

Geological Society, London, Memoirs

Chapter 20 Nirex and the great denouement

Geological Society, London, Memoirs 2002; v. 25; p. 271-287
doi:10.1144/GSL.MEM.2002.025.01.21

Email alerting service [click here](#) to receive free email alerts when new articles cite this article

Permission request [click here](#) to seek permission to re-use all or part of this article

Subscribe [click here](#) to subscribe to Geological Society, London, Memoirs or the Lyell Collection

Notes

Downloaded by University of Glasgow on 4 October 2010

Chapter 20

Nirex and the great denouement

We saw in Chapter 14 how the British Geological Survey came under pressure in various ways in the 1980s – the ‘Thatcher years’. Some of its basic funding was diverted to the universities, and one of the reasons for the collaboration between the Survey and the universities was that it provided a means whereby it could recoup its ‘own’ money, so to speak, via the NERC-funded PhD studentships. However, that in itself was insufficient, and increasingly the Survey had to go into the market to help fund its activities through contract or consulting activities. With its large staff and accumulated experience and databases, the BGS (or Institute of Geological Sciences before the beginning of 1984) could readily aspire to be the largest and best geological consulting agency in Britain, although taking on a consultative role entailed a change in its ethos. We can see this manifested in 1991 when three new divisions were established: International, Marketing, and Corporate Coordination and Information. The posts of Chief Geologist, Chief Geochemist and Chief Geophysicist were abolished. Four new programme divisions were established: Thematic Maps and Onshore Surveys; Petroleum Geology, Geophysics and Offshore Surveys; Minerals and Geochemical Surveys; and Groundwater and Geotechnical Surveys (Hackett 1999, p. 7).

A considerable amount of the BGS’s consulting work had to do with the nuclear industry and radioactive waste disposal.¹ In the early 1970s, the BGS (then IGS) and the Natural Environment Research Council began to focus on the pending major problem of nuclear waste disposal, and in the mid-1970s the BGS began a research programme into the problem of high-level waste for the UK Atomic Energy Authority, leading to reports such as Chapman (1979). However, this work ceased in 1981, following a change in Government policy. Then in 1984 the BGS started advising a company or organization called United Kingdom Nirex (NIREX = ‘Nuclear Industry Radioactive Waste Executive’) on shallow disposal options, but this work stopped in 1987, when the Government again rethought its strategy and began to develop a national geological review of options and selection criteria (David Holmes, BGS, pers. comm., 2000). A Government advisory body, the Radioactive Waste Management Advisory Committee (RWMAC), had earlier been established in 1978 to keep an eye on the disposal of nuclear waste in Britain and other matters to do with the nuclear industry.

An opportunity favourable to the BGS emerged in the late 1980s, with the award of a series of contracts to assist in the study of the rocks in the area of the nuclear reprocessing plant at Sellafield, near the Cumbrian coast, to the west of the Lake District National Park,² and the provision of hydrogeological information necessary to determine whether this site might provide a suitable

repository for the permanent disposal of nuclear waste (see Fig. 20.1). The intended rocks to receive the waste were of BVG type, under the sedimentary cover of the west Cumbrian coastal plain. There was, of course, considerable BGS expertise available with such rocks, given that the Lakeland Project had been active for several years. Thus it was that several Surveyors, including David Millward, Eric Johnson, Brett Beddoe-Stephens, Andrew Chadwick and David Evans (a geophysicist), who had all worked on Lakeland rocks in one way or another, undertook work in relation to the proposed intermediate- and low-level nuclear waste repository near Sellafield. There were also geochemists and hydrogeologists. The team leader was Douglas Holliday, whom we met in Chapter 18. He had not been a part of the Lakeland Project, his specialty being Permo-Triassic, rather than Ordovician, rocks.

The use of the Sellafield site would minimize problems of transporting waste before burial; and it was thought that there would be acceptance of more ‘nuclear activity’ in the west Cumbrian community, already accustomed to and dependent on the nuclear industry. It was known from the 1930s surveying that BVG rocks existed under the west Cumbrian plain, below a relatively thin sedimentary cover (see Fig. 4.9), but more up-to-date and detailed geological knowledge was needed to accomplish the Nirex plan, even though a new section had been provided with the revised Gosforth Sheet (1980).³

Let us now recount some of the events relating to the geological work done by Nirex,⁴ the BGS, and other consulting companies at Sellafield. This is a legitimate extension of the present study: first, because it has to do with Lakeland-type rocks; second, because it had to do with the activities and well-being of the BGS; third, because staff from both the Survey and university contributors to the Lakeland Project became deeply involved; and fourth because it raises important social and political questions about the relationship between science, government and citizens in modern democracies.

Nirex’s former Manager for Site Characterization at Sellafield, Dr Robert Chaplow,⁵ has kindly provided me with information about the early days of the company’s Sellafield project (pers. comm., 1999).⁶ Nirex was founded in 1982 (then as NIREX) as an executive body, with a remit to find a safe and permanent site for the disposal of nuclear waste in Britain. The intention was to find surface or near-surface sites for low-level waste and a deep underground site for intermediate-level waste. Initially, the organization was owned by the privatized nuclear industry; but in 1985 it became a limited liability company, the shareholders, however, being the various British nuclear industries, the main producers of the waste.⁷ The Government, through the Secretary of State for

¹ Such work was not altogether new. Indeed, some of it went back to the 1950s.

² There had long been a large nuclear industry in west Cumbria, albeit one with a chequered history, notably the serious fire in 1957 at the Windscale works. Following the decision of Parliament in 1978, the construction of a nuclear reprocessing plant was begun at Sellafield close by, and it was the permanent disposal of radioactive waste from this plant that was the main problem for Nirex so far as the present study is concerned. The nuclear plant has long been a major source of employment in the district, of great importance since the near exhaustion of the haematite deposits and the decline of the ship-building industry at Barrow-in-Furness, particularly after the close of the Cold War. It is also of great importance to Britain as a whole, for its nuclear industry.

³ The compilation of this revised map did not involve a comprehensive resurvey and preceded the Lakeland Project.

⁴ For something of the history of the socio-political and scientific developments, see Kelling & Knill (1997); Haszeldine & Smythe (1997); Couples *et al.* (1998).

⁵ Bob Chaplow (b. 1947) read geology at Imperial College, London and then went on to do a London external PhD in engineering geology while he was working for the geotechnical and civil engineering consultant company, Sir Alexander Gibb & Partners. He later lectured in engineering geology at Imperial College for four years, but subsequently returned to industry, working for Gibb, during which period his responsibilities included overseeing the geotechnical work at Dounreay. In 1993, he became a member of the Nirex staff, as Manager for Site Characterization at Sellafield (pers. comm., 1999).

⁶ For further information on Nirex’s research history and strategy, see Nirex (1997b).

⁷ In 1999–2000 the shareholders were British Nuclear Fuels, Magnox Electric, United Kingdom Atomic Energy Authority, British Energy Generation Ltd (formerly Nuclear Electric Ltd), British Energy Generation (UK) Ltd (formerly Scottish Nuclear Ltd), and the Secretary of State for Trade and Industry (1 share out of a total of 10 001 shares) (Nirex 2000, p. 9).

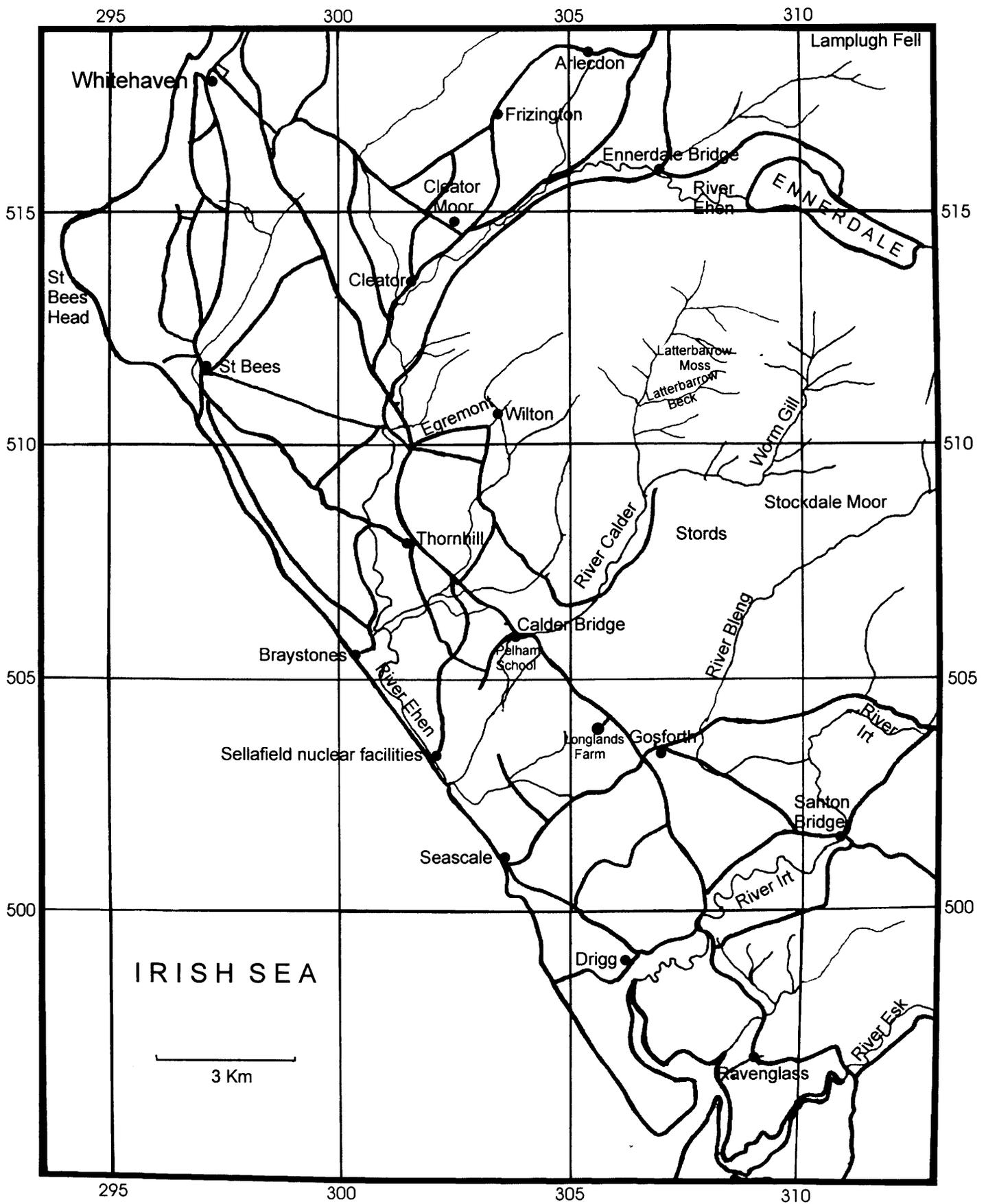


Fig. 20.1. Topography of west Cumbria in the area around the Sellafield nuclear facilities.

Trade and Industry, retained a small amount of ownership, with that Department holding a 'golden share' securing safeguard powers. The Government exercised ultimate control through its ownership of the United Kingdom Atomic Energy Authority,

British Nuclear Fuels Ltd, and the Central Electricity Generating Board. Nirex Board minutes are transmitted to the Department of Trade and Industry. The company headquarters are near the nuclear facilities at Harwell.

The main product that Nirex had to sell was expertise, and advice to the Government and the nuclear industry, but it outsourced much of the work to consultants, amongst which the BGS is of special interest to us. Nirex was also responsible for practical matters to do with nuclear waste burial. Its income derives from the nuclear industry, which in turn is derived from electricity purchasers.⁸

A disposal site in an old anhydrite mine at Billingham, near Middlesborough, NE England, was initially considered, but proved unfeasible because of local opposition. A site at Elstow, Bedfordshire, in Oxford Clay, was also considered but got nowhere (Chapman 1986). In the 1980s, then, Nirex undertook a 'desk-top' study of some 500 sites that might, *prima facie*, be suitable for waste burial. Many of them were in areas of low population in western Scotland (Chapman 1986, p. 129). The sites were successively narrowed down to 200, to 50, to 12 and then to 10, setting aside two that were offshore.⁹ The 10 remaining sites were confidential and, except for the two where exploratory investigations were eventually started (Sellafield and Dounreay in northern Scotland), they remain so. Numerous factors had to be considered: the geological situation; population densities; transport distances; and (importantly) local acceptance.¹⁰ Thus the sites were subjected to 'multi-attribute decision analysis' (MADA), according to which all relevant factors, weighted appropriately, were taken into systematic consideration.

Following the several culls of the options, three short-lists were prepared (containing three, four and five sites respectively) and submitted to the Nirex Board for consideration. In the event, the three-site list was selected (in 1989). It had the Basement Under Sedimentary Cover (BUSC) site in the Sellafield area (Cumbrian coast, near Gosforth); a site in Palaeozoic to Precambrian rocks at Dounreay, adjacent to a nuclear power station on the north Scottish coast; and a 'Site Six' (one of the 10 then under consideration), said by Dr Chaplow to be a BUSC locality also. On the basis of the information before it, the Board decided that Sellafield and Dounreay should be recommended to the Government for practical investigation. Non-geological factors were clearly important considerations; but that is not to say that Sellafield or Dounreay were not the 'best' sites, all things considered.¹¹

Planning permission from local government was required for exploratory drilling, and this was obtained for both Sellafield and Dounreay, 'Site 6' being discarded from further consideration. At Sellafield, the initial plan was to investigate the area directly under the nuclear facility, using a drilling technique that involved boring obliquely and 'steering round a corner'. The Cumbria County Council refused permission, but the decision was overturned on appeal and the design work for the deviated borehole was undertaken, through a complex web of subcontractual arrangements. The work was managed by British Nuclear Fuels Ltd as agents to Nirex. BNFL appointed Robertson Research Ltd of North Wales, in association with another company Hydrotechnica, as management contractor, who awarded the contract for the actual physical work to a Shrewsbury hydrogeological consultancy called Entec. The borehole design was commissioned by BNFL, who in turn commissioned British Coal to do the job. BNFL appointed British Drilling and Freezing Ltd to undertake the actual drilling.¹²

Possibly the web of responsibilities did not help, but whatever the reason, the first borehole did not reach its design depth and was, as described to me by Dr Chaplow, 'a disaster'! The drill got round the corner and down to 1100 m, but then stuck. The drill-string parted and the core-barrel could not be recovered. A second attempt was made, but that was no more successful and the hole was sealed off and abandoned with relatively little data acquired. However, according to Michie (pers. comm., 2001) the geological data obtained were later useful for interpreting the seismic data in the area, and the borehole also provided the first indication of saline water at depth in the Sellafield area.

