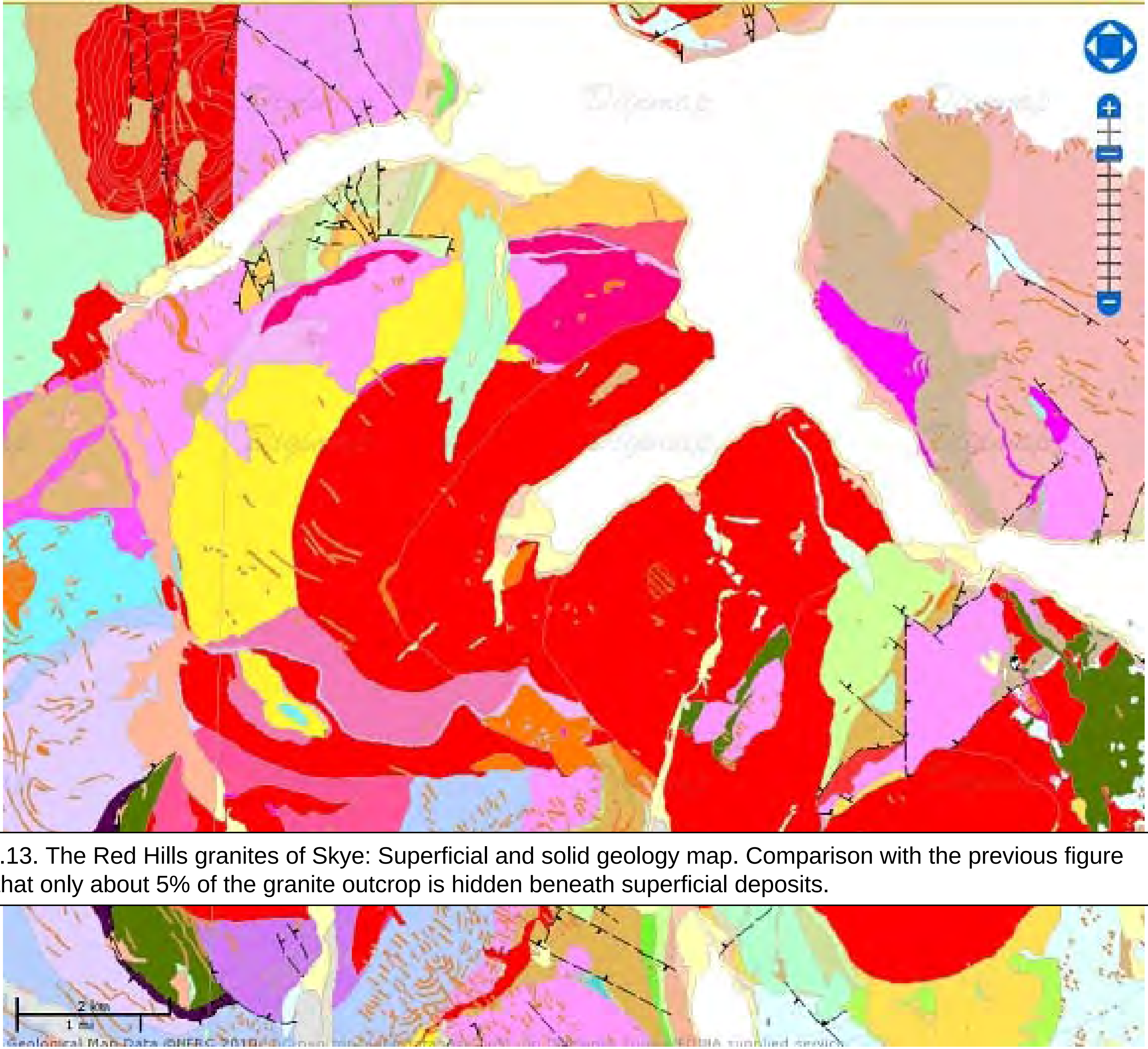


Fig. 4.8.13. The Red Hills granites of Skye: Superficial and solid geology map. Comparison with the previous figure shows that only about 5% of the granite outcrop is hidden beneath superficial deposits.

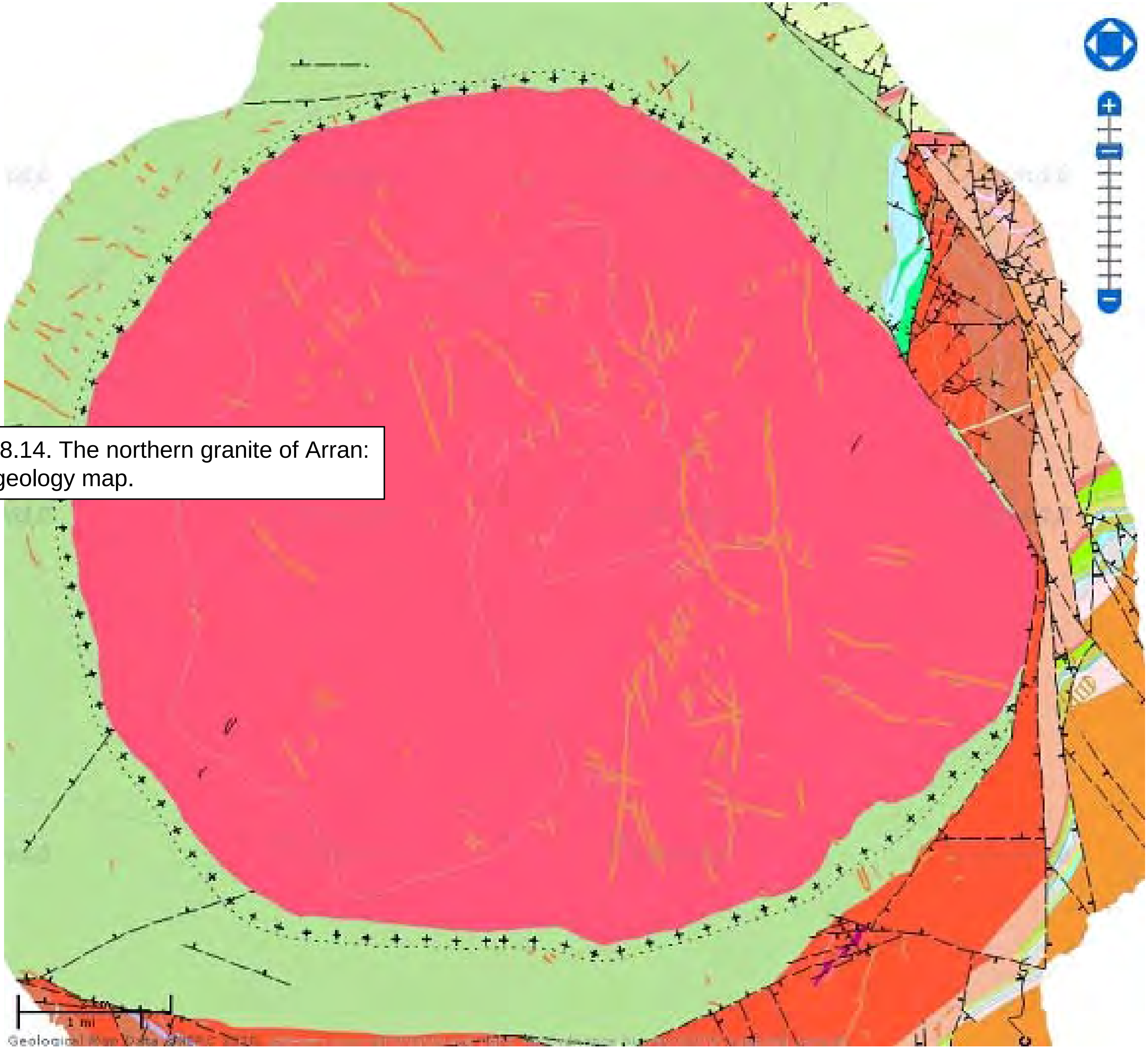
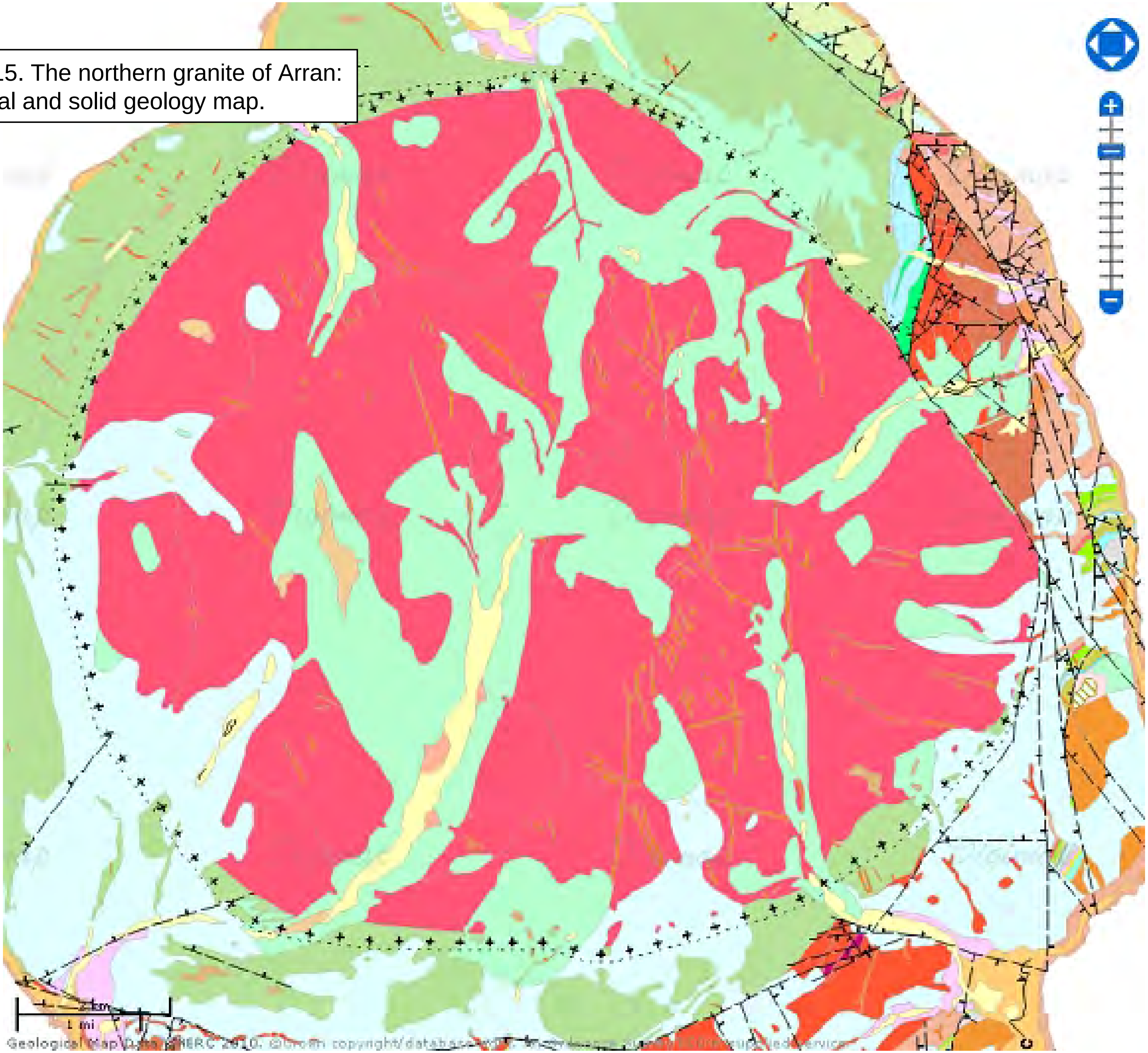


Fig. 4.8.14. The northern granite of Arran: Solid geology map.

