The 3-D structural geology of the PRZ

Supplementary Proof of Evidence
of

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Progress of 3-D surveys

1.3 Dr Chaplow states that the interpretation of the 1994 trial 3-D seismic survey is proceeding. However, processing and interpretation should have been completed in time for the start of the Inquiry. A much bigger survey is provisionally programmed to take place during 1996. Results from this survey would not be available until 1999 or thereafter.

Feasibility and utility of 3-D surveys

1.4 The Sellafield District poses no special environmental problems for 3-D surveys. Furthermore, the costs are low relative to the benefits.

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1.5 The extra benefits to be obtained from a 3-D survey, such as the extraction of rock properties, do not invalidate the fact that in the case of complex structure such as the PRZ, the 3-D method is fundamentally important as a primary tool for structural mapping.

<u>Inconsistencies in the Nirex geological interpretation</u>

1.6 Dr Chaplow states that I had not taken full account of the work undertaken on the structure of the PRZ. He has not refuted my demonstration that there are inconsistencies in the Nirex interpretations, but cites BGS Technical Report No. WA/95/47C, which was not previously available. This report is discussed in Section 2 and Section 3.

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1.7 Under cross-examination Dr Chaplow has been unable to substantiate points he raises on selectivity, inaccuracy, or cross-section location bias.

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1.8 Dr Chaplow does not refute my claim that Nirex should, at least in some respects, be following an oil industry exploration analogy.

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1.9 The PRZ was selected in 1991 on the basis of limited surveys. Its structure was only subsequently defined. Nirex’s exploration since 1991 has proceeded at a variety of scales, and has not followed a time progression from the large to the small scale. The PRZ was selected prior to assessment of the wider area, and prior to structural characterisation.

<u>Site potential</u>

1.10 Dr Chaplow has misrepresented my position on this issue.

<u>The need for deterministic models</u>

From Haszeldine, R.S. & Smythe, D.K. (eds) 1996, *Radioactive waste disposal at Sellafield, UK: site selection, geological and engineering problems*, University of Glasgow 1996, pp. 267-277.

1.11 Dr Chaplow has questioned the relevance of an accurate structural interpretation within the stochastic modelling approach adopted by Nirex. However, reliable hydrogeological modelling requires that the major features of the geology are robustly constrained. It is inappropriate to apply the stochastic approach to these major features.

Selective use of information

1.12 Dr Chaplow states that I have selectively presented information in order to justify the need for a 3-D seismic survey. Dr Chaplow gives no examples to support his contention. Furthermore, the purpose of my proof was to discuss the problems associated with the non-robustness of the present geological interpretation of the PRZ. If the present interpretation were robust, datasets indicating non-robustness would not exist.

Overview

Failure by Nirex to address key points

1.13 Dr Chaplow has not commented on these points of my original proof:

- The limitations of the 2-D tomographic surveys, and the inconsistencies between one example tomogram and the existing Nirex mapping.
- Non-availability of results of the 3-D trial survey.
- The non-scientific methodology adopted by Nirex in its early selection of the PRZ.
- The discrepancy in 3-D characterisation of the BVG structure within the PRZ found between geophysical survey results, and the structure interpolated from borehole data.

The reliability of the current structural interpretation of the PRZ

1.14 Dr Chaplow has stated that any revisions of the structural interpretation of the PRZ that are required subsequent to further data acquisition will be matters of ‘detail’ or of ‘refinement’. However, there are major shortcomings in Nirex’s current geological structure. It will only be possible to overcome the difficulties of the current interpretation through significant modification. The problem is illustrated by consideration of fault F2.

The interpretation of fault F2

1.15 Fault F2, the most prominent fault cutting the PRZ, is supposedly correlated with features on the BH5-RCF3 tomogram. F2 is identified in BH5 at 385 mbRT, and in RCF3 at 525 mbRT, but with three subsidiary strands found up to 74 m deeper. The uppermost strand has been used in all Nirex’s current structural maps. However, it does not correspond to any identified feature on the BH5-RCF3 tomogram. One feature that does correlate with F2 in BH5 also correlates with F201 in RCF3.

1.16 The interpretation of fault F2 between BH5 and RCF3 is internally inconsistent, and the nomenclature of five versions of ‘F2’ in the vicinity of RCF3 confuses the geological structure. The mapped F2 is some 88 m above the strand of F2 which appears to match the tomogram correlation better. However, revised mapping of ‘F2’ would lead to new problems, such that F2 would be required to swing anticlockwise through 90° and then back again. This would be highly unusual behaviour.