BNFL then appointed Gibb Deep Geology Group for later boreholes. This group comprised Sir Alexander Gibb & Partners Ltd in association with GeoScience Ltd (a company from Falmouth that specialized in deep drilling investigations, especially 'hot, dry rock'); a geophysical consultancy J. Arthur & Associates; the BGS; Golder Associates (UK) Ltd; and Entec Hydrotechnica Ltd. A joint venture called KSW was to be responsible for drilling the boreholes, comprising Kenting Drilling Co. Ltd, Soil Mechanics Ltd, and Gewerkschaft Walther (a German manufacturer of the wireline drilling string), and the subsequent drilling was successful. The same group undertook drilling at both Dounreay and Sellafield. Geophysical survey was also undertaken, in addition to direct drilling. The Gibb Deep Geology Group was responsible for preparing reports on the results of the investigations, in accordance with the requirements of British Standard 5882. On instructions from Nirex, all the factual reports were classified as 'Commercial in Confidence' (Chaplow, pers. comm., 2001). The various reports were thus published 'in-house' by Nirex, but were formally reviewed. Later, the Royal Society Study Group (1994, p. 90) commented on the strength of the technical reviewing.

Borehole 2, about 2.5 km inland from Sellafield, was begun in August 1990 under the new management arrangements of the Gibb Group and KSW, reaching a depth of 1610 m by April 1991. It was intended to examine and characterize the basement BVG rocks, which were relatively shallow at the locality of the borehole. A fully cored borehole was successfully achieved, and hydrogeological testing, hydrochemical sampling and geophysical logging were undertaken; and an initial assessment of the rock mass was made. Emphasis was given to obtaining a high-quality core for logging. Similar techniques were used for subsequent boreholes. During 1989–1991, regional geophysical work was also carried out in the Sellafield area, both onshore and offshore, involving seismic, gravity and electromagnetic surveys, some airborne. Boreholes 3 and 4 were drilled between December 1990 and July 1991, the former being fairly close to Borehole 1, within the area of the Sellafield works, and the latter not far from Borehole 2 (Alan Hooper, pers. comm., 2001).

By 1991, it was decided that both Sellafield and Dounreay offered potentially feasible sites, the plan at Sellafield being to store the waste in BVG rock, under the overlying Permo-Triassic sediments. In the event, the Sellafield option was preferred and detailed investigation of the site begun the same year. A suitable Potential Repository Zone (PRZ) was considered to be under Longlands Farm, owned by BNFL, about 3 km inland from the

⁸ I use the past tense here as befits a historical study, but Nirex's work still continues at the time of writing.

⁹ Nirex did not rule out the offshore options, and possibly they may be used in the future, if permitted by international agreement.

¹⁰ As one Surveyor put it to me with all seriousness, the site could not be located in Scotland or Wales because of nationalist sentiments; Northern Ireland was not a good idea because of political instability; rural Tory electorates were never thought appropriate by the Tory Government; and high population-density Labour electorates would not do either. So the Cumberland coast was probably always going to be the 'winner', as it had a previous familiarity with nuclear installations; it was a Labour electorate with a considerable unemployment problem; and most of the nuclear waste was at hand and would not have to be shunted round the country. Of course, the procedures used in the selection process were infinitely more complex than this, but perhaps the Surveyor's comment summarizes the public perceptions of the matter.

¹¹ For additional information on the choice of sites, see Nirex Report 71 (1989); and Cumbria County Council Appeal by United Kingdom Nirex Limited, APP/H0900/A/94/247019, pp. 147–169.

¹² Clarification of the interconnections supplied by Chaplow (pers. comm., 2001); also, according to Uisdean Michie (pers. comm., 2001), Robertson Research was taken over to become in part Hydrotechnica and then Entec.

Sellafield plant (see Fig. 20.1).¹³ More boreholes were put down, until no less than 29 were made by 1997, some inclined but mostly vertical, with the highest density of holes being near Longlands Farm (Bowden *et al.* 1998, p. 126). A vast amount of stratigraphic, geochemical and geophysical information was collected.

By 1992, Nirex thought it had sufficient information to suggest that the Longlands Farm site might indeed be feasible, but did not have enough for planning permission to be assured. So they proposed to gather more data, by excavating into the general area where future storage was envisaged, for direct examination of the conditions. Thus the idea of constructing a 'Rock Characterization Facility' (RCF) – an 'underground laboratory' in BVG rock – was proposed,¹⁴ where determinations could be made of the degree of rock fracture and the rate of water flow through the rock at that depth.¹⁵ Such information could be calculated by hydrogeological modelling, but there were many possible models and relevant factors. The RCF would make possible the application of the hypothetico-deductive model for science: make assumptions; build a mathematical model according with those assumptions; insert numbers for the variables in the models; deduce empirically testable information from the model; and then test the models empirically, to see which is the most satisfactory. The RCF was required to assist this last step of the process. However, the very construction of the RCF, with the intended two 5-m shafts to a depth of about a kilometre and galleries opening out into the BVG rocks, might alter the hydrological situation in the proposed site.

In 1992, application was made to the Cumbria County Council to drill 11 boreholes around the proposed RCF site and one in the centre, to give a network for monitoring water-flows. Permission was granted, and some £45 million were spent on the drilling work in 1993 (Chaplow, pers. comm., 1999). The results were published as they came out, and on 9 October 1993, a meeting of the Yorkshire Geological Society was held at the BGS Keyworth headquarters, where the results of the investigations were discussed, the papers subsequently being published in the Society's *Proceedings* in 1994. They included a number of coloured plates with the help of a subvention from Nirex. This donation was acknowledged in the journal and Nirex was flagged as the 'patron' of the Society (founded 1837). The geological investigations near Sellafield became the largest ever carried out in Britain (Holliday & Rees 1994, p. 1).

Perhaps Nirex had concerns, or was feeling pressure from public opinion, for in 1993 they invited the Royal Society to conduct an independent review. This it did, consulting widely and taking submissions from various 'green' groups as well as the nuclear industry. The report (Royal Society Study Group 1994) commented favourably on the quality of Nirex's data, but was critical on some points, particularly to do with the short timetable laid down for the work, and some lack of openness and external peer-review. Their report stated,

We were forcibly struck during this study by the extent to which some scientific reports 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. We were informed about the methodologies 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. In particu-

lar, we were not supplied with all the assumptions and parameter values underlying the calculations in Nirex report 525 . . . [Nirex 1993a], nor did we receive any results other than those given in graphical form in that report (Royal Society Study Group 1994, p. 6).

However, Chaplow (pers. comm., 2001) has pointed out that the withheld data referred to radiological, not geological or hydrogeological, matters. Further, Report 525 (which was one in which Nirex summarized its model for the flow of water through the proposed repository site and the time it might take to reach the surface after its closure) was an 'executive summary' of the earlier four-volume Nirex Report 524 (December 1993), which was available to all, and was utilized by the Royal Society's Group. Hooper (pers. comm., 2001), Nirex's Manager for Science, has taken the view that 'the Study Group was given a full account of the development of the models for groundwater flow'. He also has informed me (pers. comm., 2001) that the only documents to which access was not afforded were 'preliminary repository safety assessments'.

In any case, whatever reservations it may have had, the Study Group recommended the construction of the RCF, opining (p. 110) that Nirex had 'provided a relatively robust description of the general groundwater flow regime'. However, its report continued, 'an important unresolved issue has been encountered: the most detailed geological and hydrogeological data yet available have failed to yield a simple relationship between the inferred pattern of fracturing in the repository host rock, the Borrowdale Volcanic, and the organization of groundwater flow patterns'.

By mid-1994 Nirex felt in a position to apply to Cumbria County Council to construct the desired RCF under the Longlands Farm area; but opposition was growing. Despite the fact that there was a degree of local support for the nuclear industry, which brought employment and an element of prosperity to an area with greatly diminished haematite mining, steel and shipbuilding industries, there were memories of radioactive contamination of the Irish Sea in the early days when nuclear waste was discharged directly into the sea; of the Chernobyl disaster; and of the Windscale fire in the 1950s. Moreover, there was a public perception (right or wrong) of above-average radiogenic diseases in west Cumbria. Besides, the Sellafield works was close to the Lakeland National Park. Groups such as Greenpeace, Friends of the Earth, and Cumbrians Opposed to Radioactive Environment rallied against the proposal.

Thus planning permission for the construction of the RCF was refused in December 1994 (*Whitehaven News*, 22 December 1994). Nirex immediately appealed, and this set in train a sequence of events that led to the holding of a major public inquiry into Nirex's RCF proposal. The Inquiry, which ran from 5 September 1995 to 1 February 1996, was not held in London, Carlisle or Whitehaven, but in the town hall of impoverished Cleator Moor, an 'ex'-haematite town, near Sellafield (see Fig. 20.1). A team of five lawyers led by Lionel Reade, QC, and 44 other staff was assembled by Nirex, and 18 expert witnesses were called. Opposing them, also with expert witnesses, were representatives of Cumbria County Council, the Gosforth and Copeland Borough Councils, Greenpeace, Friends of the Earth, local conservation groups, and concerned individuals. The Irish Government also sent representatives. The local Labour MP, Jack Cunningham supported the proposal, as did the unions at the nuclear plant. The Inquiry's chairman (or 'Inspector') was a

¹³ Initially a site, 'Sellafield A', under the nuclear facilities, was considered. Later 'Sellafield B' (at the Pelham School Estate near Calder Bridge) came under discussion, and was subjected to 'MADA' in the site-selection process. Eventually the site at Longlands Farm, 2.4 km to the SE of 'Sellafield B' was fixed on, the land there being purchased in 1989, having been offered for sale to BNFL in 1987. Longlands Farm had the advantage of avoiding the Carboniferous Limestone (which could have weathered out underground in all manner of ways) under 'Sellafield B', but the locality was regarded as otherwise similar so far as MADA was concerned.

¹⁴ Such an idea was not new. The general idea of an RCF (not specific to Sellafield) was mentioned by Chapman (1986, p. 132).

¹⁵ The estimated cost was £192 million (*Daily Telegraph*, 18 March 1997).

solicitor, Mr Christopher McDonald, assisted by Mr Christopher Jarvis, solicitor, and by the mining and engineering consultant geologist, Mr Colin Knipe ('Assessor'), who evaluated the technical information.¹⁶ The cost to Cumbria Council was estimated at about half a million pounds, whereas the bill for Nirex came in at about ten million (*Whitehaven News*, 1 February, 1996).

One of the observers of the events, Chris McKeown, of whom more anon (see p. 281), has described them to me rather graphically (pers. comm., 2000). The Greenpeace lawyers and scientists were all women. They were extraordinarily dedicated, McKeown recalls – chopping food for dinner at the same time as discussing, for example, the redox properties of pyrite and whether its presence was or was not a definitive indicator of a reducing environment, relevant to the stability and mobility of certain uranium compounds (which are more mobile in an oxidizing environment). Another of the witnesses who presented evidence for Friends of the Earth, Professor David Smythe (also of whom more anon: see p. 278), recalled that Mr McDonald and his assistants sat on the platform of the Cleator Moor Town Hall; the Nirex people were at tables down the hall to their right, while the 'objectors' were at their tables on the left, each with rows of boxes containing numerous documents (Smythe, pers. comm., 2000). The Inquiry had the status of a court of law. That is, McDonald had to call, hear and assess all available evidence and then form an opinion of the merits of the cases; and he could require witnesses to reveal all they knew on any issue. In his report, Knipe had the daunting task of providing intelligible answers to the questions posed to him by the Inspector on the vast amount of technical evidence tendered. McDonald had to write a report to the Minister of the Environment (Mr John Gummer), who then had to decide whether to accept or reject the Inspector's recommendations, either in whole or in part. It took McDonald until the beginning of 1997 to complete his report.¹⁷

After deliberating, the Minister accepted the Inspector's recommendations on 17 March 1997, and Nirex's appeal was dismissed, in what *The Independent* (18 March 1997) described as a 'surprise decision'. So the work on the Longlands Farm site was run down and was closed before the end of the century. There was no further search for a British repository site in the twentieth century. Mr Gummer's decision was reached in the context of an upcoming general election, and widespread opposition to the scheme.

It is said that Nirex was shocked by the result, for – in public – they had expected to win the appeal, and certainly wished to do so, having already spent about £400 million on research in west Cumbria and on administrative and legal costs (*The Independent*, 17 March 1997) – a figure confirmed in round numbers to me by Bob Chaplow, with, however, only about half the sum going into actual technical work (pers. comm., 1999, 2001). It was, as it appears to me, something of a David and Goliath contest, in that the Nirex team was defeated by a coalition which, though well briefed, lacked the funding available to Nirex.¹⁸ Having lost the case, the Nirex Board voted its Managing Director, Michael Folger, a pay bonus greater than the annual salary of Dr Rachel

Western of Friends of the Earth (*Whitehaven News*, 6 November, 1997), who assisted the Friends' solicitor, John Popham, and did much to lead the campaign.