Fig. 4.8.15. The northern granite of Arran: Superficial and solid geology map.



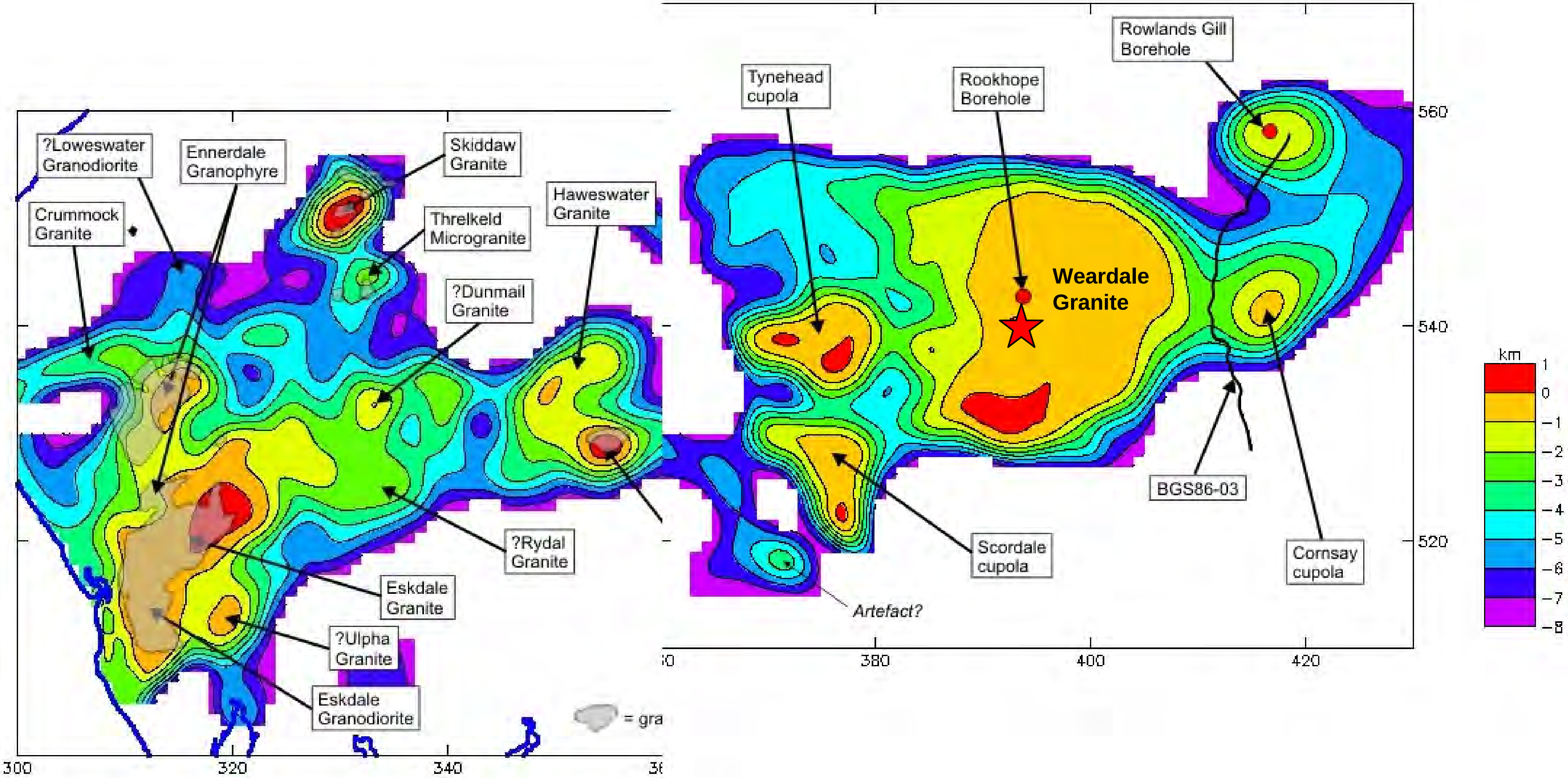


Fig. 4.8.16. Contour map of depths to the top of the Lake District and North Pennine granitic batholiths (British Geological Survey 2006). The star indicates the location of the Eastgate no. 1 borehole, which encountered a sub-vertical fracture zone of ultra-high permeability within the Weardale granite.

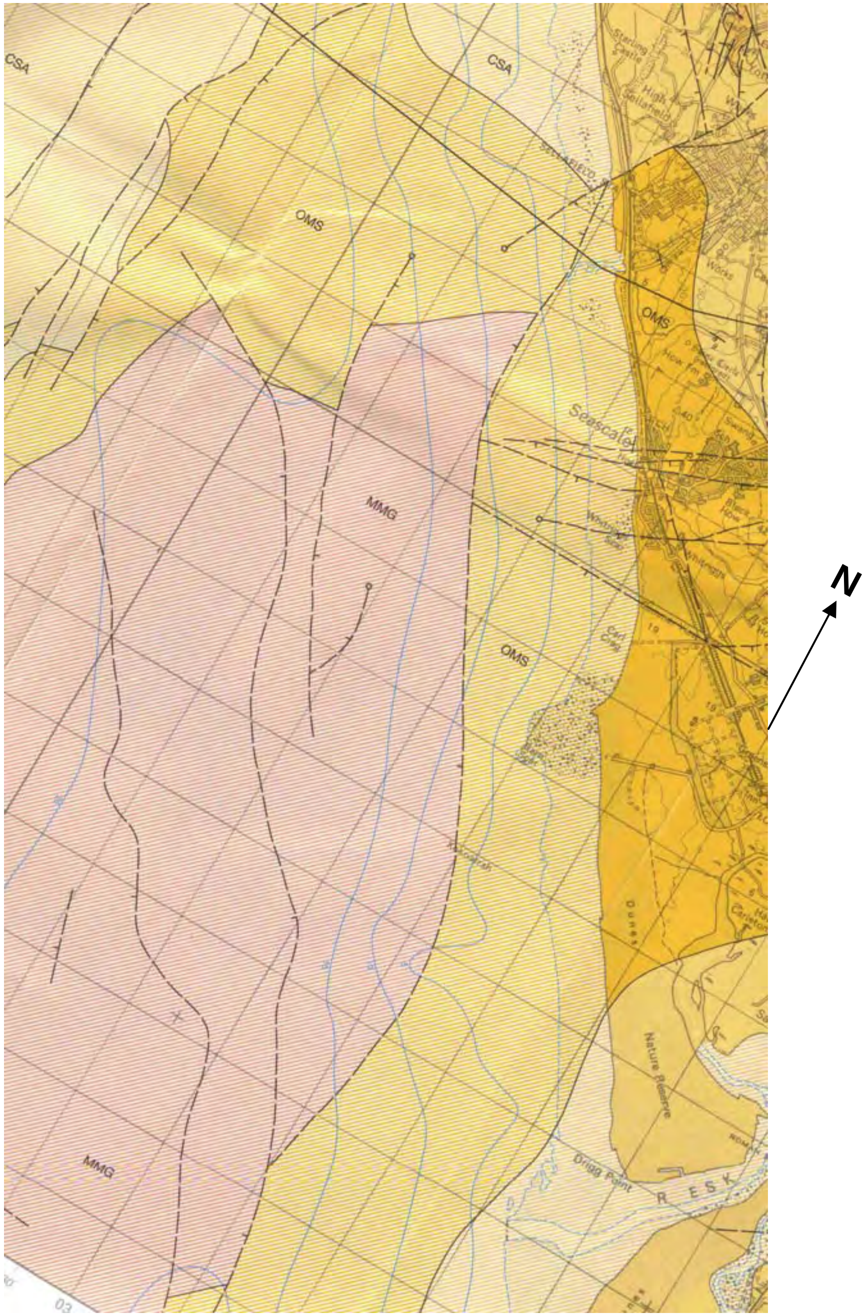
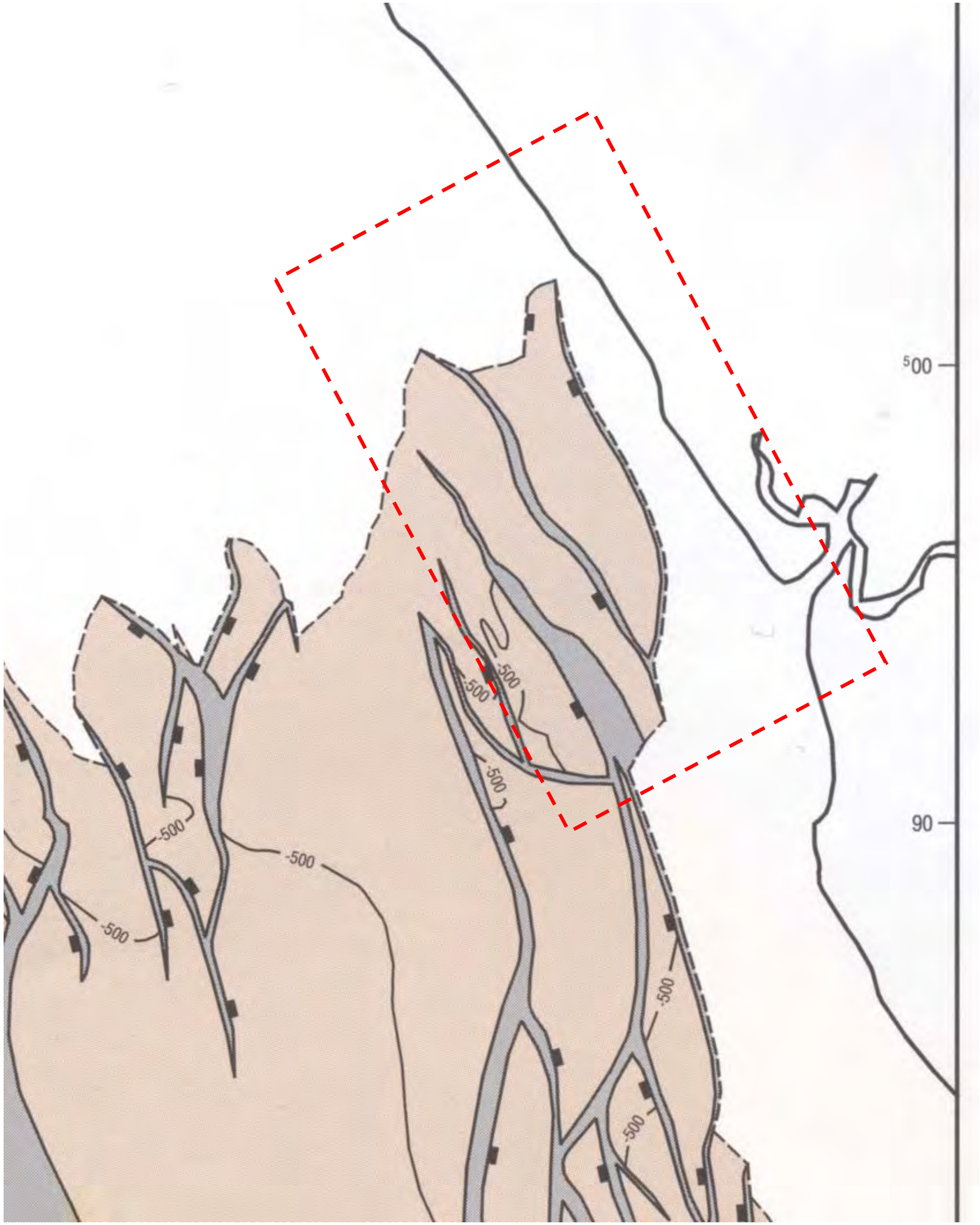


Fig. 4.8.17. Extract from BGS solid geology map Gosforth Sheet 37.