1.17 Thus the Nirex interpretations to date have completely failed to resolve the highly complex three-dimensional structure of the PRZ. It is likely that there is no single ‘F2’, but rather some five or six faults within the PRZ, which Nirex has unsuccessfully tried to map as a single, simple surface.

1.18 This oversimplification of current Nirex mapping is fundamental to the whole geological structure of the PRZ. The ‘F2’ problem extends vertically over a distance of about 100 m and horizontally over distances of several hundred metres. At the 10 m scale at which there should be a reliable deterministic model of the PRZ, Nirex’s interpretations fail. This example demonstrates that there may be very serious errors in the interpretation of the major faulting in the PRZ.

1.19 The authors of BGS Technical Report No. WA/95/47C state that the magnitude of structural changes between seismic lines only hundreds of metres apart emphasises the ‘meso-scale complexity’ of the Sellafield Site. The authors conclude that only a comprehensive 3-D seismic programme will ever be capable of supplying an adequately predictive 3-D subsurface model. Thus they identify the same key problem and recommend the same solution that I have outlined in my proof of evidence.

Time required for further work

3-D seismic surveys

1.20 An estimate of the minimum time required for a 3-D vibroseis survey covering 7-10 km^2 in part of the Sellafield area, assuming that acquisition can be successfully completed by the end of October 1996, suggests that a properly validated interpretation would not be available before mid-1997. Since 3-D seismic data interpretation normally requires a complete revision of all previous structural models, it will be mid-1998 at least before the model can be said to be robust.

Possible implications of additional survey work

1.21 Subsequent to the revision of the structural interpretation that is likely to be required following completion of the 3-D seismic survey, re-location of the RCF site may be considered. Hydrogeological modelling cannot begin until the interpretation phase of the 3-D survey is complete.

2. POINT BY POINT REBUTTAL

2.1 All the rebuttal points refer to the supplementary proof of evidence presented by Dr Chaplow (PE/NRX/14/S1). These points are discussed below in the order in which they occur in my proof of evidence (PE/FOE/3).

Points of disagreement

2.2 Dr Chaplow has summarised my evidence [PE/NRX/14/S1 para. 6.14], using three quotations from only two paragraphs in Section 10 of [PE/FOE/3]. This summary is inadequate. By paraphrasing just two of my seven paragraphs 10.2 - 10.8, Dr Chaplow has avoided mention of the following essential components of my evidence:

- [para. 10.2] "*Inconsistencies in the current interpretation show that major faults, as well as minor geological structures, are likely to have been misintepreted and/or not identified*."
- [para. 10.3] "*Best practice in analogous geological situations is to employ 3-D seismic reflection surveys*."
- [10.4] *Perturbation of the present PRZ hydrogeological flow by the construction of an RCF will be unavoidable (O'Nions 1995) [PE/NRX/17]. A baseline set of geophysical, geological and hydrogeological data must be in place before underground construction starts*."
- [10.5] "*The 3-D structural re-interpretation should be completed and demonstrated to be robust before the results are passed to a 3-D hydrogeological modelling stage*."
- [10.6] "*Further [3-D] surveys should be commissioned and shot if required, such that a stable interpretation of the geology is achieved. The area over which the survey work is carried out must be adequate:*
- *To provide a sufficient framework for reliable hydrogeological models, and*
- *To allow the identification of the correct location for the PRZ*."
- [10.7] "*Sufficient time must be permitted for evaluation of results before the next phase is planned and executed. The results and their interpretation must be subjected to a proper process of peer review*."

These points are discussed in Section 3 below.

2.3 Following his abbreviated summary of my evidence, Dr Chaplow states his three points of disagreement. I shall address each one of these in turn.

Progress of 3-D surveys

2.4 Dr Chaplow states [PE/NRX/14/S1 para. 6.15 subsection (i)] that "*interpretation of a trial 3-D seismic survey is proceeding*". However, he has failed to assist the Inquiry by providing the Inquiry with 3-D data and interpretations. The trial 3-D survey acquisition phase was completed and reported to Nirex in November 1994 [PE/FOE/3/14]. The standard processing and interpretation time required for such datasets is of the order of six months. It is thus of concern that the results of the survey have not been made available to the Inquiry. Dr Chaplow has made reference to a larger survey "*provisionally programmed to take place during 1996 such that the results will be available before RCF shaft excavation commences*". Dr Chaplow has not stated when he now intends RCF shaft excavation to begin. The geological re-interpretation that is likely to be required following acquisition and interpretation of this 3-D survey dataset would indicate that RCF excavation should not start until 1999 or thereafter. Realistic timescales for such a large-scale 3-D seismic survey are discussed in Section 3 below.