Before getting into more strictly geological issues, it may be mentioned that those protesting against the Nirex case represented the RCF proposal as a kind of 'Trojan Horse': it was claimed that if the research facility were constructed so much money would be spent on it that there would be an irresistible pressure to continue and turn the 'research hole' into an actual repository. Thus it was that there was a 'demo' outside the Inquiry at the time of the Inquiry, with a large model horse paraded through the street, hauled by hooded figures with death masks, one carrying a 'grim reaper' scythe. An illustrated report in *New Scientist* (Edwards 1996) stated that the estimated cost of the completed repository would be £1.8 billion. Passions ran high.

According to the impression and recollection of the technical assessor, Colin Knipe, the RCF was indeed intended as the first stage in the establishment of a repository near Sellafield. Nirex presented it as a 'stand-alone project' – the RCF was not to be thought of as connected to an eventual repository. However, during the course of the Inquiry Mr McDonald came to regard the two projects as essentially linked, and in his final conclusions he wrote:

[T]he work on the repository project is much too advanced for Nirex to be able to claim that the potential repository is merely hypothetical, and that it should be ignored for the purposes of the present appeal apart from reviewing the choice of location. Nirex has been working on the Sellafield repository project for several years: . . . and parts of the RCF could well be used for repository construction. The connection between the RCF and the repository is direct and obvious, and so cannot be set aside in the rest of the appeal determination process (Annex 1 to Inspector's Report, APP/H0900/A/94/247019, p. 266).

This, one might say, was the 'Trojan Horse' aspect. However, the Inspector did not ask Nirex to make a case for the whole project.

Nirex was required to demonstrate the relative merits of Sellafield, as opposed to other possibilities, and demonstrate how they had arrived at the Cumbrian site as their first choice. In Colin Knipe's view (pers. comm., 2001), the selection process that led to Sellafield emerging as the preferred site was 'by no means transparent', but was 'highly contrived'. Sellafield, he thought, should never have got through the sieving process: it did not have a low hydraulic gradient; it was not a geologically simple locality; it was not a geodynamically stable locality, being close to the Lakeland Boundary Fault; it did not have readily predictable groundwater flow paths; and the flow paths were undesirably short.

Leaving aside now these interesting matters, let us return to the scientific issues, with particular reference to the work of the BGS. The plan for the RCF was to excavate a cavity in BVG rocks below Longlands Farm – in the Fleming Hall Formation (see p. 276), at a depth of about 650 m. There, if results proved favourable, the nuclear waste might be buried to all eternity. But would such a burial be safe – such that the deaths resulting would

¹⁶ Colin Knipe (b. 1943) was reared in Barrow-in-Furness and acquired an interest in Lakeland geology from an early age. He studied geology at King's College, London, and after a short stint of teaching in Barrow he went into the area of local government strategic planning, where he became familiar with planning procedures for town and country planning. He also assisted in the work of a national minerals assessment unit for the BGS. He was offered a position there, but preferred to take one (in 1968) in the geotechnical, land and mineral resources company Johnson, Poole and Bloomer, at Stourbridge, founded in 1844, the oldest extant company of its kind in Britain (see Rayska 1994), of which in time he became the senior partner. He was invited to take on the job of technical assessor at the Cleator Moor Inquiry following his involvement in two other large technical inquiries: a coal-mining site in Wales (Pull Du) and a clay-pit near Wrexham that had been outgassing methane (pers. comm., 2001). For previous mention of Knipe, see p. 127.

¹⁷ Apart from numerous newspaper reports on the case, one can conveniently consult the Inspector's final report to the Government, a copy of which was made available to me *gratis* by the Cumbria County Council ('Appeal by United Kingdom Nirex Limited': File APP/H0900/A/94/247019); and all the evidence given by the Cumbria County Council, Greenpeace, and Friends of the Earth was collected in the form of a book edited by two of the scientists who opposed the Nirex appeal (Haszeldine & Smythe 1996).

¹⁸ Alan Hooper (pers. comm., 2001) has questioned this. He described Greenpeace as 'a well-funded organisation both nationally and internationally and [it] appeared to have more funding for the aspects of the technical work than [did] Nirex'.

be no more than 1 person million⁻¹ year⁻¹, as safety requirements stipulated?¹⁹ Obviously, lying near the foot of the mountains, the area was subject to a large hydrostatic pressure, and if the rocks were significantly fractured or faulted, water might be expected to seep through them, so that if the chemical containment of the radioactive materials (by concrete and steel, etc.) proved inadequate then radioactivity might be transmitted to the water, eventually reaching the surface or contaminating drinking supplies. To know whether this might eventuate, hydrogeological modelling was needed; and that required detailed knowledge of the geology of the area, and particularly the pattern of faults and the physical and chemical properties of the rocks intended to form the site for the repository. It will be recalled that, according to the thinking of Branney & Soper (1988), the BVG rocks of central Lakeland were broken into a complex pattern of faults arising from caldera collapse in the area of the Central Fells. But what was the situation over to the west and at depth?

Earlier surveying for the Gosforth Sheet had revealed a substantial fault zone running approximately parallel to the coast, and bringing BVG and New Red Sandstone rocks into contact at the surface. This 'Lakeland Boundary Fault' (a northern extension of which was later named the Thistleton Fault) ran more or less along what is now the western boundary of the National Park. Other faults in the New Red Sandstone were also recognized by the early twentieth-century Surveyors (see Fig. 4.9). The area was now remapped in detail for Nirex by BGS staff, working in collaboration with Nirex geologists such as Uisdean Michie,²⁰ Andrew Bowden, Catherine Bumpus, Nick Davies, Anna Littleboy and David Mellor. The earlier survey of Trotter, Hollingworth, Eastwood and Rose undertaken in 1932 (Trotter *et al.* 1937) represented the area between Wastwater and Gosforth on the Gosforth Sheet (37) as having outcrops of rhyolites and dacites, with some andesites to the east, beyond a fault. In the reissue of the map (1980), revised by L. C. Jones in 1979, the rocks were indicated as 'Undivided (mainly lavas)', and a modification of the southern part of their boundary line was made, as compared with 1937.

There was an extended description of these rocks in the Gosforth Memoir (Trotter *et al.* 1937), where they were referred to as andesitic lavas, and rhyolites and associated rocks. A photograph showed good columnar jointing in the 'andesitic lava' (Trotter *et al.* 1937, plate IIB). The locality was not specified precisely, but it appears to have been in the area of 'Table Rock' (NY 088 036) near Bolton Head Farm ENE of Gosforth, where they were referred to as follows:

An interesting feature of these rocks . . . is the frequent occurrence in them of fragments of distinct type, notably microlithic andesite . . . and fragments in varying stages of felsitic devitrification. In some cases the phenocrysts of the enclosing rock are arranged tangentially to the margins of the inclusions. Some, at least, of the fragments appear to be of foreign material caught up in the flow rather than of flow-breccia origin, . . .

In the essentially non-porphyrific types a rough parallelism of the felspar laths induced during flow . . . gives rise to a platy fracture. . . . Narrow veins parallel to the direction of the flow, and consisting of epidote, chlorite and chalcedony . . . or epidote, chlorite and calcite . . . appear to have been formed at a late stage that corresponds with the infilling of the vesicles in other rocks (Trotter *et al.* 1937, p. 32).

This passage was written well before Oliver introduced the category of ignimbrite into Lakeland petrological vocabulary, but the description is, I think, compatible with the rock being of that type. So, as Uisdean Michie recounted to me (pers. comm., 1999), when the resurvey was done in the 1990s there was an attempt to link the evidence from the Borrowdale Volcanics exposed at the western edge of the Lakes with analogous rocks found under Sellafield and Longlands Farm in the boreholes. At the surface, attention was focused on the area east of Gosforth, where, at Table Rock and elsewhere, in Blengdale, or the valley of the River Bleng, a downfaulted area of ignimbrites, etc., was mapped, different from the Birker Fell Andesites to the east, from which they were separated by the Thistleton Fault.

These (re-)examined ignimbrites were not petrologically identical to those of the Scafell Caldera further east, so carefully examined by the Liverpool-Sheffield team. Consequently, a new stratigraphic column was erected for the western area, by examination of rocks exposed at the surface to the east of Gosforth, and in boreholes sunk there and also to the west, under the Permo-Triassic cover around Longlands Farm and Sellafield.

From the surface exposures and more particularly the boreholes, a new stratigraphy for the area below Longlands Farm began to emerge, and the various formations were named after farms in the area above the intended repository between Sellafield and Gosforth (Millward *et al.* 1994):²¹

<i>Unit Name</i>	<i>Lithology</i>
Fleming Hall Formation	Massive, homogeneous, andesitic, mainly densely welded medium- to fine-grained tuff and lapilli tuff (up to 520 m)
Brown Bank Formation	Tuffs with dacitic sheets, welded and locally rheomorphic (45–263 m)
Bleawath Formation	Eutaxitic <i>fiamme</i> -rich lapilli tuff with pumice and lithic clasts (up to 416 m)
Broom Farm Formation	Variable volcanoclastic sandstone (13.5 m)
Moorside Farm Formation	Massive, unbedded, poorly sorted, lithic-rich lapilli tuff, with coarse breccias (over 114 m)

These units could be identified in the drill cores and their characteristic chemical and radiometric signatures determined. When the geochemical signatures were compared, it became evident that the rocks near Table Rock, previously located in the Craghouse Member of the Birker Fell Andesites (Petterson *et al.* 1992), belonged to the Fleming Hall Formation at a higher level in the stratigraphic column. There was, then, the possibility of correlating the subterranean BVGs of the intended RCF area with surface exposures further east (on the other side of the Lakeland Boundary Fault Zone). That is, the subterranean BVGs might be linked into Lakeland geology (Millward *et al.* 1994). However, as it turned out, the western ignimbrites were not one and the same as those of the Central Fells.

A more detailed stratigraphy for the western rocks was subsequently provided in the west Cumbria Memoir (Akhurst *et al.* 1997), and eventually in the re-issued Gosforth map also (BGS 1999b). The Akhurst stratigraphy is reproduced in Figure 20.2.

It is instructive to look at the revised geological map for the

¹⁹ This is a paraphrasing of the long-term safety standard, as set by the UK regulator.

²⁰ Michie (b. 1945), Principal Geologist and Earth Sciences Adviser at Nirex, hailed from Lewis and graduated in geology and mineralogy at Aberdeen. He joined the Survey in 1968 and became involved in several UK Atomic Energy Authority and British Nuclear Fuels research projects, including the study of the geology of the Dounreay area as a potential repository. In 1980 he moved to the Central Electricity Generating Board and developed a programme for the procurement of uranium resources. He joined the Nirex staff in 1990 and was intimately involved with its Sellafield programme. See Michie (1998, p. 257).

²¹ This paper gave somewhat different profiles for areas to the north of the PRZ and beneath the Sellafield and Drigg Works.

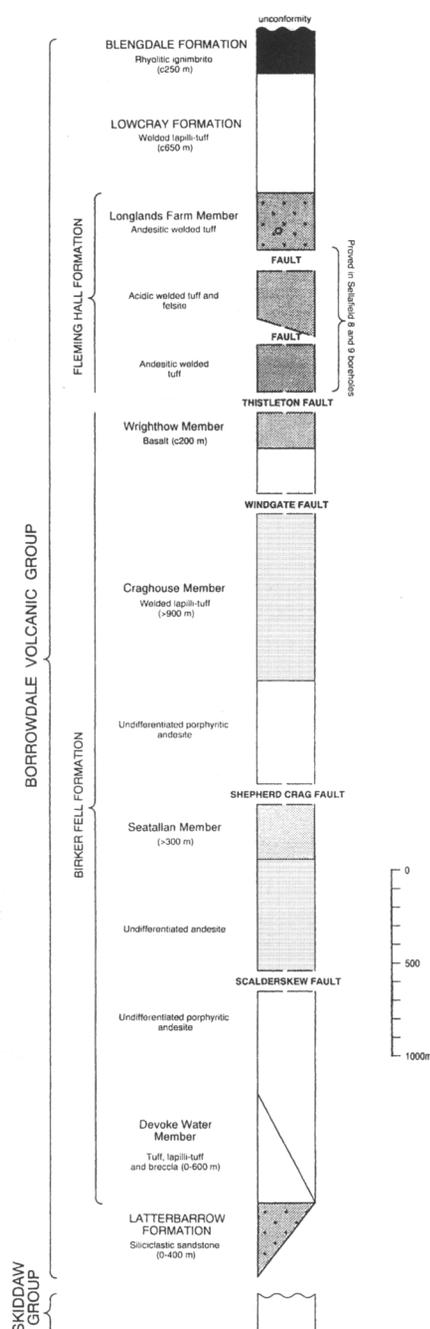


Fig. 20.2. Stratigraphy of the Borrowdale Volcanic Group in the Gosforth area, according to Akhurst *et al.* (1997, p. 44). IPR/23-7C British Geological Survey. © NERC. All rights reserved.

Gosforth area, part of which is reproduced in Plate VIII. The Thistleton Fault forms the eastern boundary of the BVG ignimbrites. The interesting thing to remark in this context is the general form of the ignimbrite complex, which can be construed as the eastern side of a caldera collapse structure, with the western part obscured by Permo-Triassic cover. This was essentially the theory advanced in Millward *et al.* (1994, p. 34) and subsequently developed in Beddoe-Stephens & Millward (2000). That is, the Surveyors had the idea that the Branney & Soper (1988) model for the Central Fells might be applied to the rocks of the western margin of the Lakes, with a separate caldera complex involving ignimbrites ponded within a caldera-type depression. It should be

noted that the part of the Gosforth (1999) map reproduced in Plate VIII was also published in Akhurst *et al.* (1997, p. 24), which stated (p. 112) that the area was surveyed in the years 1990–1993 (by Surveyors Petterson, Barnes, Crofts and Auton).