Key: MMG (flesh-pink) – Mercia Mudstone Group.
OMS (fawn offshore, sienna onshore) – Ormskirk Sandstone.
CSA (light buff) – Calder Sandstone.

Fig. 4.8.18. Depth to Base Mercia Mudstone Group (British Geological Survey 1997, map 1).

The dashed rectangle shows the area of the solid geology map shown in the previous figure.



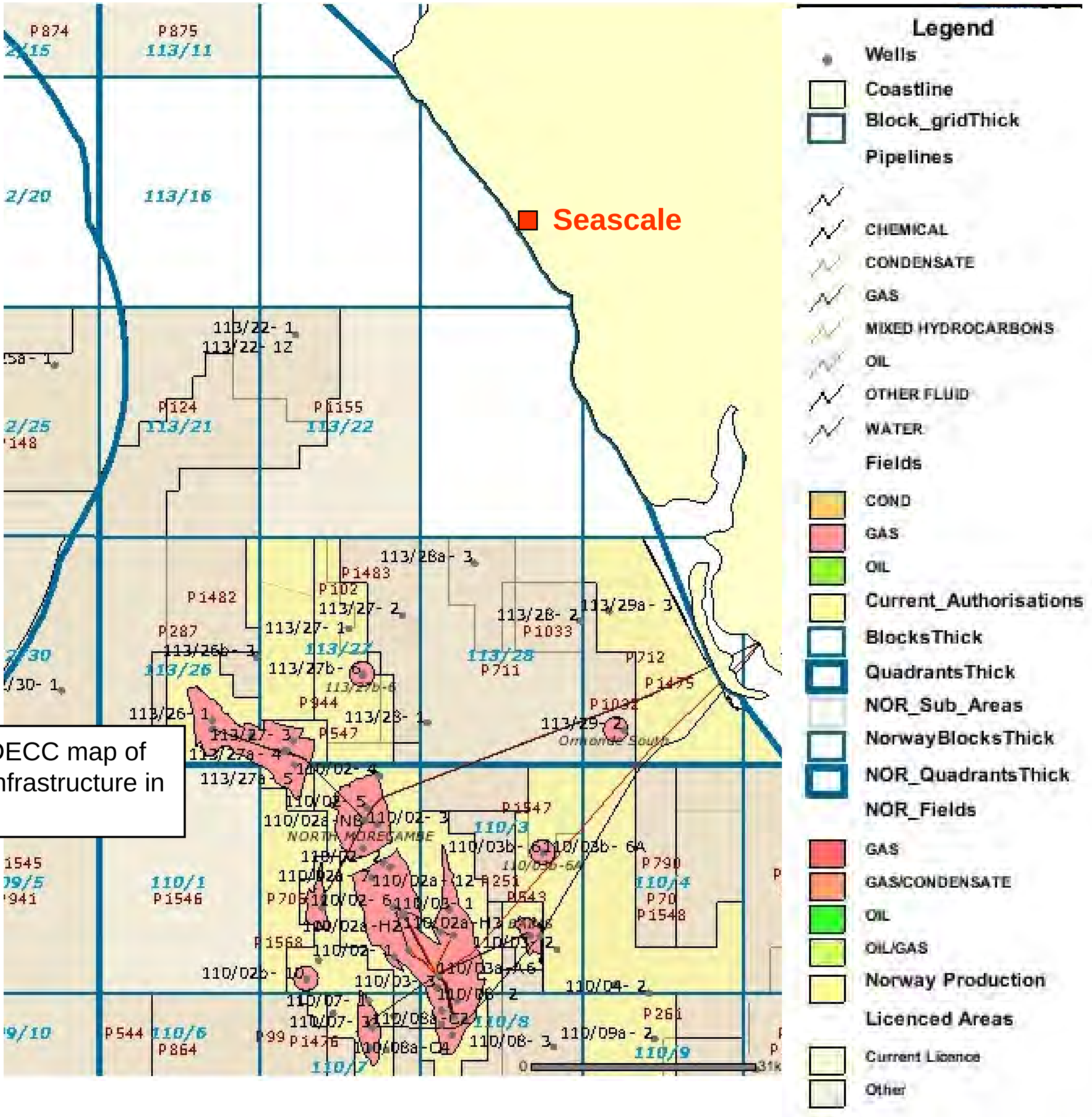


Fig. 4.8.19. Extract from DECC map of exploration licences and infrastructure in the eastern Irish Sea.

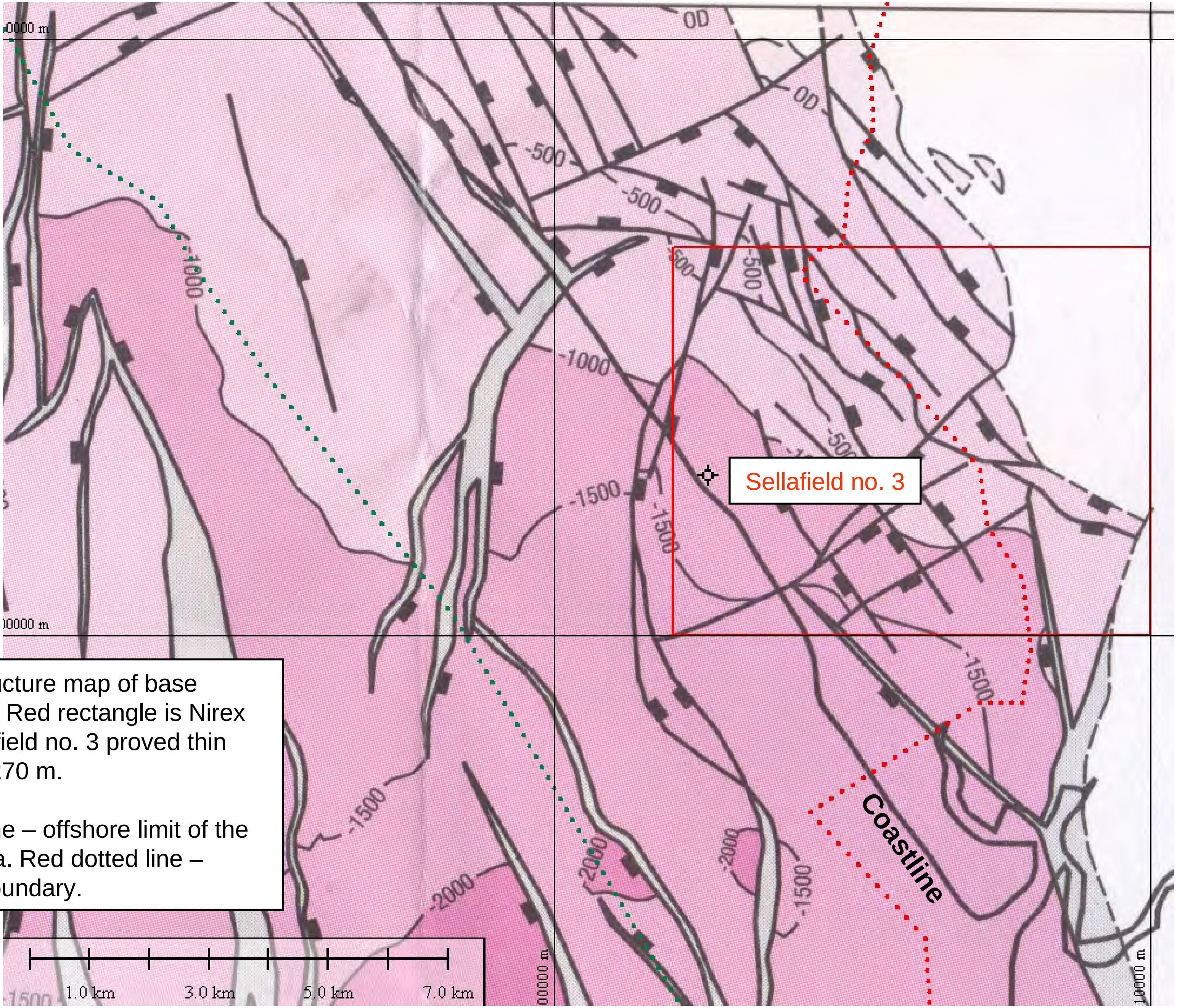


Fig. 4.8.20. Structure map of base Permo-Triassic. Red rectangle is Nirex Site area. Sellafield no. 3 proved thin anhydrites at 1270 m.

Green dotted line – offshore limit of the partnership area. Red dotted line – national park boundary.