Feasibility and utility of 3-D surveys

2.5 Dr Chaplow and I agree [PE/NRX/14/S1 para. 6.15 subsection (ii)] that 3-D seismic surveys provide greater resolution of small-scale structures than do 2-D surveys. I agree with him also that it may not be necessary to have defined every small scale structure within the PRZ before useful hydrogeological modelling can take place. He states that the possible benefits of 3-D surveys have to be weighed against their "*environmental impact and high cost*". 3-D vibroseis surveys have been conducted through cities and through market gardens with thousands of hectares of plants under glass. The Sellafield District poses no special environmental problems for such a survey. Furthermore, the costs are low relative to the benefits, which include, specifically, the avoidance of relocation costs which may be incurred through reliance on an inadequate structural interpretation.

2.6 Although Dr Chaplow asserts that "*the main structures ... are robustly defined*", presumably implying that a 3-D survey will not lead to revision of major structure in Nirex's case, this is in complete contrast to oil industry experience. I demonstrate in Section 3 below that Dr Chaplow's confidence is misplaced.

Additional benefits of 3-D surveys

2.7 I agree with Dr Chaplow [PE/NRX/14/S1 para. 6.15 subsection (iii)] that rock properties at depth can be inferred from 3-D surveys in a manner that is impossible with 2-D surveys. To achieve this benefit the 3-D surveys must first be processed and interpreted to obtain information on the geological structure prior to extraction of rock properties from the dataset. The additional information to be gained in this way may require one to two years of further work, over and above the time taken to process and interpret the data to permit structural interpretation. It must be noted that further to these additional benefits, in the case of complex structures such as the PRZ, 3-D methods are of fundamental importance as a primary tool for structural mapping.

Inconsistencies in the Nirex geological interpretation

2.8 In para. 6.19 (PE/NRX/14/S1) Dr Chaplow refers to my demonstration of *"inconsistencies between data sets and interpretations presented by Nirex.* Dr Chaplow states that I had not taken *"full account"* of the work done on the structure of the PRZ {Nirex Report S/95/005} [COR/530] or of the companion *"detailed underpinning report on the geological structure of the PRZ {BGS Technical Report No. WA/95/47C, June 1995}"*.

2.9 There are three points arising from Dr Chaplow's para. 6.19:

- He has not tried to refute my demonstration that there are inconsistencies in Nirex interpretations.
- Nowhere does he specify which parts of Nirex Report {S/95/005} that he believes I have neglected to take into full account.
- He quotes a report {BGS Technical Report No. WA/95/47C, *June 1995*} (my italics) which was cited indirectly in his original proof of evidence [PE/NRX/14].

2.10 Concerning BGS Technical Report No. WA/95/47C I stated:
"Six of the ... seismic lines ... are apparently described and/or reproduced in the confidential BGS Report WA/94/47C. The source of this reference is Inquiry document COR/518, which refers to Nirex Report no. S/95/005, which in turn refers to this confidential report. However, there are no publicly available reports describing their acquisition, processing or interpretation. Only the depth geological maps and cross-sections of Report No. S/95/005 are available. These maps and cross-sections are interpretations, not data, and it is therefore not possible to make any judgement about the data quality." [PE/FOE/3 para. 6.4].
With respect to the version of the report which became available in September 1995, it is possible to make some assessment of the quality of the 2-D seismic data.

2.11 Appendix I of the report contains copies of the post-stack depth-migrated seismic lines from the survey UKN92-2D, lines 001-005 (dip lines) and 012, 014 and 015 (strike lines). The data have interpreted geological features drawn upon them. I find no major flaws in the interpretation, which appears to be competent. However the 2-D data are evidently flawed in a fundamental way, in that they are attempts to image a complex 3-D structure. For example, line 015 is blank, other than for a doubtful flat feature at about 100 mbOD. The interpreters have been unable to pick any deeper seismic reflection features, as there are none. Line 15 runs NW-SE across the middle of the PRZ, linking the BH2-BH4 area with BH5.

2.12 Dr Chaplow appears to be misleading the Inquiry about the status of the BGS report cited by him [PE/NRX/14/S1 para. 6.19]. The copy now available for public consultation is Issue 1.0 (i.e. the earliest accepted version), countersigned by its BGS authors on 4 September 1995. The Nirex acceptance cover page is countersigned '*R Chaplow 14 September 1995*'. Dr Chaplow therefore appears to be either:

- Citing a draft, unapproved version (dated June 1995) which had not been put through Nirex's usual Quality Assurance validation procedures, or
- Referring to a different, confidential, report, not available to outside parties, from that which has now been placed as evidence before the Inquiry.