At the end of the twentieth century, a new stratigraphy was published for the western ignimbrites by Beddoe-Stephens & Millward (2000), confirming that the textures and chemical compositions of the ignimbrites of the western caldera differ significantly from those in the Central Fells, being densely welded and of rather low silica content (63%). Hence a separate caldera sequence was proposed for these rocks, in what the authors termed the ‘Gosforth succession’. In fact, this became one of four caldera or volcanic basin systems envisaged for the Lakes area: Sellafield, Helvellyn, Duddon and Gosforth. The last of these is down-faulted (to the west of the Thistleton–Lakeland Boundary Fault Zone) and supposedly represents a young succession, preserved by the down-faulting. No evidence was found for this former volcano having been underpinned by a granite pluton.

All this had implications for the physical structure of the rocks in the intended RCF zone, for by analogy with the main Lakeland exposures one might also expect to find a tangle of volcano-tectonic faults within the concealed BVG. Also, as we might anticipate, the observations were in line with what might be expected from the theory of caldera collapse. Thus, for example, the Nirex Report (SA/97/032) detailed the results of the investigations in early 1996 for Boreholes 8 and 9, the first of which pierced the Permo-Triassic cover north of Gosforth, penetrating to the BVG rocks below, while the second went directly into the exposed Longlands Farm Member of the Fleming Hall Formation to the ENE of Gosforth. These boreholes were sunk with the intention of comparing the exposed and unexposed western BVG rocks, but the mapping, borehole cores, wireline logs and seismic survey revealed a bewildering complex of faults.

Such results (and others obtained earlier nearer Sellafield) raised the question of whether a sufficiently large block of BVG – of low permeability and good geotechnical properties, such as to allow excavation of underground cavities – existed in the proposed repository area, capable of accommodating radioactive waste safely. The nature of the overlying sedimentary cover was also important, as this influenced the flow paths, the path lengths, and the discharge zones for any material that might escape from the repository. To have a sound opinion on these matters, it was necessary to have a correct understanding of the pattern of faults, and also whether faults did in fact act as conduits for water. It might seem likely that they would; but there was the possibility that they had become sealed, subsequent to their formation, by the deposition of calcite, pyrite or whatever. The pattern of faults in the BVG below Sellafield could not be mapped out from the surface, because of the cover of Permo-Triassic sediments.²² These sediments did contain some identifiable faults, which might represent subsequent movements along old, underlying fractures, but the likelihood was, considering the mode of formation of the BVG and all the movements related to Iapetus closure, the subsequent ‘big crunch’ in the Emsian and Tertiary uplift, that there were many more subsurface faults than could be recognized at the surface. These faults had to be located and mapped satisfactorily.

From the beginning of the Nirex work at Sellafield, a considerable amount of geophysical survey – gravimetric, geomagnetic, radiometric, electromagnetic and seismic – was undertaken, both onshore and offshore and with airborne as well as land measurements (Michie & Bowden 1994, p. 7). All this was done in addition to and separately from the study of the general surface survey of the Sellafield region, undertaken by the BGS under contract to Nirex. (This fitted into the Lakeland Project and Land Survey programme rather well, though it drew Surveyors away from areas

²² The Triassic component of these was called the St Bees Sandstone in the 1930s survey, but this unit was renamed the Sherwood Sandstone with three constituent formations: Ormskirk Sandstone, Calder Sandstone and St Bees Sandstone (Barnes *et al.* 1994).

such as the southeastern Lakes, where they might otherwise have been working to complete the Lakeland mapping.)

So the geophysical data were analysed, with the help of information from the boreholes, yielding mostly two-dimensional sections of the BVG rocks underlying the Sellafield area. These revealed a complex pattern of subsurface faults – but much play was made by Nirex's opponents at the Inquiry about the rather rapidly changing interpretations of the fault systems, with a succession of reports showing interpretations that were not merely becoming more refined but were in some respects inconsistent with one another (for a simplified summary, see Edwards 1996; Haszeldine & Smythe 1997, p. 253). The early interpretations were made using vibroseismic techniques with the tests performed on roads, with 'infill' survey based on reflections from signals generated by small explosions.²³ However, the results were only analysed two-dimensionally, and such profiles did not readily reveal whether there was a mass of rock under Longlands Farm that might serve as a repository. For this purpose, one either had to go down and look, by constructing an RCF, or one needed to use an improved vibroseismic technique, and advanced computing facilities, which could reveal the three-dimensional structures.

As mentioned, Nirex was anxious to move ahead with its programme, and thus it was that it proceeded to the Inquiry largely on the basis of information derived from its two-dimensional profiles, rather than three-dimensional information. But this was, perhaps, a case of where it would have been better to have hastened slowly, for the question of which kind of technique or analysis was necessary and sufficient became a central issue for the Inquiry. Here the evidence and arguments of Professor David Smythe, then of Glasgow University, are particularly important for the present account (Smythe, pers. comm., 2000). We have already met Smythe's name in connection with his paper with Beamish about possible fault structures under the Southern Uplands (see p. 151).

Smythe was employed in the Marine Division of the BGS from 1973 to 1987 doing geological and geophysical work in the western seaboard of northern Britain and the North Atlantic. The work had to do with oil exploration and the search for nuclear waste sites. In 1988, he was appointed to a chair in geophysics at Glasgow University, funded by 'Britoil' (the privatized British National Oil Corporation), but this company was soon taken over by British Petroleum. Smythe found it difficult to get industrial funding from other companies, as they assumed he was funded by Britoil (BP), although BP had apparently lost interest in its Glasgow operations and put little money into the Glasgow department. So in 1989 Smythe joined a group that was investigating the famous deep borehole on the Kola Peninsula near Murmansk, and collected deep crustal seismic reflection data²⁴ – in a window of scientific opportunity between the end of the communist era and the collapse of the Russian economy and the emergence of the Mafia, which soon made it ill-advised to engage in financial contracts in Russia.

In 1990, Smythe was asked to join a panel set up by British Nuclear Fuels Ltd to review the work being done at Sellafield by Nirex and its contractors, consisting of himself (geophysics), John Lloyd (Birmingham, hydrogeology), Michael Coward (Imperial College, structural geology), and Brian Williams (Aberdeen, sedimentology). Fairly soon afterwards, he decided to resign from this group, partly because of pressure of work at Glasgow, and partly because, as it appeared to him (Smythe, pers. comm., 2000), the

review process was being driven by a pre-arranged timetable, which was intended to yield a positive outcome by the end of 1994, going through all the geological assessments, planning permission applications, and reviews by then.²⁵ As funding from NERC had not been obtained for the Kola project, Smythe felt under pressure to apply for contract research grants to keep the Glasgow coffers supplied. He had the equipment appropriate for a 3-D survey at Sellafield, derived from the Kola project.

Thus Smythe approached Nirex to see whether they were interested in using his facilities and expertise. Alexander Gibb & Co. (or the Gibb Deep Geology Group) had previously prepared a report (GIBB/92127A/RS/TR/046, not seen), which argued that a 3-D survey of the area of the potential repository zone (PRZ) should be undertaken, using dynamite explosions as the source. Smythe was asked to comment on this. This he did in a report submitted in January 1994, in which he recommended that a high-resolution 3-D vibroseis trial survey be conducted, such as he (or Glasgow University) would be in a position to undertake, for a price expected to be a lower figure than what Gibb would charge, though the commercial company could probably deliver more rapidly. In particular, it was necessary to determine whether the vibroseis equipment could yield satisfactory results when used 'off-road'.

Smythe's offer led to much internal discussion at Nirex. There was doubt as to whether the BVG's deep structure could be imaged satisfactorily using a vibroseis source. There might be adverse effects of the work on the local fauna. There was also the large cost of a full-scale survey to consider – perhaps some £4 million. But something was needed, as there had been some inconsistencies between the borehole evidence and that from the earlier 2-D surveys and accurate knowledge of the geological structures was needed if satisfactory hydrogeological modelling were to be achieved. Michie took the view that a full 3-D survey was needed if a planning application for a repository was to be supported by appropriate evidence, but this would need to be preceded by a trial survey such as the Glasgow group might be able to undertake. In the event, Nirex opted for a pilot study, to be undertaken by Smythe and his team, rather than a large-scale investigation such as the Gibb proposal envisaged.

Thus Smythe and Glasgow University obtained a contract (for £270 000) to undertake a pilot study, which he carried out in 1994, in conjunction with his students and in collaboration with an ex-Coal Board company called International Mining Consultants Ltd (later IMC Geophysics Ltd). He thought that the work was scientifically and technically interesting and of national importance. He was not in principle opposed to the idea of the underground disposal of nuclear waste. While in the field, some of Smythe's apparatus was sabotaged by protest groups, but the damage was not too serious and a preliminary report was presented to a Nirex meeting at Harwell on 16 December 1994. According to Smythe's recollection, his work revealed the existence of a hitherto unrecognized N-S fault running through the proposed area of the repository, but according to Michie (pers. comm., 2001), the 3-D vibroseis technique produced structural information that helped resolve the various strands of a fault that had previously been recognized in the area ('Fault 2'). As it happened, four days later the Cumbria County Council refused the application for the construction of the RCF, but the timing was presumably coincidental. An acquisition report, which made some use of material provided by Smythe, was compiled by

²³ 'Vibroseis' is the trade-mark of a device that uses a vibrator plate acting on the ground for a few seconds to generate a wave-train comprising a sweep of frequencies. Several such instruments are sometimes used over an area in conjunction with one another. From the recorded data, a computer can produce a conventional-looking seismic section, such as can be obtained from the use of explosions. The vibroseismic technique is amenable to the determination of geological structures in two or three dimensions.

²⁴ This important work allowed direct examination of mid-crustal rocks and comparison with their seismic signatures.

²⁵ This group was disbanded after Smythe left and another one was subsequently formed by Nirex itself. This included Lloyd and Coward, and included the volcanologist professors Stephen Sparks (Bristol) and G. D. Price (London) for geomechanics. It was chaired by Professor Keith O'Nions from Oxford (Uisdean Michie, pers. comm., 2001).

Gibb and submitted to Nirex (Report 622) on 28 December 1994 (Chaplow, pers. comm., 2001).

Subsequently, Smythe submitted his draft report on 31 March 1995 (Nirex Report 760), and a two-page abstract was published in the proceedings of the annual meeting of the European Association of Exploration Geophysicists, which happened to meet in Glasgow that year (Smythe *et al.* 1995). Nothing more than this was published as a fully refereed academic paper.

Given that there was a time-window created by the initial refusal of planning permission, Nirex might have proceeded to a full 3-D survey, which might have been ready by 1996–1997, but Chaplow was concerned that the costs would be high if the whole area of the PRZ were investigated at depth, and he recommended that a full evaluation of the results achieved to date should be made before proceeding to more data collection. Adding complexity, Smythe changed his mind about some details presented at the December meeting, and then reverted to his original position; and he also reported an additional correction (Chaplow, pers. comm., 2001). So Smythe's report was sent off to review by a company called IKODA, who came up with 13 pages of comment, in consequence of which Smythe was requested in August 1995 to revise his report, taking the comments into consideration. His revised report was eventually received by Nirex on 18 September 1996 (Chaplow, pers. comm., 2001). Thus we find that each party viewed the other as being slow in delivery.

In the meantime, Smythe had accepted an invitation from Rachel Western to appear as a witness on behalf of Friends of the Earth for the Cleator Moor Inquiry, but his situation was becoming difficult at Glasgow because of the delay of Nirex's response to his draft report. As he recalled, he felt under pressure for failure to produce publications – the latter being absent partly because of the time spent on the Nirex work (Smythe might have been better off publishing the results of his Kola Peninsula investigations). Also, because of the delay in the response to his draft report he had no publications to show (other than the abstract mentioned above) that could be ready for the 1996 university review process.

Perhaps unsurprisingly, given the sequence of events recounted above, Nirex did not utilize the results of Smythe's work in evidence at the Inquiry. In late 1995 and early 1996, in response to Nirex's criticisms of some details of his preliminary report, Smythe was trying to re-process data, using an expensive computer program, borrowed 'on approval' with a 'sunset clause'. The program was found to have a bug in it, which Smythe had to fix, and the work was not completed before the 'sun set' at the end of February 1996. It was only with difficulty that he was later able to obtain funds from the Robertson Trust to enable the University to purchase the program's licence. By the time Smythe's report was completed, the Inquiry was over. In fact, Smythe had been struggling with his computer while it was in progress. But he made it clear to the Inquiry that, in his opinion, a 3-D seismic survey was needed, and that it would be premature to proceed to the construction of the RCF before such a programme was completed and its results analysed (Haszeldine & Smythe 1996, p. 269).

The question of what I would call the 'prematurity' of the appeal and the Inquiry is thus raised. So too are issues of commercial confidentiality and the crossing of the roles of academic and industrial work. Problems can occur when the activities of an academic become tangled with industrial money, not to mention the law (as at the Cleator Moor Inquiry). We are a world away from the days of the gentleman amateur, J. F. N. Green, or the independent Cambridge professor, J. E. Marr. Smythe's personal position was evidently difficult; but it was industry that supplied the expensive instruments required to conduct his 3-D survey and analyse the results.