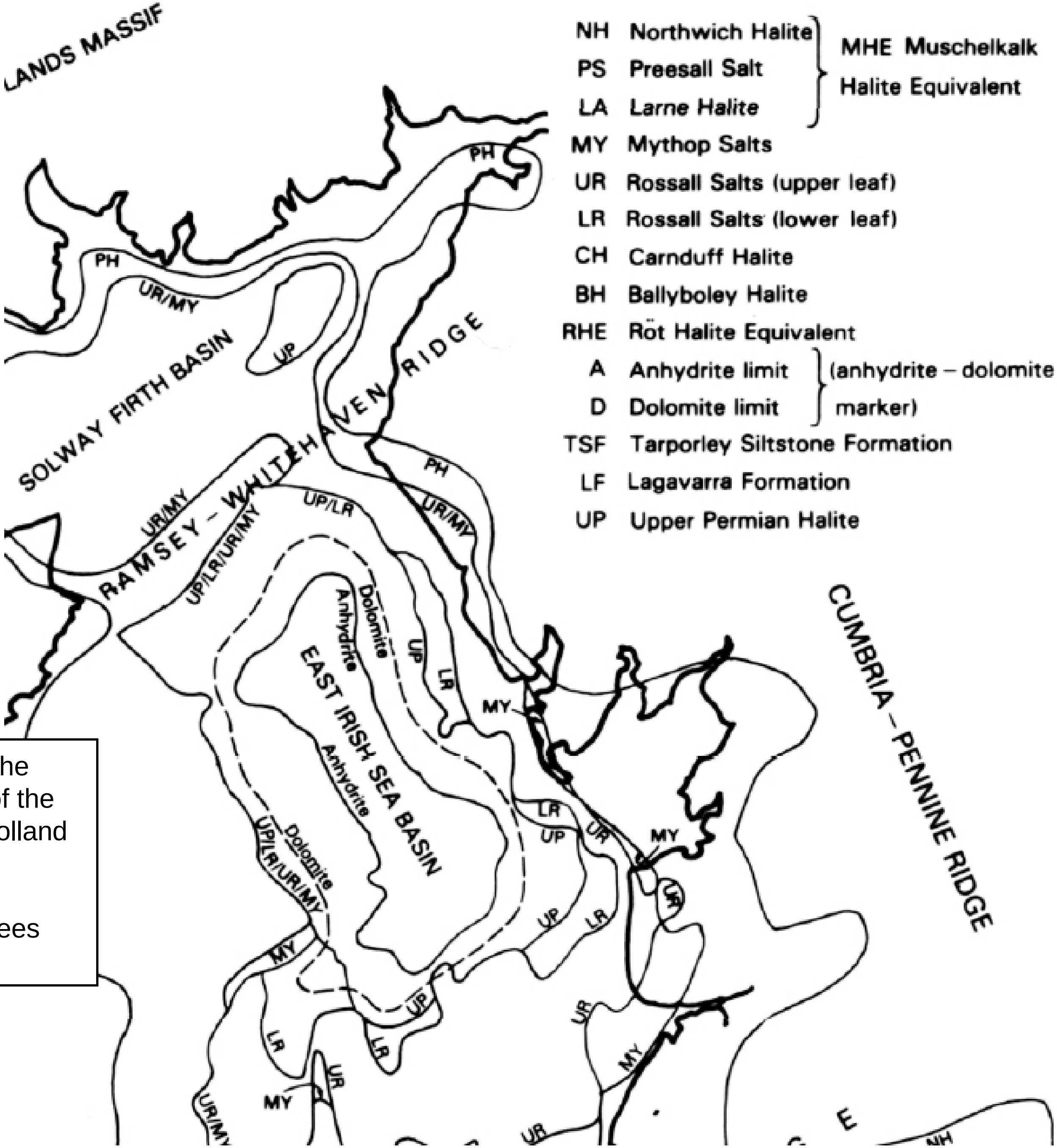


Fig. 4.8.21. Depositional limits of the Permian and Triassic evaporites of the East Irish Sea (Jackson and Mulholland 1993).

UP – limit of Upper Permian (St Bees Evaporite) anhydrites.

Fig. 5.2.1. Stanford, Norfolk. Circle of 4 km radius with no population within.

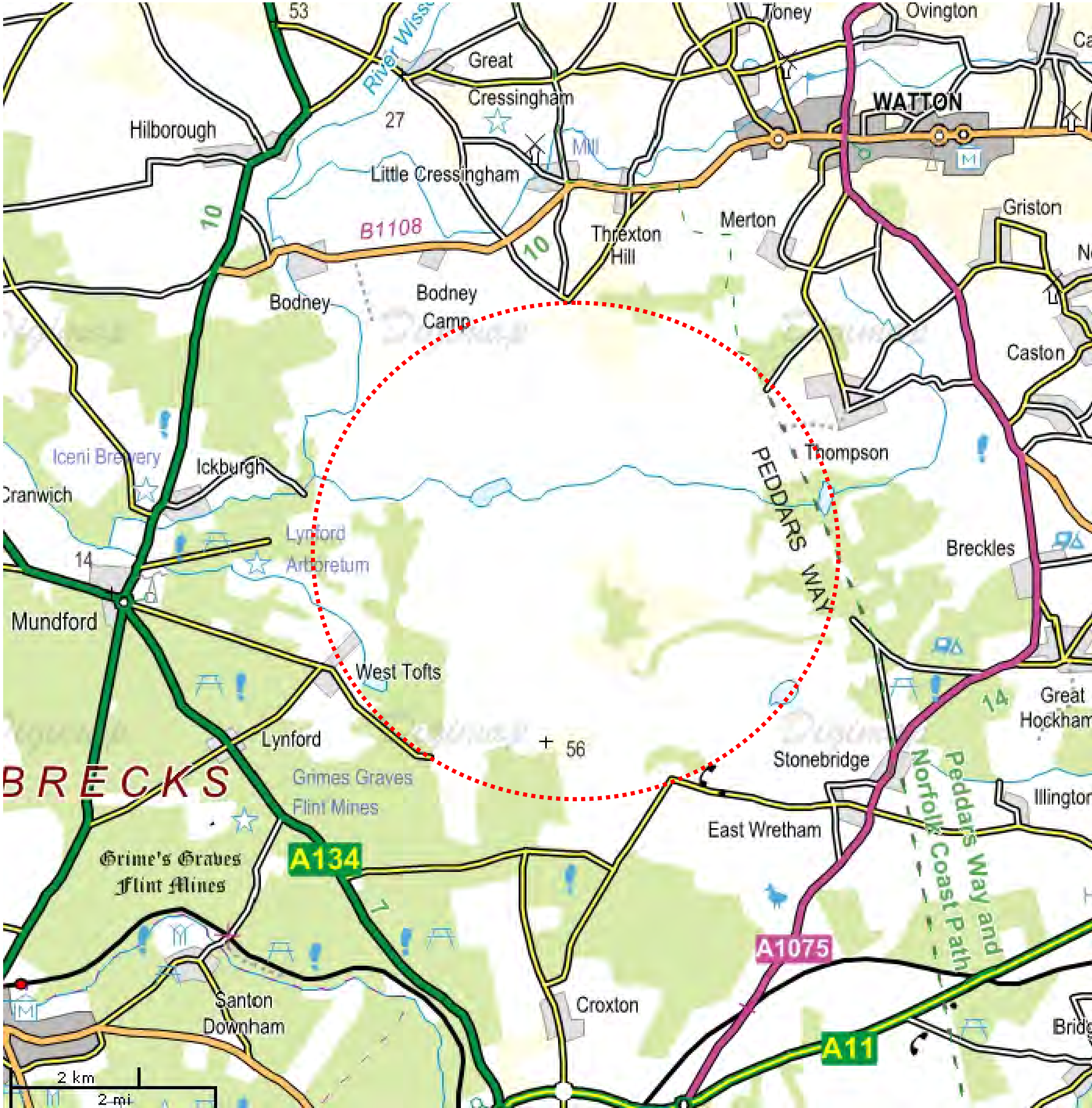
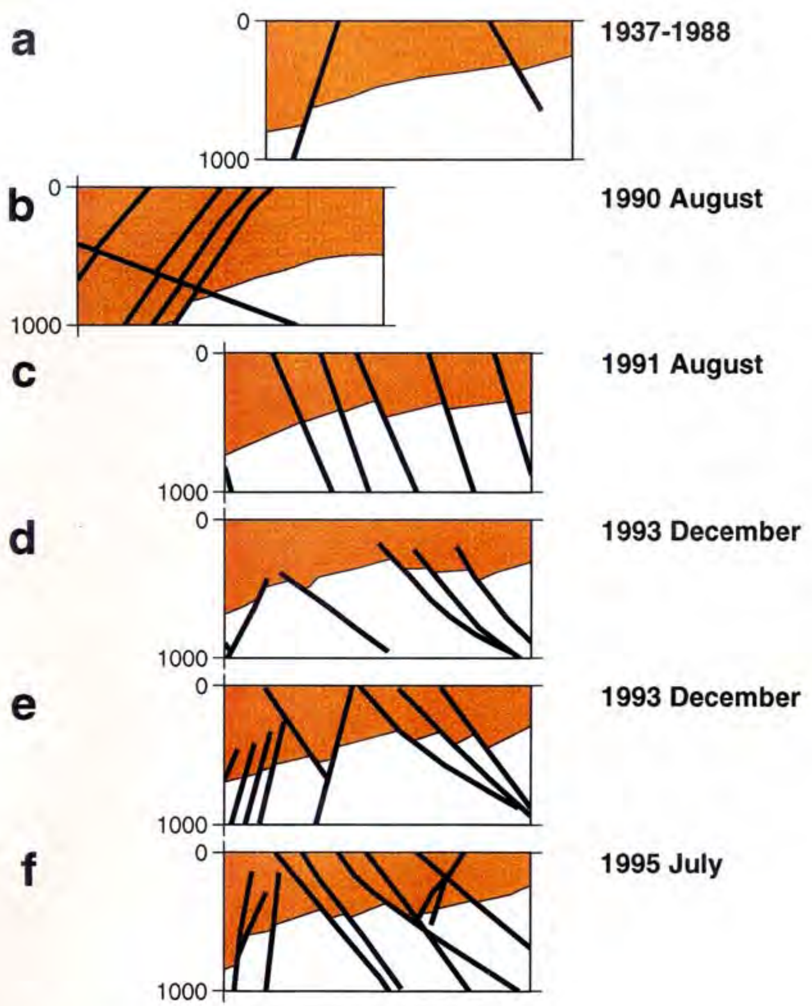
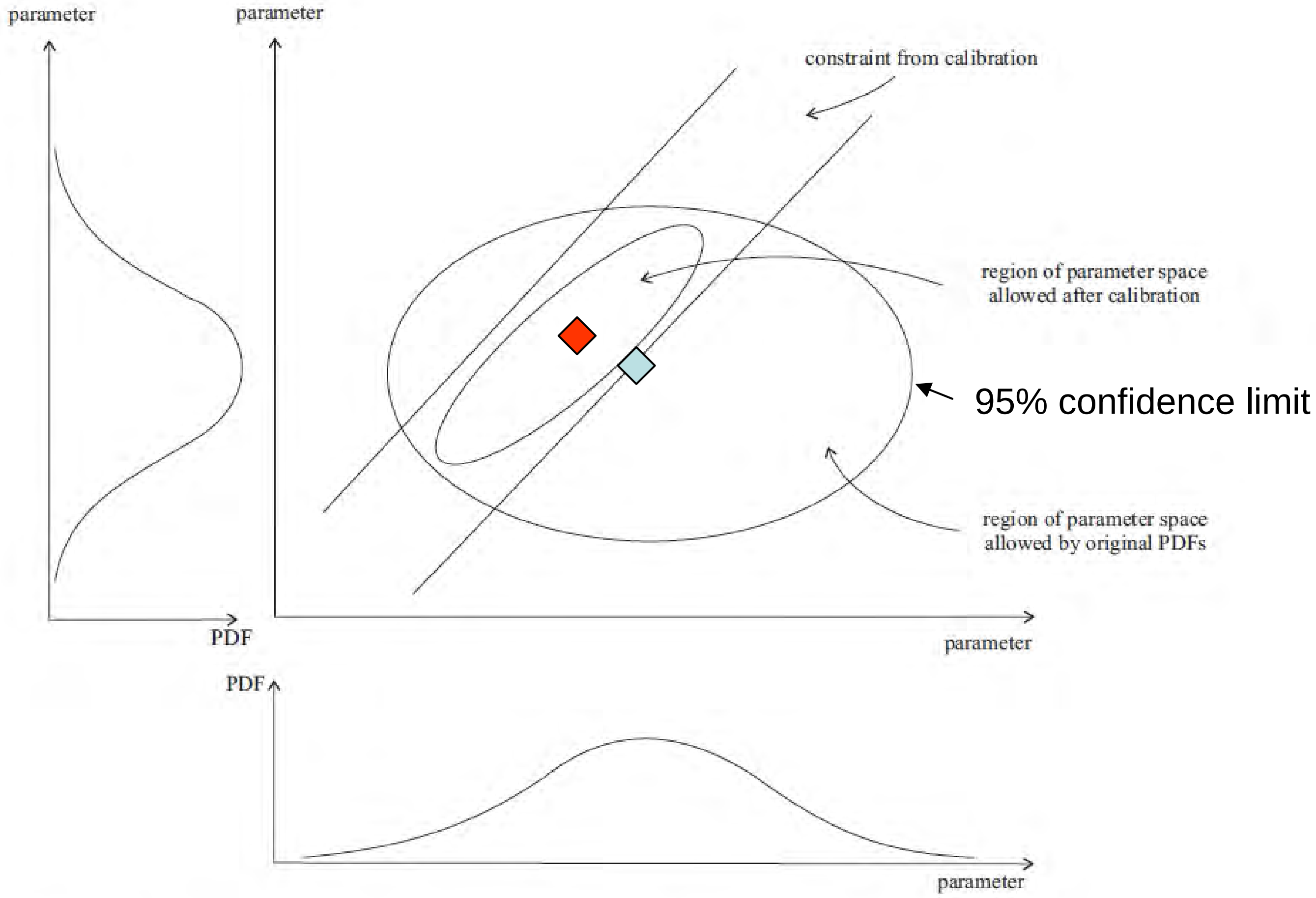


Fig. 5.6.1. Illustration of the instability of Nirex interpretations at Longlands Farm.



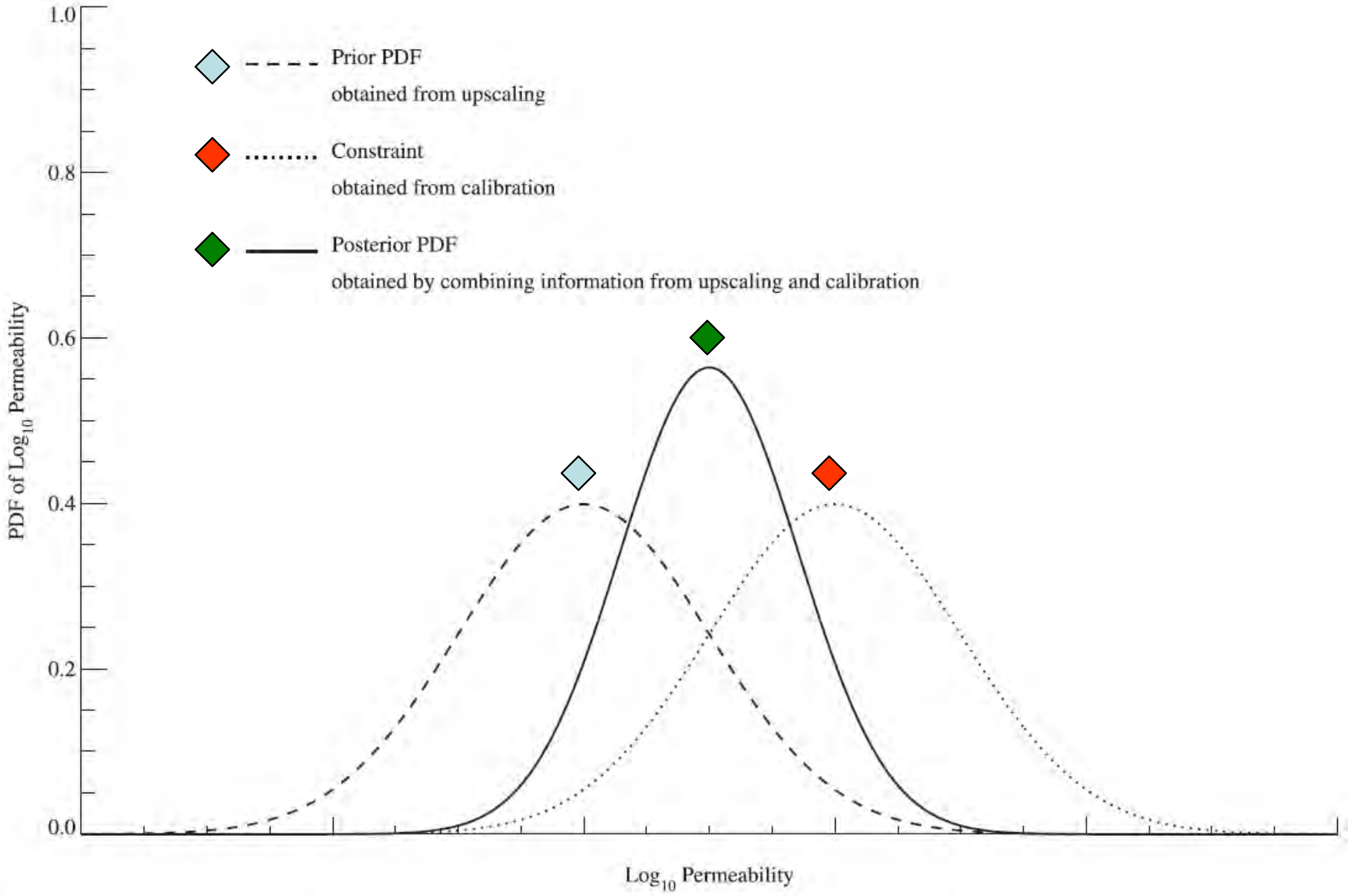
[redacted] **Interpreted cross-sections through the PRZ at several epochs.** Only the major faults (solid black lines) and post-BVG sedimentary cover (colour) are shown. All sections are 2200 m long, located in Figure 1(key map). The sections are aligned vertically along Cross-section 26 {S/95/005; Drawing No. 010062}. Epochs and information sources are as follows:

a. 1937-1988 (approx.): Trotter *et al.* 1937, plate V [FOE/3/13].
b. 1990 August: *Nuclear Engineering International*, reproduced in GOV/616.
c. 1991 August: Hooper (1991), reproduced in GOV/616.
d. 1993 December: Nirex Report no. 524, Vol. 1, fig. 3.6. [COR/517]
e. 1993 December: Nirex Report no. 525 fig. 6. [COR/505].
f. 1995 July: Nirex Report S/95/005 Cross-section 17; Drawing no. 010061.



[redacted] **Schematic illustration of the effect on the allowed regions of parameter space of taking into account the parameter constraints from calibration.**
The Figure shows the allowed region of parameter space for the original PDFs, the region of parameter space allowed by the constraints from calibration, and the region of parameter space allowed taking into account both the original PDFs and the constraints.
The allowed regions should be interpreted as the regions associated with significant probability density.

Fig. 5.6.2. Overlap of allowed regions of parameter space of Probability Density Functions (PDFs), shown for illustrative purposes as two-dimensional. The peak value of the PDF function is marked by a blue diamond. An independent constraint from calibration may be a linear zone traversing the initial PDF area, as shown by the parallel lines. So the region of parameter space allowed by this calibration is reduced to the elongated ellipse, with the peak value marked by a red diamond.



[redacted] Illustration of the combination of a prior PDF and a constraint from calibration to produce a posterior PDF.

Fig. 5.6.3. The prior PDF is weighted by the calibration constraint to yield the posterior PDF.