Smythe was not, of course, the only person who appeared as witness against Nirex at the Cleator Moor Inquiry. Leaving aside here the 'minor groups', there were also:

For Cumbria County Council

Professor John Mather (Royal Holloway College, University of London) on 'Nirex Site Characterization at Sellafield'²⁶

Dr John Starmer (Environmental Resources Management, Virginia, USA) on 'Nirex Performance Assessment for Post-Closure Safety'

For Greenpeace Ltd

Dr Andrew Stirling (Science Policy Research Unit, Sussex University) on 'The Nirex MADA'

Dr Rae Mackay (University of Newcastle) on 'The Effect of Extent of Site Investigation on the Estimation of Radiological Performance and its Relevance to the Proposed Rock Characterization Facility at Sellafield'²⁷

Dr Stuart Haszeldine (University of Glasgow) on 'Subsurface Geology, Geochemistry, and Water Flow at a Rock Characterization Facility (RCF) at Longlands Farm'

Mr Philip Richardson (Geosciences for Development and the Environment, Ashby de la Zouche, Leicestershire) on 'International Practice Regarding In-situ Geological Research Facilities'

Dr Helen Wallace (Greenpeace, London) on 'Model Validation and the Role of the Proposed Rock Characterization Facility at Sellafield'

For Friends of the Earth

Dr Patrick Green and Dr Rachel Western (Friends of the Earth, London) on 'The RCF and Government Policy'

Dr Peter Kokelaar (University of Liverpool) on 'The Borrowdale Volcanic Group'

Professor David Smythe (University of Glasgow) on 'The 3-D Structural Geology of the PRZ'

Mr George Reeves (University of Newcastle) on 'Hydrogeological Investigation Programmes: Best Practice'

Dr Shaun Salmon (Aspinwall & Co., Leeds) on 'The Hydrogeology of Sellafield'

Dr Stephen Hencher (University of Leeds) on 'Fracture Flow Modelling'

Dr John Allison (Bullen & Partners, Croydon) on 'The RCF: Engineering Issues'

Dr Roy Wogelius (University of Manchester) on 'The RCF: Geochemical Issues'

The following gave evidence on behalf of Nirex:

Mr Michael Folger (Managing Director, Nirex)

Dr L. D. Phillips (London School of Economics)

Dr John Holmes (Director of Science, Nirex)

Dr Robert Chaplow (Manager for Site Characterization, Sellafield, Nirex)

Dr Alan Hooper (Manager for Science, Nirex)

Dr D. W. Mellor (RCF Science Manager, Nirex)

Professor Keith O'Nions (Royal Society Professor in Earth Sciences, Cambridge, and Professor of Physics and Chemistry of Minerals, Oxford)

together with 11 further expert witnesses from various geotechnical consulting firms. Introductory and closing statements were also made for each group.

The 'proofs of evidence' presented at the Inquiry by the Cumbria County Council, Greenpeace, and Friends of the Earth groups were published by Haszeldine & Smythe (1996) under the imprimatur of the Department of Geology and Applied Geology, Glasgow University. The intention was to put the objectors' side

²⁶ Mather had previously worked for the BGS, and had been involved in the search for suitable places to bury high-level waste.

²⁷ I am informed by Uisdean Michie (pers. comm., 2001) that Dr Mackay did not in fact appear against Nirex, but informed the Inspector that he was satisfied by his review of the company's proposals.

of the story in the form of an accessible permanent document. Nirex initially put their evidence on the World Wide Web, but it was subsequently withdrawn, and now can only be accessed from the company by request. Nirex did not like the Glasgow book, and the company's Chief Executive Officer contacted the University, pointing out (as I understand from Chaplow, pers. comm., 2001) that Professor Smythe was required to clear materials relevant to the company with Nirex before publication. In fact, many things had been said on public record at the Inquiry (some at the Inspector's behest) and reported in the media, and the Glasgow book *per se* merely made these matters of public record readily accessible. It would, I submit, be preferable if the Nirex evidence were still on the Web, and likewise readily accessible.

It should be noted that the BGS did not formally present evidence at the Cleator Moor Inquiry, though they did prepare a report (SA/95/002) with maps and drawings that summarized the information that they had acquired. This was submitted as part of Chaplow's evidence. According to Douglas Holliday (pers. comm., 1999), the BGS did not want to become involved in the legal forum and Nirex preferred to rely on its lawyers to a considerable extent, though it also called expert witnesses (see above).

The foregoing account has taken us some distance from Lakeland geology as such. So let us return to our geological theme, and what was done at Sellafield, yet also saying something further about the evidence tendered at the Inquiry. In doing this we re-introduce the volcanologist Peter Kokelaar, leader of the Liverpool team doing the contract mapping in the Central Fells.

Kokelaar took the Inquiry through the theory of caldera collapse developed by Branney (and Soper) for the Central Fells, and pointed to the recent paper by Millward *et al.* (1994), which, as we have seen, sought to apply such concepts to the BVG rocks under the Longlands Farm area. Kokelaar emphasized the general complexity of BVG faulting, the lateral variability of rock types in the unit, and the fact that even the massive ignimbrites frequently had cooling joints of unpredictable extent. Nirex had found difficulty in correlating faults appearing in boreholes only 10 m apart; and, on Kokelaar's view, the company's assumption that the extent of throw of a fault could be correlated with the thickness of fault-rock was not justifiable for the BVG. In Kokelaar's opinion, even if an RCF were constructed, and the particular spot where the excavations were made proved suitable, it would *not* mean that rock close by would be appropriate. This could not be certain, any more than one could form a clear idea of the details of structure from isolated boreholes (Haszeldine & Smythe 1996, pp. 230–231). The BGS workers had not, in Kokelaar's view (pers. comm., 2000), sufficiently emphasized the complexity of the BVG faulting to Nirex in their various reports. Nirex did not seek to make contact with the Liverpool group, which was perhaps regrettable, given its competence on Lakeland volcanics. Nirex did, of course, utilize the BGS expertise. And, as we have seen, the BGS geologists had found that the geology of the western 'Gosforth' caldera differed somewhat from that of the Central Fells, though both were thought to display volcano-tectonic faulting.

It fell to Chaplow to rebut the points made by Kokelaar and Smythe, and we have a full record of their rejoinders, along with summaries of Chaplow's arguments (Haszeldine & Smythe 1996).²⁸ Chaplow argued that Kokelaar had exaggerated the complexities of the BVG and had made generalizations about it over too wide an area. He had not shown that the proposed repository site was near a caldera margin. Kokelaar countered that he was using information from Nirex's own report (S/95/005), which suggested that the proposed RCF or PRZ was located at the site of a volcano-tectonic fault of a piecemeal caldera. Also, 'geo-

logical complexity do[es] not occur only at caldera margins' (Haszeldine & Smythe 1996, p. 234).²⁹ This was, to Kokelaar, an important point: by the theory of caldera collapse, faults could occur anywhere within a collapsed caldera (see Fig. 16.8).

Chaplow further stated (Haszeldine & Smythe 1996, p. 234) that Kokelaar was treating the BVG cooling joints 'deterministically' rather than 'stochastically', which would be what was needed for dealing with rocks having many small-scale fractures. Kokelaar countered that he did not know of any Nirex report that had attempted a 'stochastic' treatment of the cooling joints. 'Nirex', he said, did not 'comprehend the full significance of their own results' (Haszeldine & Smythe 1996, p. 235).

This exchange raised an interesting feature of Nirex's approach. In 1994 they had assembled an 18-member Expert Group (including four Nirex staff, seven people from the Atomic Energy Authority, and two from the BGS), working with a professional 'facilitator' (from 'Facilitations Ltd') to try to formulate a model for the fracturing of the rocks at Sellafield, and hence to estimate the risks that the fractures might entail. Clearly, every fault, fracture or crack, large or small, could not be examined separately, and the overall permeability thereby calculated. So instead of direct measurement or experimental test, they sought to consider various parameters and 'elicit' the role of each separately. The participants were given training by the facilitator in the art of eliciting – or in 'elicitation methodology' (Nirex 1995, vol. 1, A3). Four types of rock channel were considered: (0) small channels (examined by permeability measurements); (I) joints 10 cm to 50 m long (as revealed by boreholes); (II) fractures 50 m to 5 km long (as revealed by boreholes); and (III) major faults more than 5 km long (revealed by geological and geophysical survey). With this grouping, '[a]ppropriate distribution functions, together with PDF's [probability distribution functions] for the uncertain parameters that characterize the distributions were then constructed for the parameters of the fractures in each category, based on the available data and on *expert judgment*' (Nirex 1995, vol. 1, p. 5.1, emphasis added).

Thus, I take it, there was a kind of 'brainstorming' process in which the experts sought to gauge the nature and contributions of the various factors, and develop formulae to model the flows and estimate the consequent risks. In fact, they spoke of 'effective parameters', since the parameters themselves were rarely amenable to direct determination. The preface to the third volume of the report acknowledged that the study was 'not a comprehensive safety assessment, which would require the systematic evaluation of a wider range of repository features, external events and underlying processes and pathways'. So the report gave the combined 'elicited' views of the expert group concerning a highly intractable problem. I think one can reasonably say that the problem of the fractures was approached on the assumption that it was stochastic in nature. Whether it was thereby solved I leave it to others to judge. The RCF programme was, it should be emphasized, intended to enable Nirex to *test* its model(s).

The arguments of Smythe were rather more complicated than Kokelaar's, though he also introduced some straightforward matters, such as the view of the Royal Society Study Group that the choice of the Longlands Farm site was based on ownership of land and mineral rights and easy access to Sellafield rather than geological suitability. Thus, in Smythe's view, the cart was in a sense before the horse. The site was first selected; then the task was to prove that it was technically suitable. Smythe also claimed that the initial choice of the Longlands Farm site was 'largely based on pre-war geological knowledge' – the work of Trotter *et al.* (1937).³⁰ He showed that sections of the proposed site, as they

²⁸ I take it that it worked conversely, but I have no transcript of the cross-examination of the Nirex witnesses or lawyers.

²⁹ One can see how this would be likely to be so from Branney & Kokelaar (1994); see Figure 16.8.

³⁰ However, at the Inquiry, and as subsequently reiterated to me in correspondence, Chaplow pointed out that the BVG was not too deep under Longlands Farm, and there was no complicating Carboniferous Limestone there. If the repository were placed too deep there would be problems with additional rock stresses and elevated temperatures.

appeared in Nirex reports of 1990, 1991, 1993, 1993 and 1995, differed considerably. Even two reports for December 1993 showed substantially different profiles. Clearly, knowledge of the structure of the site was still evolving, and one could not be certain that the present understanding was 'robust' or reliable. It was this uncertainty that was picked up by *New Scientist* (Edwards 1996) and presumably did not help to inspire confidence in the wisdom of digging under Longlands Farm.

However, Smythe's main complaint, as might be expected from what has been said earlier, was that there were uncertainties in the knowledge of the structure of the BVG under Longlands Farm because the seismic analysis commissioned by Nirex was 2-D rather than 3-D; or the evidence from Smythe's provisional report on his 3-D work undertaken in 1994 had not been (sufficiently) taken into account. The faults, as determined from borehole evidence and Nirex's 2-D methods in their evolving understanding of the subsurface geology of the Longlands Farm area, were all shown as planar, which was not necessarily correct.

In fact, Smythe reported to the Inquiry that the BVG rocks under Longlands Farm dipped at about 20°–30° to the SE, which, he maintained, was in accordance with borehole evidence and interpretations of gravity and aeromagnetic data previously published by Kimbell (1994) from aeromagnetic survey. Yet Nirex had published a report (S/95/005) based on borehole evidence and 2-D seismic survey that showed the dip of BVG units as varying between south and SW (Haszeldine & Smythe 1996, p. 248). This inconsistency indicated that more work was needed before constructing an RCF.³¹ Hydrogeological modelling would be premature if the geological structures in the BVG were not known accurately.

In responding, Chaplow stated that interpretation of a 3-D trial – Smythe's 1994 work, in fact – was proceeding, and that there was a provisional programme for more such work to be undertaken in 1996 before proceeding to construction of the RCF. But on Smythe's estimate, such results would not be ready before 1999; so the hydrogeological modelling could not be done satisfactorily before then.

Another expert witness at Cleator Moor, appearing on behalf of Greenpeace, was the previously mentioned Stuart Haszeldine, at the time a colleague of Smythe at Glasgow, though he later moved to Edinburgh. Haszeldine (an environmental geologist with special interests in diagenesis, the genesis of ore deposits, and sedimentology, along with petroleum geology and the hydrogeology and geochemistry of subsurface waters), together with a PhD student Christopher McKeown (previously mentioned), undertook computer modelling of groundwater flows at Sellafield, using data made available by Nirex (which at that time had a library in Cumbria).³² Whether such a modelling exercise was warranted, in view of the arguments advanced about uncertainties by Smythe and Kokelaar, is perhaps arguable. The point was that Nirex and the Glasgow group used the same data but obtained different results for the likely flow of water and movement of radioactive compounds through the proposed locality of the RCF.

The way Haszeldine became involved in the arguments is

somewhat curious (though he had had earlier contacts with Greenpeace). In 1991, he was taking a party of undergraduate students up to NW Scotland to look at the famous thrust-belt there, and heard that drilling was going on at Dounreay. So they decided to pay a visit on the way back and see what 'geology in action' was like. They saw the rigs, and the people they met were helpful, but it appeared to McKeown that the men working for different contractors and doing the different tasks did not know what the others were doing, and there seemed to be a disconnected work pattern. McKeown and another student became curious and wanted to look into the matter further.

After finishing his honours degree at Glasgow, McKeown worked for a short time on a small hydrogeological modelling project and then Haszeldine asked him to do something similar where radioactive materials were involved. This was completed and McKeown then went off to Australia for a brief period. On returning to Glasgow, he wrote up his report in provisional form and sent it to Greenpeace, thinking they might find it interesting. They did, and invited Haszeldine to put in a small research proposal on geochemical modelling, which gave McKeown six months' research time. Greenpeace liked this too, and invited a proposal for further work, which ultimately funded McKeown for a PhD under Haszeldine (McKeown 1997). Thus the Cleator Moor Inquiry came in the middle of McKeown's PhD work, and he was able to supply information to his supervisor in his evidence to the Inquiry, though McKeown has informed me that he improved and developed his ideas between the time of the Inquiry and the completion of his degree (pers. comm., 2000). The Inquiry was premature for him too!

Working from Nirex's Report 524 (vol. 3) (1993), Haszeldine argued at the Inquiry that the water movement was *upwards* in the area of the proposed RCF, due to the flow of water down from the Lakeland mountains, and the presence of a large mass of underground saline water (known from Nirex's Borehole 3), to the west of the site, adjacent to the coast, which deflected the movement of fresh water.³³ So, '[T]he PRZ is positioned directly on the main subsurface of flow potential of meteoric water moving from the Lake District towards the coast. *This PRZ is in the worst position on this "Site" to allow containment of any waste by present-day hydrogeology*' (Haszeldine & Smythe 1996, pp. 129–130, emphasis in original).

In fact, Haszeldine claimed, the Glasgow group's computer modelling (essentially McKeown's) showed that water might reach the surface in the time-range 10 000–300 000 years, although if there were significant unsuspected fractures the time could be less than the lower figure. Also, the RCF alone could not ascertain whether or not there was such a fracture in the vicinity. Haszeldine opined that the deeper Bleawath Formation was less fractured and would be more suitable as a repository than the Fleming Hall Formation (but then, we should remark, it would cost more to construct a repository, with the greater amount of rock to be excavated, the greater pressures, and the higher temperatures). The Glasgow group's numbers had already been published at the time of the Inquiry (Haszeldine & McKeown

³¹ Uisdean Michie has commented on this issue to me (pers. comm., 2001), pointing out that the dips in the BVG are variable, with ignimbrites being draped over different erosion surfaces, with changes of dip across fault zones. However, recent work (Beddoe-Stephens & Millward 2000, fig. 2) shows the general dip in the Fleming Hall Formation in the Gosforth area to be to the south. After the Inquiry was over, Nirex re-processed and reinterpreted Smythe's 3-D trial survey and produced a contoured surface for the base of the Fleming Hall Formation with fairly uniform dips of SSW to SW (Nirex 1997c, fig. 16). Michie also construed Kimbell (1994, p. 109) as supportive of a SSW to SW dip; and he stated that the study of Boreholes 8 and 9 supported a S to SW general structural dip. But these arguments were not all available at the time of the Inquiry.

³² Haszeldine (pers. comm., 1999) recalls that Nirex was generally willing to provide what was requested, but, as he put it, some items had to be 'winkled out of them'.

³³ The saline water was initially discovered during the incomplete drilling of Borehole 1 (see p. 273). Michie (pers. comm., 2001) has asserted that 'Haszeldine and McKeown's modelling was not able to deal with variable density groundwater' and used single values for rock properties. His own generalized model (Michie 1998, fig. 14) gave pathways such that water reaching the surface inland would have travelled only through the rocks of the sedimentary cover. Such water as might pass through the region of the potential repository was represented as remaining in the lower saline waters, exiting below the Irish Sea rather than on land. Michie noted to me that the BVG rocks were shown by the Nirex investigations to be less deep inland from Sellafield than earlier supposed, and hence more conveniently placed for a repository.

1995) and were known to Nirex, but the Company had doubts about the computer programs used by the Glasgow group (see p. 286 and Note 33).

Haszeldine's interpretations were in stark contrast to results previously obtained by Nirex (1993a). In this report, Nirex concurred with Haszeldine and McKeown that water would move upwards from the repository area in the BVG, but when it reached the overlying (Sherwood) Sandstone they thought it would move horizontally for about a kilometre, then pass downward to a depth below that of the repository, proceed west for another kilometre, then rise again, before travelling horizontally at a depth of about 450 m, with water eventually reaching the seabed about a kilometre offshore. This was the report about which the Royal Society Study Group had been unable to obtain responses to its enquiries concerning the related database, because of 'commercial confidentiality'; and it was later criticized by the Radioactive Waste Management Advisory Committee (Kelling & Knill 1997, p. 12).

Of course, the Nirex plan was not just to drop radioactive materials into a 'bare' hole in the ground. There was to be engineered chemical containment. The fill material had to be porous, to allow escape of gas, and not too hard, so that material could be retrieved in case of dire necessity, if required. Thus the chemical situation within the country rock itself was relevant to the likely success or failure of containment in the repository; and this was another issue on which Haszeldine focused attention.

It was known that in oxidizing conditions the uranium radionuclides would form mobile compounds and the converse would be true in reducing conditions. Nirex and BGS took the view that there was presently a reducing environment in the neighbourhood of the proposed repository, evidenced by the presence of pyrite. This suggestion might seem remarkable when we consider what has been said in Chapter 4 about the widespread occurrence of haematite in west Cumbria. Kingsley Dunham, we recall, developed a theory about iron-bearing brines moving into the rocks of Cumbria from the Irish Sea Basin and depositing haematite therein (an idea congruent with some of the suggestions described in Chapter 18). Haszeldine (Haszeldine & Smythe 1996, p. 138) now developed this hypothesis. He suggested that the iron was derived from what are now the red beds of the Permo-Triassic sediments of the Irish Sea hydrocarbon basin. Formerly the iron would have existed as ferrous ions in the reducing conditions accompanying the production of hydrocarbons. With a rise of pressure due to hydrocarbon production, the ferruginous (and saline and acidic) solutions could have been driven eastwards towards the sandstones of west Cumbria. The acid would have assisted in developing cavities (sops) in the Carboniferous rocks, and the ferruginous solutions would have penetrated wherever they could, in faults and joints. Then, mixing with oxidizing waters from west Cumbria, conversion to ferric iron occurred with precipitation of haematite, though chiefly in the upper strata, so far as BVG rocks were concerned. This was consistent with Nirex's claim that they had found small quantities of pyrite in some boreholes. However, the very existence of the west Cumbrian ore-field, with abundant ferric iron (albeit in insoluble form), was, for Haszeldine, at odds with the idea that the prevailing environment for the Fleming Hall Formation, at the top of the BVG, was reducing in character.

Haszeldine (Haszeldine & Smythe 1996, p. 173) sketched a diagram ('compiled from Nirex data') showing the variation of oxidizing and reducing conditions at different depths in the Sellafield area, based on the presence in boreholes of pyrite or haematite. According to his understanding, the depth for the proposed RCF or eventual repository put it well within the zone of oxidation, where higher-valency uranium compounds would be mobile. Pyrite might be 'ubiquitous' as the senior Nirex scientist Alan Hooper (at the time of writing, Chief Scientific Adviser) argued in his evidence to the Inquiry, but it was by no means the dominant mineral. However, in the view of Douglas Holliday, 'There's loads of pyrite there; there's been reducing conditions

since the Triassic at the repository level'. The BGS kept telling Haszeldine this, said Holliday, but he did not want to take it on board (pers. comm., 1999). Michie (pers. comm., 2001) took the view that once precipitated, the highly insoluble haematite would not be relevant to the redox condition of the circulating groundwaters. And if pyrite were present at all, the solutions could not be oxidizing, as this mineral is unstable under such circumstances. Colin Knipe (pers. comm., 2001) reckoned that the evidence was not conclusive ('case not proved') as to whether the presence of pyrite or oxide indicated truly oxidizing or reducing conditions.

In fact, the question of the redox situation below Longlands Farm was one on which the geologists of the mid-1990s could not agree, and there were several letters on the topic in *Geoscientist* in 1997. Jenny Huggett (April, p. 6) pointed out that pyrite was uncommon and appeared 'corroded', which suggested that it was suffering oxidation. By contrast, haematite was relatively abundant at the depth of the proposed repository. Chaplow (June, p. 6) drew attention to a preliminary paper by Bath *et al.*, which emphasized the uncertainties of the matter. David Savage (June, pp. 6-7) of the BGS pointed out that at the pH of the groundwaters for the BVG at Sellafield, haematite could be stable in both oxidizing and reducing circumstances. Moreover, he took the view that pyrite was 'extremely common in the BVG beneath Sellafield', and he regretted that the abandonment of the RCF project meant that a more careful examination of the problem would not henceforth be possible. Haszeldine & Smythe (July, p. 19) contended that Nirex's borehole tests had revealed oxidizing conditions, but Nirex had "corrected" these measurements to reducing values by assuming the existence of iron pyrites lining all the fractures within the BVG'. Huggett (September, p. 5) denied Savage's claim that pyrite was abundant, and pointed out that its maximum abundance was at a depth much greater than that of the proposed RCF. She added that Section 6C.164 (p. 203) of the Inspector's (Christopher McDonald's) Report had stated that 'there were considerable uncertainties about groundwater Eh, pH & ionic strength, especially at the preferred repository horizon'. BGS Director Peter Cook (October, p. 7), on the other hand, supported the view that at a high pH haematite might even 'form "reducing" fluids', and in any case, since the haematite had probably been there since the Mesozoic, this product of an ancient mineralization might not be relevant to a discussion of modern redox conditions. Finally, in December 1997 (pp. 4-5), some of the authors of 'Nirex 1995' (Report S/95/012, vol. 3), with others, wrote to say that the redox potential of the water within the rock pores would, following the corrosion of the container giving rise to the formation of ferrous ions in the repository, be determined not by that of the groundwater flowing into the repository but by the solid phases of the materials therein with which the groundwater might interact. It might, they averred, take more than a million years for dissolved oxygen and other possible oxidants brought in by the groundwaters to produce an oxidizing environment overall. Thus were some of the arguments within the scientific community.

There is insufficient space here to continue in this vein and discuss the myriad arguments that were presented at the Inquiry, or were generated by it, and I have only dealt with a few of the protagonists' contributions. Suffice it to say that, in responding to the questions posed to him by the 'Inspector', Colin Knipe broadly agreed with the arguments brought against Nirex, on the basis of the mass of evidence presented. He did, however, say that 'the Sellafield investigation ha[d] involved one of the most comprehensive and technically sophisticated pieces of geological characterization ever carried out in the UK and that the individual items of research and investigation . . . [were] of high quality' (Annex 1 to Inspector's Report, APP/H0900/A/94/247019, p. 43).

The arguments about the original choice of Sellafield as a site were also rehearsed. As we have seen, Knipe objected to the manner in which the choice had been made. Various geological options were canvassed, among which the aforementioned 'basement under sedimentary cover' was one of the geological

environments earlier recommended as potentially favourable by John Bredehoeft and Tidu Maini (1981).³⁴ This option is worth some consideration here. In their paper, the authors had in mind a large continental area of low relief, with hard, stable basement rock of low permeability below a blanket of sedimentary rocks whose groundwater flow characteristics were well understood and capable of being securely modelled; or a locality adjacent to a sea or ocean, with dipping basement rocks with a sedimentary cover that would serve as an aquifer to conduct solutions to depth below the sea or ocean, could be suitable.

Such circumstances occurred in some states in America, such as Colorado and Kansas, and Maryland. In Colorado, there are mountains to the west of Denver and Precambrian basement rocks extending eastwards towards Kansas. These have a quite thick topping of shale of low permeability, below which are permeable sediments that could act as an aquifer, but do not reach the surface until well to the east in Kansas. Thus any water that might pass through a repository in the basement rocks in Colorado would be widely dispersed before reaching the surface in Kansas. In Maryland, there are eastward-dipping basement rocks, above which are dipping sediments that could act as an aquifer, leading waters down below the Chesapeake Bay estuary and under the Atlantic (for review, see Michie 1998). The latter case is more similar to that in Cumbria, but whether or not the waters would exit before reaching the sea seems uncertain in both the Maryland and Cumbrian cases. Both envisaged inland masses of salt water that might divert fresh groundwater towards the surface, but for the Maryland case the Appalachians would be more distant from an envisaged repository than are the Lakeland mountains from Sellafield. Nirex contended that their modelling suggested that the exit would be somewhere under the Irish Sea. The description of the Longlands Farm site as a 'variant' of the 'basement under sedimentary cover' situation was, it seems to me, 'hopeful'.³⁵

On the balance of the technical arguments, then, Knipe advised against the appellant's case. McDonald accepted Knipe's advice, and John Gummer accepted McDonald's recommendation that 'the appeal be DISMISSED'. Thus for the first time, the tide turned against the nuclear industry in Britain, in a David and Goliath battle. Chris McKeown has told me (pers. comm., 1999) that they never really expected to win. The 'establishment' usually does.

In talking to Bob Chaplow (pers. comm., 1999), I raised with him some of the issues mentioned in the preceding narrative. Regarding the faults in the BVG in the Sellafield area, the pattern of which seemed to change as research progressed, thus creating public unease, Chaplow explained that there was confusion at the Inquiry about the true significance of the faults (regardless of their precise pattern).³⁶ The flow of fluid did not necessarily follow the faults (or joints), which might have been 'sealed' by deposits of various minerals subsequent to their formation. Study of this problem was still in hand at the time of the Inquiry and evidence about it was tendered, but the results were (unfortunately for Nirex) not fully published until 1997 (Nirex 1996, 1997*d, e, f*), though a relevant paper by Sutton (1996) appeared earlier and the work was described in the 'proofs of evidence' (Alan Hooper, pers. comm., 2001). What the engineers did in so-called 'pump-

tests' was reduce the pressure in different parts of a borehole (isolating different parts with water-inflated rubber packers) and monitor the groundwater pressure responses, either in the same borehole or in one adjacent to it. (The cross-hole pump-tests were started in March 1994 and continued for seven months.) Surprisingly, water was *not* found to follow the known lines of fault, which must, therefore, have effectively been sealed. However, that did not mean that the rock was impermeable. Rather, it showed that it could (at least on occasions) follow a maze-like network of unmappable narrow channels. So the discussions about faults and their alignments at the Inquiry *may* not have been wholly relevant to the envisaged storage area's reliability.