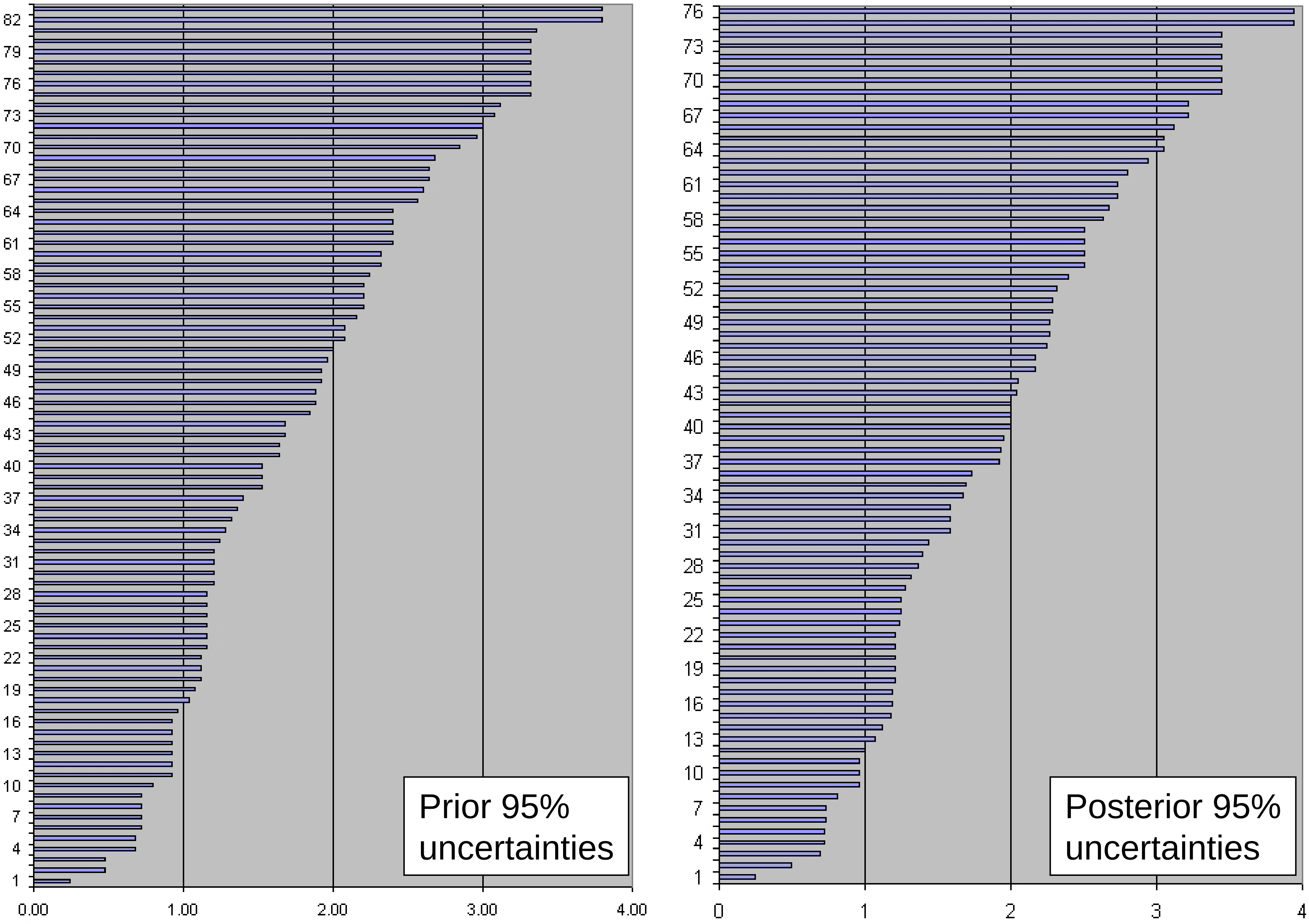
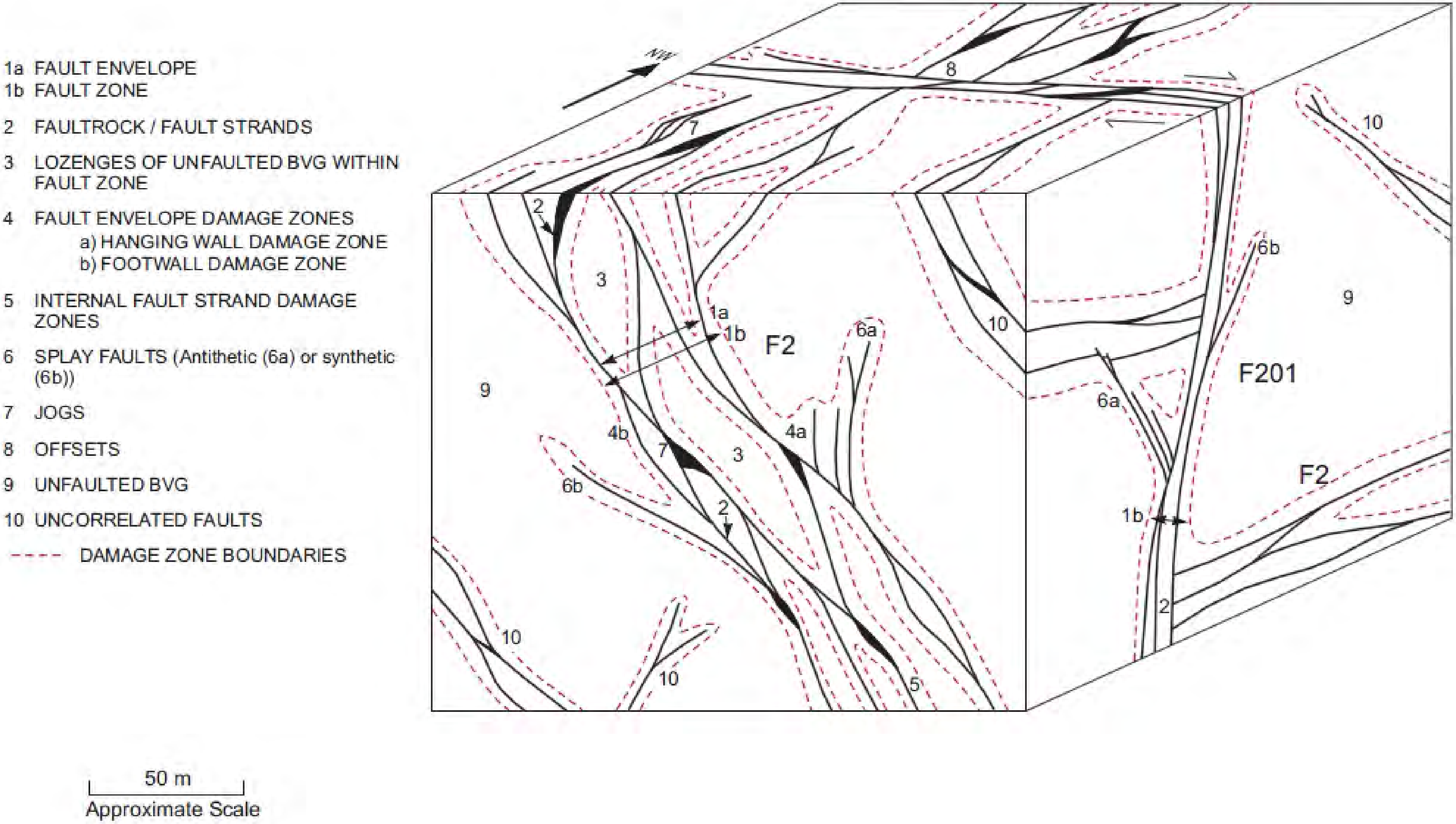
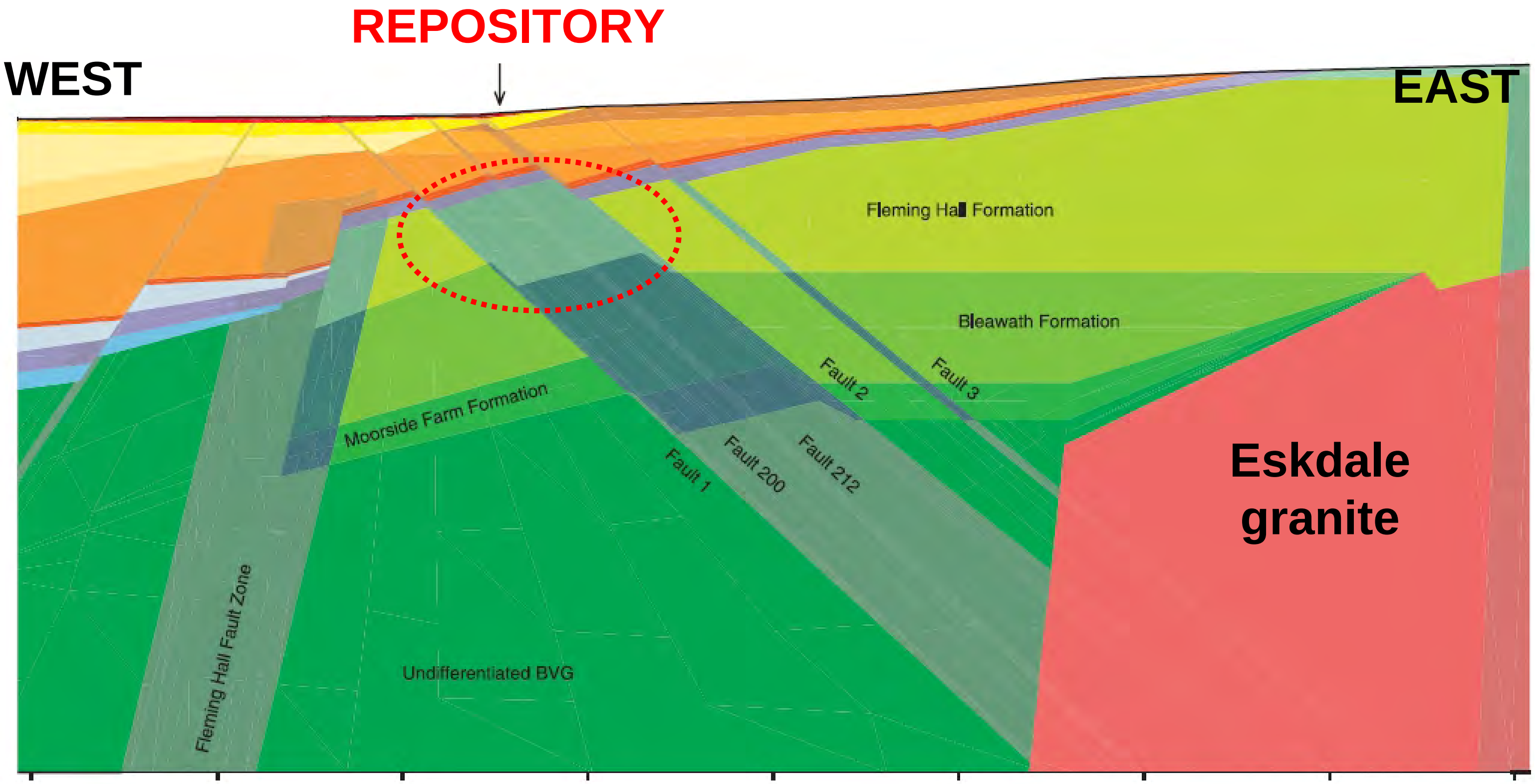


Fig. 5.6.4. Uncertainties in permeability for the various rock types, ranked from low to high. Scale is logarithmic. Only the right-hand side of the symmetrical uncertainty range is shown here.



[redacted] **Conceptual model of moderate to large displacement faults in the Borrowdale Volcanic Group and terminology (see Reference [4.24] for further details).**

Fig. 5.6.5. Nirex 97 conceptual model for faulting in the BVG.



[redacted] **Detailed view of the subdivision of the BVG in the PRZ for the reference two-dimensional model.** The faulted region in the BVG between Fault 1 and Fault 2 is known as the F1-F2 Structure.

Fig. 5.6.6. The whole complex of faulted Borrowdale Volcanics at repository level (circled) is assigned just one value of permeability. This is tantamount to an admission of failure of the model.