What Nirex found was that water flow tended to follow particular zones, with a characteristic kind of calcite mineralization, rather than clearly recognizable faults. However, even where the calcite was present, it was not always accompanied by flow. In such cases, its presence presumably indicated some earlier flow, and the calcified zone might be a 'potentially flowing feature'. Thinking along such lines, Nirex had been able to achieve results that meshed satisfactorily with their modelling. The technology used involved a high degree of expertise, the cross-hole testing for Boreholes 2 and 4 (shown schematically in Nirex 1997*d*, fig. 17), for example, being the most complex undertaken in the world at that time. Evidence about the borehole pump-tests was, as mentioned, tendered at the Inquiry, but the detailed analysis of 'potentially flowing features' and the conceptualization of faults was incomplete. Whether it would have made any difference to the outcome is a moot point. At the time of my interview with him, Chaplow rather doubted that it would. I am myself, however, inclined to the view that it would have assisted Nirex's case, while noting Colin Knipe's point that open channels might in fact assist subterranean dispersal of fluid (see p. 286).

In retrospect, the whole Nirex enterprise appears to have been in too much of a hurry. (The company had already in 1996 invited three companies to tender for the construction of the RCF; *Daily Telegraph*, 1 August 1996.) In 1996 and 1997 there was an outpouring of publications on the geological structure of the Sellafield site, on 3-D seismic surveys, hydrogeology, etc., with special emphasis on the permeability of rock in fault zones and mineralization in such zones, utilizing the results in the 'pump-tests' used in the boreholes.³⁷ A meeting was held at the BGS Headquarters at Keyworth in October 1997, co-sponsored by Nirex and the BGS, with sessions chaired by Drs Holliday, Moseley and Chaplow; and the latest results and computer programs were presented and discussed. The papers were subsequently published in December 1998, in a special issue of the *Proceedings of the Yorkshire Geological Society* (the Society again receiving a subvention from Nirex for the colour plates in the publication). Nirex had additionally published its work in a special edition of the Geological Society's *Quarterly Journal of Engineering Geology* (vol. 29, Supplement 1, 1996).

Thus Nirex was moving more into the public domain, recognizing that its previous *modus operandi* had not helped its case at Cleator Moor. 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

³⁴ Bredehoeft was a senior hydrogeologist with the US Geological Survey. Maini was a Senior Research Fellow in Rock Mechanics at Imperial College, London. He had earlier acted as a consultant to the UK Atomic Energy Authority (Northern Division) on the question of the choice of sites for the disposal of high-level waste – a search for which was subsequently abandoned in Britain. I am informed by Uisdean Michie (pers. comm., 2001) that, in fact, Maini developed some of his ideas about 'basement under sedimentary cover' sites from his work at Sellafield.

³⁵ It should be noted, however, that Haszeldine & McKeown (1995, p. 87) described the Sellafield site as 'a variant of a long-recognized proposal for underground disposal (Bredehoeft and Maini, 1981)'; and their paper was reviewed by Bredehoeft, who presumably accepted the diction. (I thank Uisdean Michie for drawing my attention to this point.)

³⁶ It was unfortunate, though, that at the Inquiry the Nirex lawyers did not seem to have very clear ideas about faults. According to Haszeldine (pers. comm., 1999), he was asked during his cross-examination to comment on the extent of the fault between two boreholes on a diagram, but the particular diagram only showed the fault on one borehole. He thought at first it was a 'trick question', but then realized it was a 'misguided question', asked by a lawyer, not a geologist.

³⁷ For a list of the reports see www.nirex.co.uk.

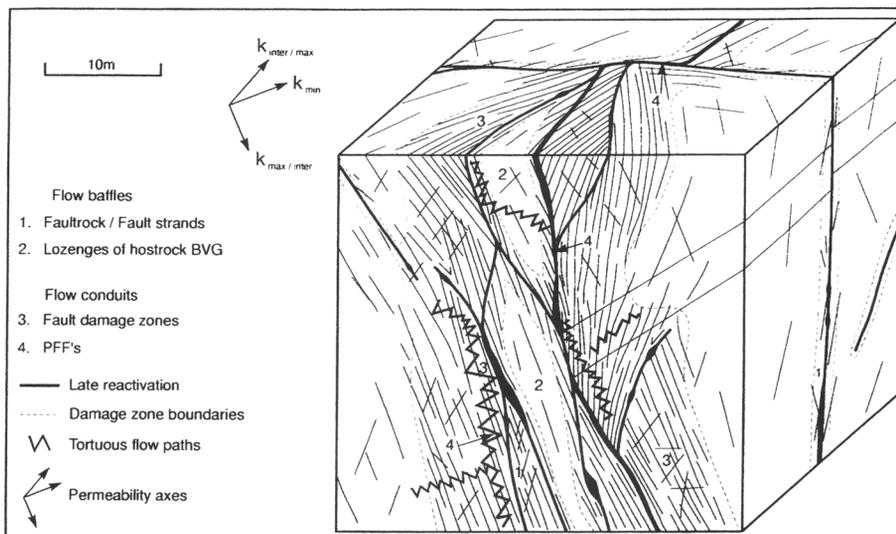
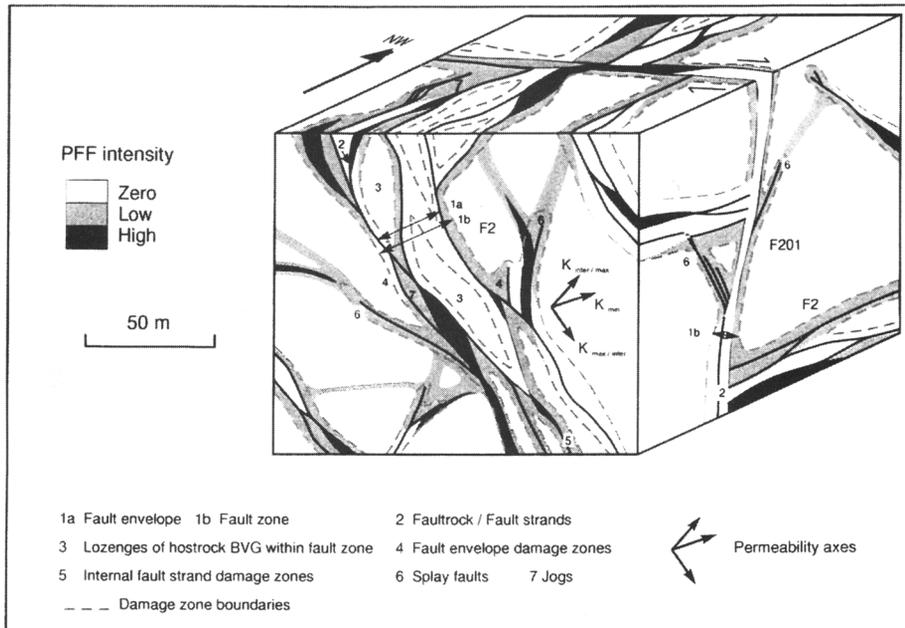
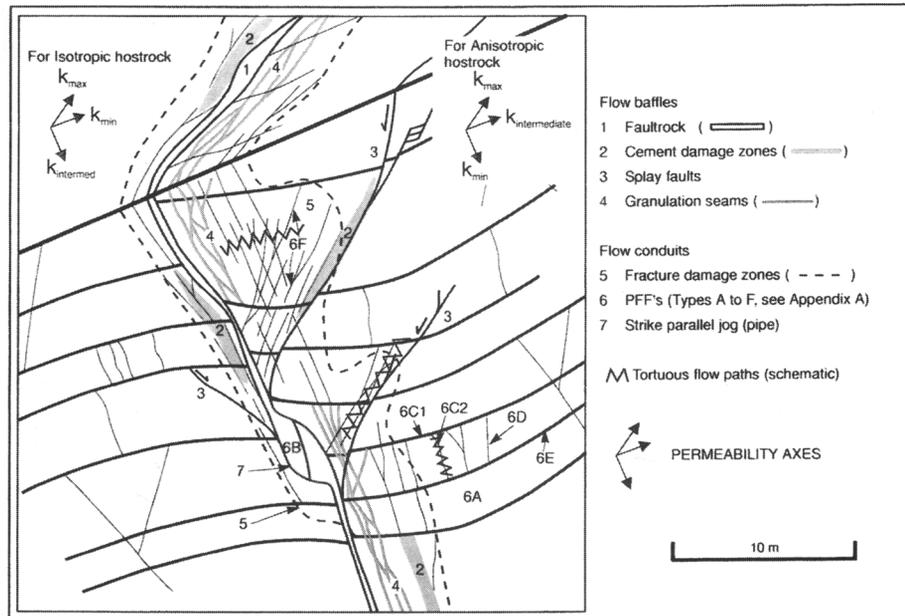


Fig. 20.3. Detailed models of fault structures in BVG rock in Sellafield area, near proposed nuclear waste disposal site, according to Gutmanis *et al.* (1998, pp. 166 & 167). Reproduced by courtesy of the Yorkshire Geological Society.

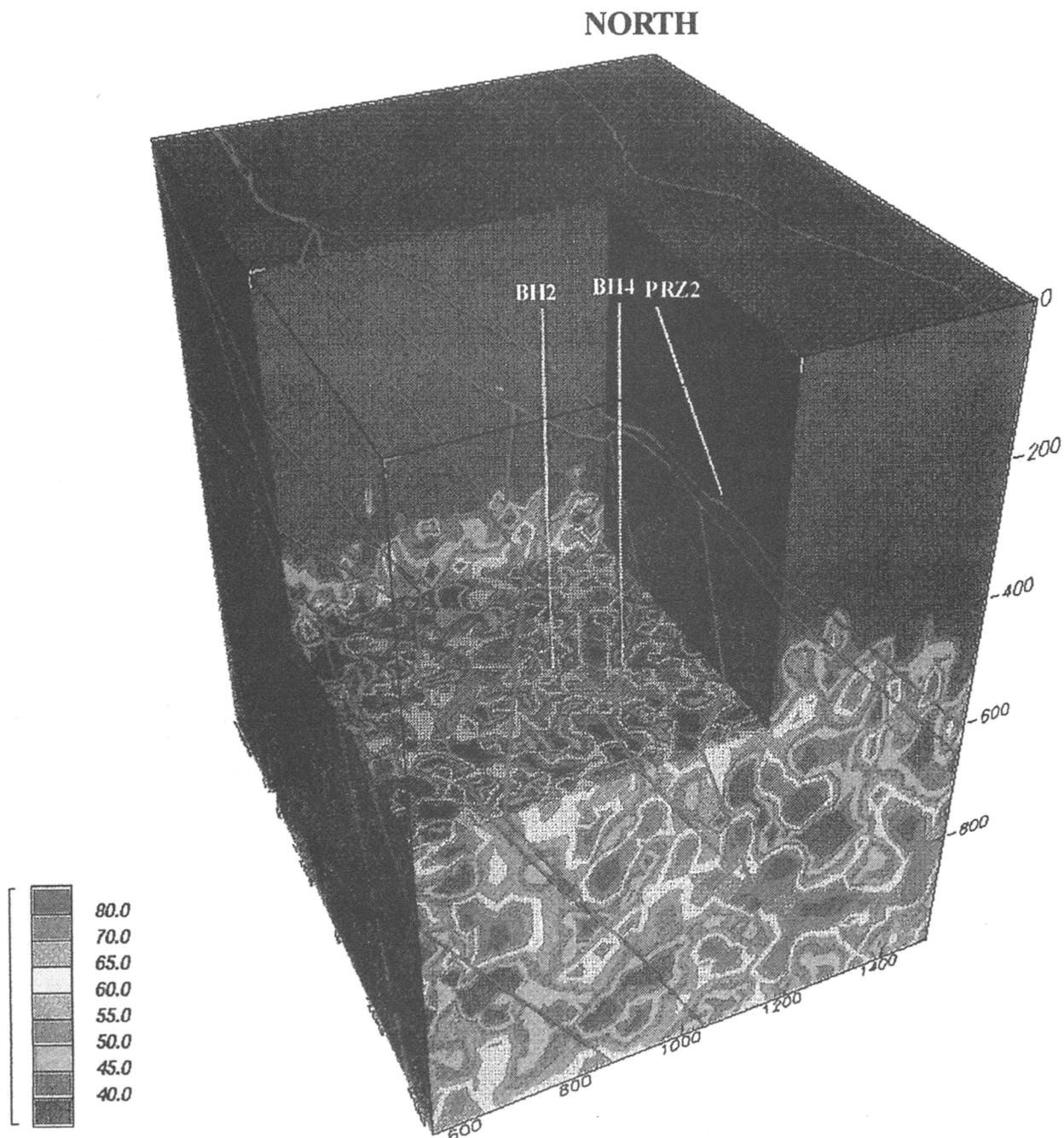


Fig. 20.4. Rock 'quality' and faults at locality of proposed 'rock characterization facility' (RCF), according to Davies & Chaplow (1998, p. 196 [black-and-white]); and Bowden *et al.* (1998, p. 135 [colour]). Reproduced by courtesy of the Yorkshire Geological Society.

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.

As mentioned, attention was now being focused on the faults within, and the 3-D structure of, the BVG for the proposed repository area. Thus Gutmanis *et al.* (1998), from Geoscience Limited, Falmouth, produced diagrams such as are reproduced in Figure 20.3, which show a fault zone in great detail, with 'potential flowing features' indicated. However, these figures were modestly called 'conceptualizations' and, as I understand from Chaplow, the block diagrams shown here do not in fact refer to an actual locality in the site intended for the RCF, or any eventual repository.

Chaplow with Nick Davies from Nirex (Davies & Chaplow 1998) also described their procedures for determining the 'geotechnical characteristics' of rock, from the huge database by then

assembled by Nirex. The boreholes were imaged acoustically and by resistivity determinations, and the physical 'strength' and elastic properties of the different segments of the cores were determined; likewise the stress field in the Sellafield area. Measurements were made from core samples of compressive strength, Young's modulus, Poisson's ratio, 'effective' porosity, and saturated density. Measurements of Young's modulus, Poisson's ratio, porosity, bulk density, compressional sonic velocity, and shear sonic velocity were likewise made by wireline techniques. Geomechanical factors called 'tunnelling quality' (Q) and 'rock mass rating' (RMR) were calculated from empirical (engineering-style) formulae, and the whole was represented in a three-dimensional block diagram with different colours representing different values of RMR (Davies & Chaplow 1998, p. 196; Bowden *et al.* 1998, p. 135; Brereton *et al.* 1998, p. 211). Information derived from the trial 3-D seismic survey to identify the distribution of rock mass properties throughout the block was also

included. So one could gauge which volumes of rock were most 'solid' – or, rather, of high RMR, with low apparent permeability and hydraulic conductivity – and thus likely to offer a good site for waste burial. This was technological progress that might be used some day, some place, but by 1998 no tunnelling or waste disposal was to take place in the rocks thus examined so intensively (see Fig. 20.4).