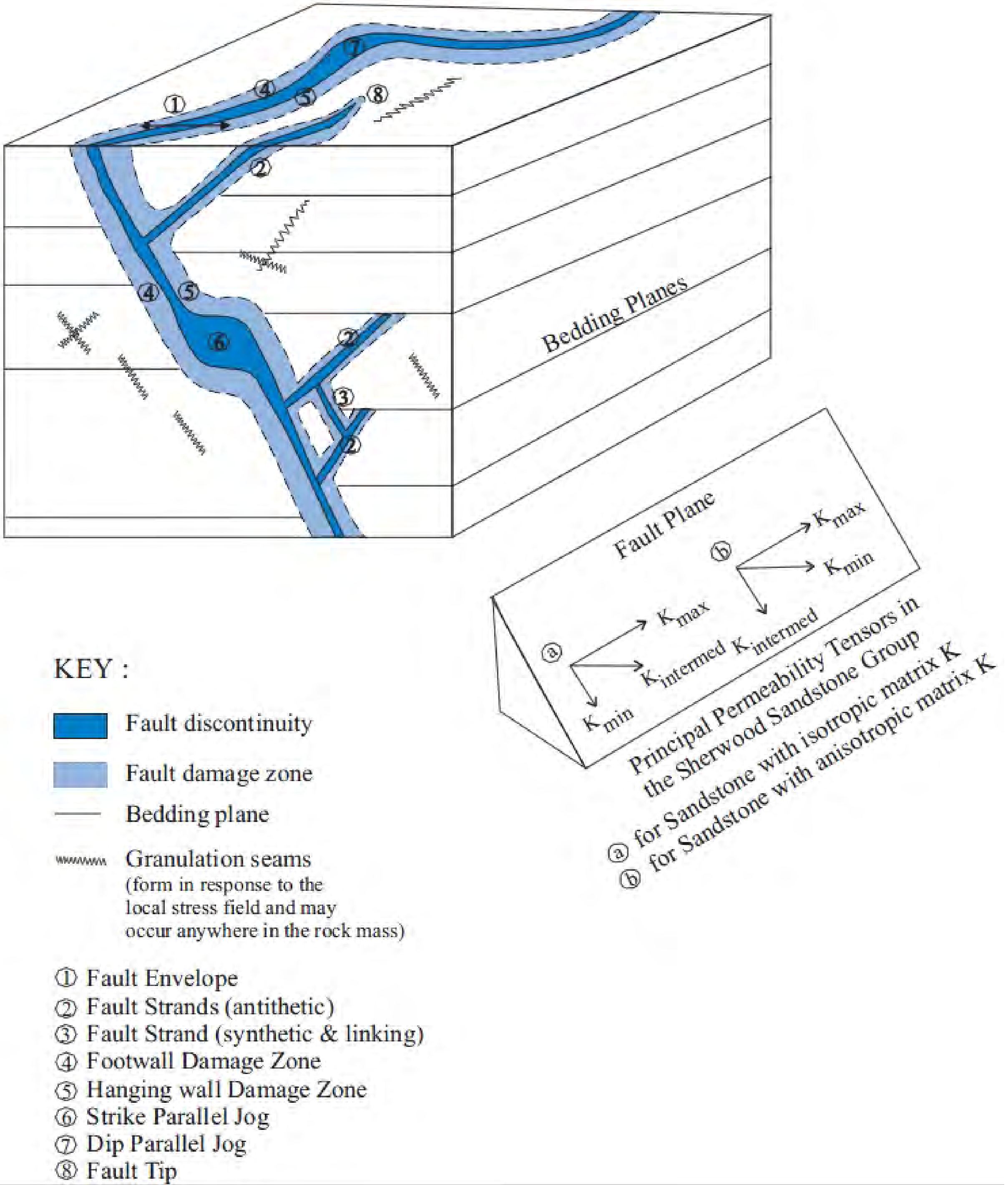
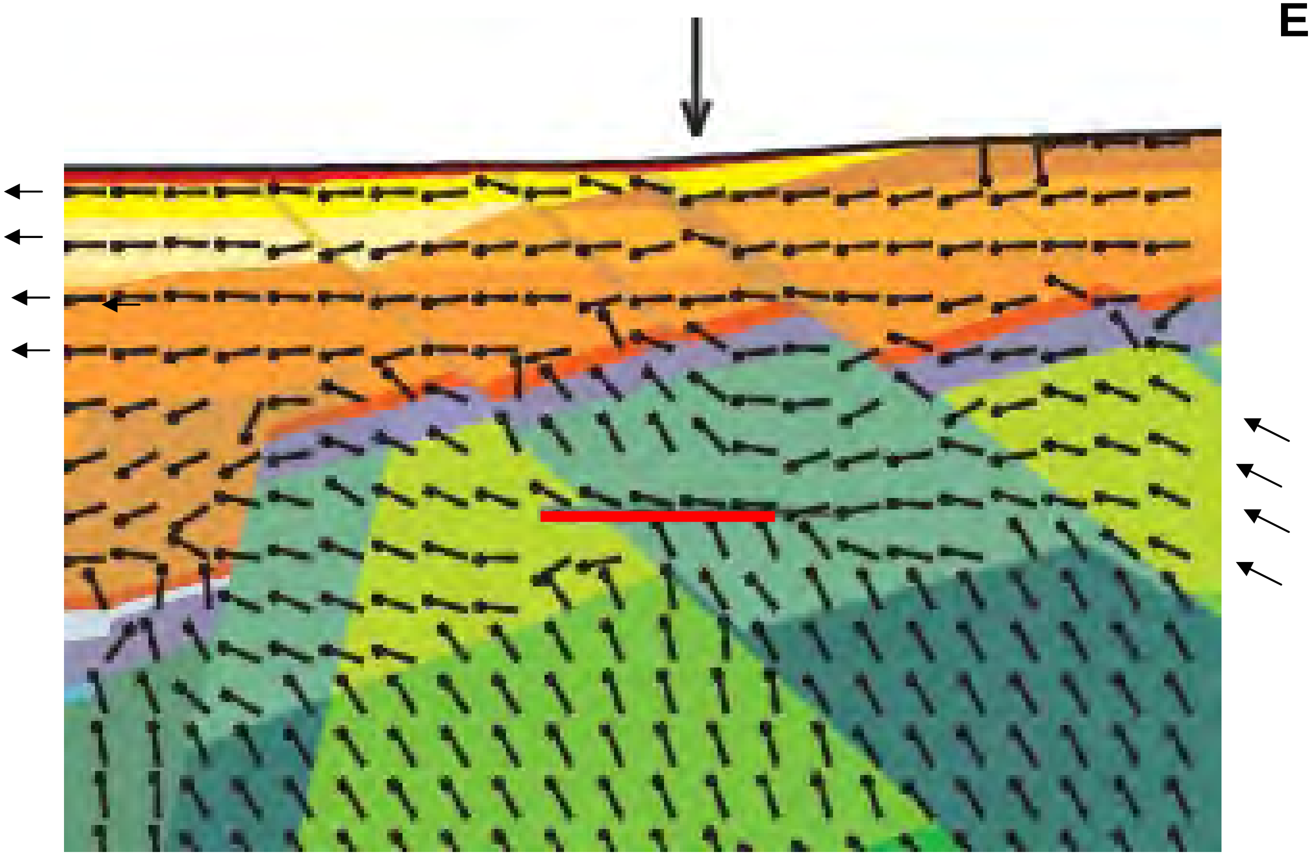


Fig. 5.6.7. Nirex 97 fault modelling within the Sherwood Sandstone Group sediments.



WEST

REPOSITORY

EAST

Flow arrows

Fig. 5.6.8. Close-up view of a Nirex 97 model result, showing unit vectors indicating flow direction (but not scaled by magnitude). It is anomalous that none of the faults appear to affect the flow.

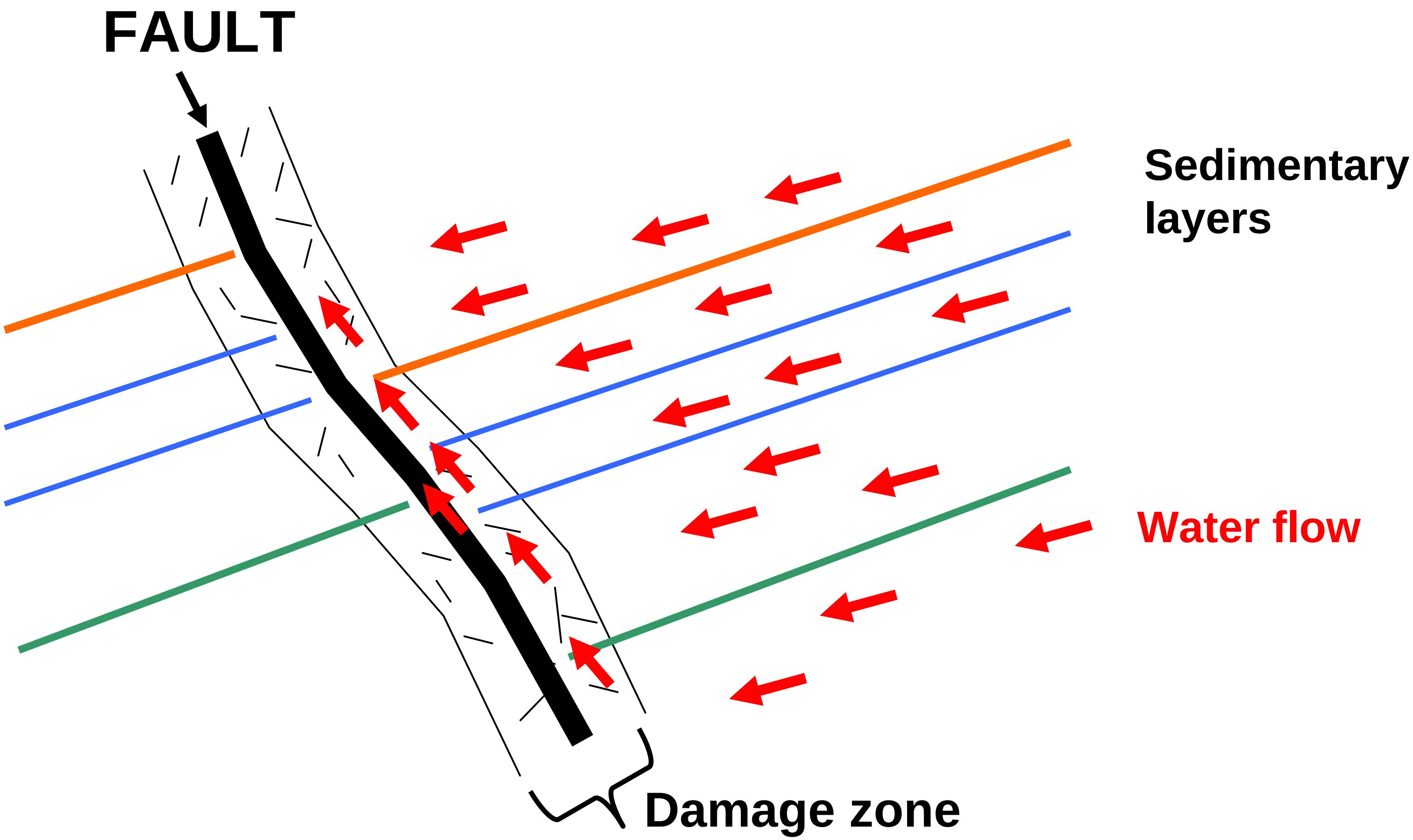


Fig. 5.6.9. Cartoon showing how a fault zone diverts water flow.

Fault core – could be a barrier; could be a conduit.
Damage zone – a conduit.

But fault zones have been assigned permeabilities similar to, or the same as, the unfaulted rock.

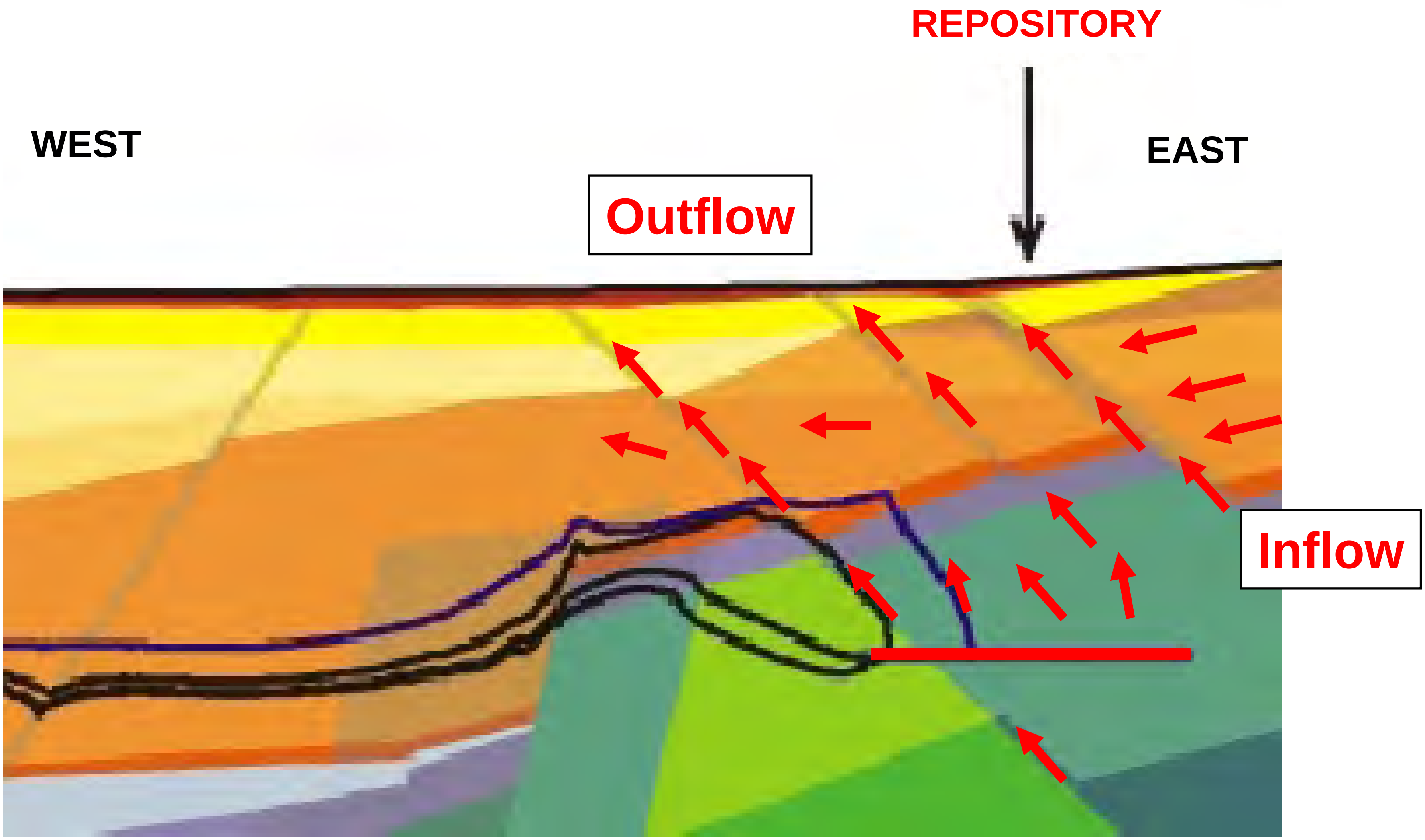
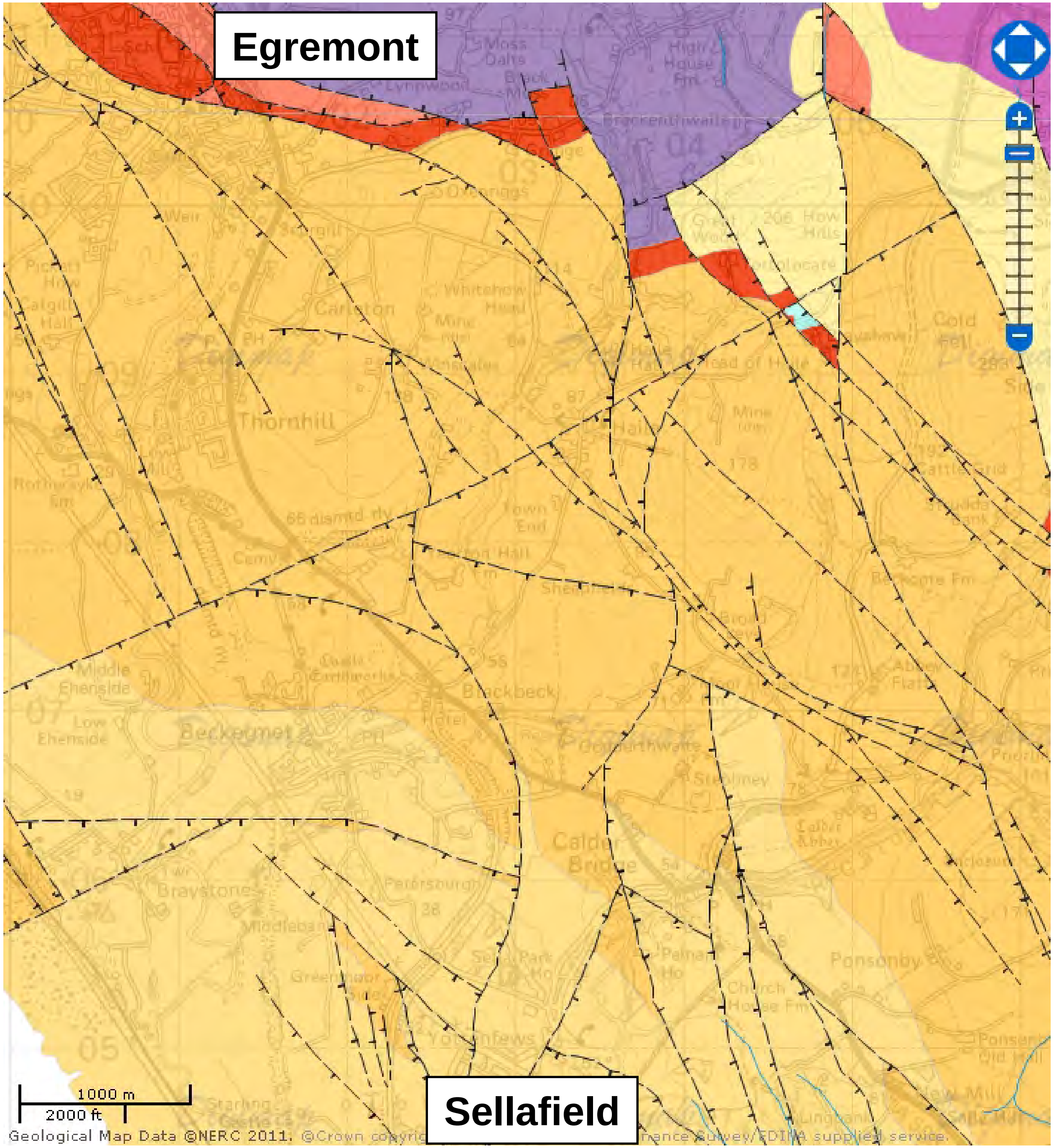


Fig. 5.6.10. Detail of Nirex 97 flow model.

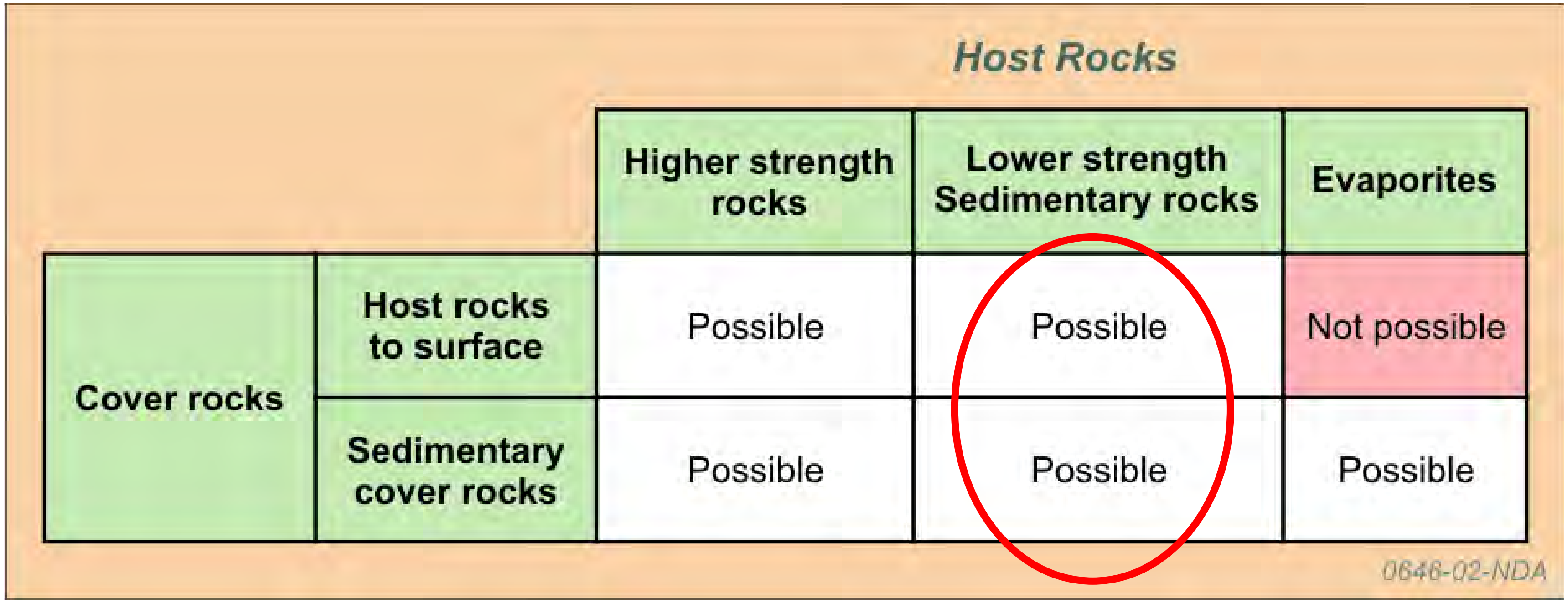
Red arrows show more realistic flow directions. The purple and black solid lines emanating from the repository are the flowlines predicted by Nirex.

Fig. 5.6.11. Geology map of the area between Egremont and Sellafield where United Utilities is drilling water wells, targetting faults to get the best flow rates.

Red / orange / buff colours are the sedimentary aquifer rocks.



Geological Map Data ©NERC 2011. ©Crown copyri … rance Survey/EDINA supplied service.



		Host Rocks		
		Higher strength rocks	Lower strength Sedimentary rocks	Evaporites
Cover rocks	Host rocks to surface	Possible	Possible	Not possible
	Sedimentary cover rocks	Possible	Possible	Possible

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Fig. 5.8.1. NDA table 4.1. Host rocks and cover rocks (Nuclear Decommissioning Authority 2010). The two entries have been ringed because they mean the same thing – sediments from host rock depth to surface.