A team from the BGS also looked in detail at the mineralization in the fractures in the BVG under the Longlands Farm area, concluding (from the evidence of what mineralized, or penetrated, what) that there had been nine distinct episodes of mineralization (Akhurst *et al.* 1997, pp. 37 and 87; Milodowski *et al.* 1998). A summary of these is shown below, being related to supposedly known geological events as indicated:

- | | | |
|---------------|--|--|
| 1. (oldest) | Silicate mineralization | Pre-Acadian high-temperature hydrothermal mineralization |
| 2. | Silicate and carbonate | Main Caledonian epithermal mineralization |
| 3. | Sulphide (pyrite) and ?silicate | Fe–Cu–As–Zn–Pb mineralization (associated with mid-Devonian intrusions) |
| 4. | Sulphate | Early post-Carboniferous anhydrite mineralization |
| 5.* | Silicate | Kaolinite–illite–silicate mineralization |
| 6.* | Carbonate ± sulphate | Carbonate-dominated mineralization |
| 7.* | Silicate and oxide | Illite and haematite mineralization |
| 8. | Oxide (iron and manganese oxides) | Oxidative groundwater mineralization |
| 9. (youngest) | Carbonate ± sulphate ± sulphide (pyrite) | Calcite–sulphide–sulphate mineralization from Quaternary and recent groundwaters |

Episodes marked with asterisks were taken to be associated with the expulsion of brines from the Irish Sea Basin during the progressive burial of the Carboniferous and Permo-Triassic sequences. Episodes 1–3 were found only in the Ordovician rocks, but the other episodes affected both Ordovician and younger rocks. Episode 1 was taken to be related to silicate re-mobilization shortly after the deposition of the BVG and appeared in all such rocks. Episode 2 appeared to be linked to the copper mineralization in the Lakes. Episode 3 was likewise associated, but was poorly preserved. No Lakeland equivalent was known for Episode 4. Episodes 5 and 6 produced the dominant mineralization in the fractures. It was suggested that the mineralizing fluids (brines) might have originated in organic-rich Carboniferous rocks in the Irish Sea Basin. Episode 7 might be linked with deep burial in the Irish Sea Basin during the Jurassic. Episode 8 was perhaps associated with invasion of meteoric groundwater during Tertiary (Miocene) uplift, which perhaps produced similar phenomena in Lakeland mines. Episode 9, involving fracture infilling at depth, represented recent changes, but not ones previously remarked in Lakeland proper, since pyrite and calcite would have been generally leached from the surface rocks under the conditions of high rainfall; or pyrite would have been oxidized.

It will be seen, then, that the Survey was making substantial advances in basic understanding of Lakeland and neighbouring geology through the Nirex work. It is interesting that the scheme outlined above was not dissimilar to that hypothesized by Haszeldine at the Inquiry, though Milodowski *et al.* (1998) had late pyrite (Stage 9) deposited over the older haematite mineralization

(Stage 7), and their oxidative Stage 8 was thought to be restricted to the sediments near the surface (weathered sandstones and Quaternary sediments). However, the interesting results then emerging were not going to get the RCF constructed. It may also be remarked that, in the opinion of Colin Knipe (pers. comm., 2001), the information about the sealing of fractures was in a sense a 'two-edged sword'. In his view, for minimization of risk of nuclear materials, one needed dilution and dispersion. So one *could* argue that permeable faults and joints favoured this, giving longer flow paths. The less permeable the rock, the more vertical would be the flow paths. However, the actual flow of a faulted rock system would depend on the orientation of the faults, which therefore needed to be well understood.

Another issue I raised in discussion with Bob Chaplow in my conversation with him in 1999 was the fact that Haszeldine and McKeown had come up with different estimates from those of Nirex for the time that might elapse between water passing through the repository and its emergence at the surface or getting into drinking water (10 000 years³⁸ as opposed to a range of 25 000–50 000 years³⁹), given that the Glasgow investigators had used Nirex data in their modelling. Had Nirex scrutinized McKeown's thesis and the Haszeldine–McKeown (1995) paper, I asked.

Well, naturally Nirex did look at these documents. They examined 'McKeown's paper' and 'thought it was an interesting study' (Chaplow, pers. comm., 1999), but Nirex objected that McKeown was using an average permeability from measurements from small-scale tests, inadmissibly using these to characterize large-scale features. Also, I was told, McKeown selected the lowest permeability for the overlying sandstones and the highest for the BVG; and he assumed that faults acted as conduits – which as we have seen above was a questionable assumption, though the issue of the sealing of the faults had not been thoroughly investigated and published at the time of the Inquiry. In addition, McKeown's computer modelling programs⁴⁰ might not necessarily have been adequate, suggested Chaplow. Nirex had in fact undertaken a study of McKeown and Haszeldine's groundwater modelling prior to the Inquiry, and concluded that the OILGEN program they used had 'severe limitations' in that the assumptions used in its modelling were such as to tend to give low transit times (Chaplow, pers. comm., 2001). Nirex used programs such as NAMMU (Release 6.2) for groundwater modelling, and NAPSAC (Release 3.0) for fracture network modelling (Hooper, pers. comm., 2001). (See further: Heathcote *et al.* 1996.) In any case, Chaplow pointed out, McKeown had only spent three man-years on the task, whereas the company had spent some 50 man-years with 'state-of-the-art' modelling and iterative procedures. Leaving that aside, there is evidently scope for disagreement as to which is the 'best' program for investigations of this kind. (Of course, the RCF would, I take it, have facilitated the *testing* of the various computer programs!)

While Nirex wound down its investigations at Sellafield, Haszeldine and McKeown subsequently published the essential features of McKeown's thesis (McKeown *et al.* 1999). The paper arrived at a figure of 15 000 years for water to move from the region of the repository to the surface. Comparisons were made between modelled and empirically determined hydraulic heads in Borehole 2, according to three possible values for hydraulic conductivity in the BVG, and the best fit was obtained using a mean value of 1.2 m year⁻¹, from which value the figure of 15 000 years for water to reach the surface was calculated. No reference was made to Nirex's pump-testing results. McKeown's work was done *before* the pump-test information was fully published by Nirex (though it was discussed at the meeting on Sellafield geology held at the

³⁸ In his thesis McKeown (1997, p. 254) gave a figure of 15 000 years.

³⁹ Nirex (1995, vol. 3, table 2.3). Nirex also provided estimates of overall risk over time, suggesting that there would be peaks of risk (of about 1 in a million) at 20 000 years, and subsequently at over 1 million years after repository closure (Nirex 1995, vol. 3, pp. 9.1–9.2). The first peak would be due to the mobile radionuclide ³⁶Cl, which was thought to be likely to move more rapidly than water.

⁴⁰ OILGEN, 1989 and Geochemist's Workbench™, 1994.

Geological Society in May 1994, at which McKeown was present).⁴¹ In any case, the mean value for flow in the BVG was thought to be the controlling quantity for the overall calculation, and would apply regardless of whether water flowed through solid rock, open joints, or ones sealed by mineralization.

After McKeown, Haszeldine had another PhD candidate working on the modelling task – this time a Chinese student, Kejian Wu, arrived from remote NW China, with a Master's degree in hydraulic engineering geology from Lanzhou University. He came to Scotland to work with Haszeldine in 1995 and successfully obtained his PhD at Edinburgh (Wu 1999), co-supervised by Gary Couples of Heriot Watt University.

Like McKeown, Wu used Nirex data, but sought to do the modelling on a much larger scale (c. 120 km long and 7 km deep) than that of McKeown's study. Needless to say, detailed knowledge of the structure of the whole area to the east of Sellafield was not available at depth through boreholes; it could only be inferred from the available maps and geophysical evidence. Despite such limitations, Wu (pers. comm., 1999) endeavoured to develop a general structural picture for the Lakes and link that with the detailed knowledge available for the Sellafield area. He took into consideration the low permeability of the rocks at depth and arrived at a figure of about 50 000 years for the possible emergence of water at the surface from the proposed repository site, which is not dissimilar to the upper end of the range earlier proposed by Nirex (1995).

Haszeldine (pers. comm., 1999) also continued his work on the hydrogeological problems at Sellafield, investigating the possible influence of the radiogenic heat from a repository in producing convection currents in the surrounding groundwater. Such a complication had been considered previously by Runchal & Maini (1980)⁴² for high-level wastes and is standardly considered in textbooks. To my knowledge, it did not get into the debates at Cleator Moor, though *prima facie* it is an important consideration. So the end of the story was surely not reached by the end of the twentieth century, but my account has been carried far enough for present purposes.

The Nirex work at Sellafield was the most expensive 'single' geological investigation carried out in Britain, other than the North Sea oil projects. It generated a vast amount of geological knowledge about a small region, with collaboration between Nirex and a plethora of consultancies, of which the BGS has been chiefly of interest for our present purposes. Nirex's money assisted the publication of the BGS West Cumbria Memoir, and the research on the Quaternary of west Cumbria provided a considerable contribution to basic science (see Chapter 19). The same might be said of the contributions to knowledge of the BVG and of various mineralizations in faults and joints. While the flow of money from Nirex to the BGS lasted, some BGS staff that I have spoken to were only too happy simply to have it coming, to fund interesting research. On the other hand, one of them described the company as 'a somewhat maligned organization that deserves more credit than it sometimes gets'. The data collected by Nirex for their investigations at Sellafield were later (2001) transferred to the BGS at Keyworth, where they are likely to provide a

valuable resource for future research. Indeed this is already happening. For example, Helen Reeves, a PhD candidate at Durham University, is, at the time of writing, working on a study of the relationship between the local stress field in the BVG and the flow of fluids in the rock fractures, making use of Nirex data (Reeves, pers. comm., 2001).

Even so, Nirex was, I think, in too much of a hurry. It hastened into its planning application and subsequent appeal before it had all the necessary weapons in hand. The procedure for the choice of site was, I suggest, inappropriate; but the truth is, it seems to me, that no site in Britain is wholly suitable. Perhaps the best site, geologically speaking, would be the Mesozoic clays running down under the sea from East Anglia, or possibly the underlying basement rocks.⁴³ But that would be politically unpopular, and there would be problems in transporting nuclear waste across country from Cumbria or wherever to East Anglia. Nirex were not necessarily wrong in searching for the solution that seemed most acceptable politically, and involved the least transport costs.

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. Smythe's involvement with Nirex led to substantial personal problems. And after the Inquiry, Nirex had to shed jobs (*Daily Telegraph*, 25 March 1997). Though initially granted a pay bonus, the Nirex Managing Director, Michael Folger, was replaced in April 1998 (Nirex news release, 9 April 1998). The BGS lost one of its major contracts, such that whereas Nirex provided £3.2 million in 1995–1996, this had declined to zero by 1999–2000, and there were staff cuts that financial year (Hackett 1999, p. 8).⁴⁴ Two geologists whom we have encountered in the present narrative, Eric Johnson and Brett Beddoe-Stephens, left the BGS at about that time.

On a broader front, Britain continues to accumulate waste and has nowhere to dispose of it permanently. Indeed, at the end of the twentieth century Britain had no ongoing search for an alternative repository site; and a company, Pangea, was unsuccessfully sounding out whether Australia would offer its desert spaces. Britain has, however, an immense amount of information (much of great interest to those concerned with Lakeland geology) about a potential hole in BVG rocks that will never become a reality.⁴⁵

So, in this chapter we have entered into some detail about matters that may appear extraneous to the history of geological research in the Lakes. However, it is important to consider both the social and economic context of research and the social consequences that may flow from scientific work, or the manner in which it is applied. It is of interest for the present study that what started, in a sense, as an academic debate about the nature of faulting in the BVG and the structures of the ancient Lakeland volcanoes ended up as a matter of concern in a court of inquiry, of relevance to the safety or otherwise of a proposed nuclear waste repository. There were major long-term implications for Britain's energy policies, not to mention the economic and environmental well-being of the old industrial area of west Cumbria.

⁴¹ The Nirex (1996) report on pump-tests was written in December 1996, and some pre-prints were distributed in February 1997, after the Inquiry had finished. See also Nirex (1997d).

⁴² I thank Uisdean Michie for this reference.

⁴³ Little detailed knowledge of these rocks was available at the end of the twentieth century, but interestingly they appear to be of 'Lakeland' type: mid-Ordovician volcanics and late Ordovician–Silurian greywackes and slates.

⁴⁴ However, Douglas Holliday (pers. comm., 1999) told me that that the effect was not so serious as might be imagined. The Sellafield work tapered off rather than coming to an abrupt halt, and the Survey was able to take up other contracts that it had not been able to accommodate previously, while it was putting so much effort into the Nirex investigations.

⁴⁵ Or will it? A newspaper report in 2001 (Lean 2001) stated that the British Government was 'urgently drawing up plans to prevent opposition through public inquiries to the building of nuclear dumps and power stations, motorways, airports and other controversial developments. The plans, which could allow ministers to give the green light to hotly contested projects virtually by decree, pose the greatest threat to democracy in planning since the system was set up by a Labour government half a century ago.' The plans were said to have been 'sparked by frustration at the length of some fiercely fought public inquiries'. A proposed new Terminal 5 for Heathrow Airport was particularly mentioned, but finding a site for nuclear waste was evidently on the agenda again. The 'Davids' may never get another chance to use their sling-shots.