Evolution of interpretation of the PRZ

2.13 Dr Chaplow quotes part of my proof of evidence [PE/FOE/3 para. 6.20] concerning the evolution of the subsurface geological picture over the last half century or so, and in particular over the last five or six years in which the site has been subject to intense investigation work by Nirex [PE/NRX/14/S para. 6.16]. He states [PE/NRX/14/S para. 6.17] that I have apparently contradicted myself by saying on the one hand, that the picture has not "*fundamentally changed*", while on the other hand it is being "*substantially revised every year or so*". The points raised here were discussed in the cross-examination of Dr Chaplow.

2.14 The pertinent points at issue are:

- Choice of cross-sections depicted.
- Accuracy of reproduction of these cross-sections.
- Significance of transect location.
- Significance of degree of variability observed.

The points listed above are discussed in turn below.

Choice

2.15 Dr Chaplow has stated that the six cross-sections depicted by me [PE/FOE/3 fig. 1] were "*selected ... to show the greatest possible differences*" [PE/NRX/14/S para. 6.17]. This is incorrect. The six cross-sections depicted were the only six available within the PRZ area. Dr Chaplow has not indicated that there are any other published sections extant. There has therefore been no selectivity.

Accuracy

2.16 Under cross-examination Dr Chaplow conceded that there is no inaccuracy in the reproduction of the cross-sections.

Transect location

2.17 Dr Chaplow has stated that the six cross-sections [PE/FOE/3 fig. 1] were "*not all from the same transect*", implying that this variation accounts for a large portion of the differences between them [PE/NRX/14/S para. 6.17]. The locations of the transects were given accurately on a separate figure [PE/FOE/3 fig. 2]. Dr Chaplow is unable to explain how the slightly different transect locations can account for the evidently very different interpretations, particularly as cross-sections C, D and E of [PE/FOE/3 fig. 1] are all at the same transect location. Furthermore Dr Chaplow is unable to explain why sections D and E, both dated December 1993, are far from identical. Thus it may be seen that the variation in interpretations does not arise as an artefact of transect location.

Significance of degree of variability

2.18 Dr Chaplow agrees with me that the 'fundamental' aspects of the geology, as depicted in the six cross-sections, are:

- Permo-Triassic sedimentary cover.
- Cover rocks resting on Borrowdale Volcanic Group.
- That the whole section (0-1000 m depth) is cut by normal faults.

These features, together with the absence of Carboniferous rocks subcropping in the PRZ locality, were known over 60 years ago [PE/FOE/3 para. 4.5], and have not changed since.

2.19 Dr Chaplow stated in cross-examination that "*the overall structure of the site has not substantially changed*". He maintained instead that "*the detail has changed*". The relevance and magnitude of these ongoing changes in the structural interpretation is discussed in more detail in Section 3 below.

The oil industry model

Oil industry expertise and experience

2.20 The oil industry comparison is mentioned by Dr Chaplow [PE/NRX/14/S, paras. 1.45-1.47], and discussed in detail by him in his section 12. He states (para. 12.4) that Nirex has "*drawn on a wide range of expertise and experience from the hydrocarbons industry*". He then lists four major Nirex contractors, including the BGS, and states that Nirex exchanges information with two oil companies, Shell and BP, even though "*the oil industry is not a direct analogy to the work being undertaken by Nirex*".

2.21 Dr Chaplow makes no attempt to refute in detail the evidence put forward that Nirex should, in some respects, follow a similar approach to exploration as that adopted by the oil industry. The elementary point made by Dr Chaplow concerning the difference in *permeability* and *flow rates* within the respective targets [PE/NRX/14/S, para. 12.3] is not relevant to the question of my expertise. Regarding the question of oil industry expertise, I worked for Nirex's most important geological contractor, the BGS, for 14 years, mainly on oil-related exploration and mapping work. In addition, my opinion that the oil industry is a useful model for Nirex to emulate is discussed in only two pages or so of Dr Chaplow's supplementary proof.

Step-wise progression from large to small scale

2.22 Dr Chaplow states (para. 12.8) that "*Detailed examination of the Nirex investigation programme reveals close similarities with the practice in the hydrocarbons industry. The adoption of a progressive, step-wise methodology from the regional reconnaissance scale towards the District and then the Site and finally the PRZ is a clear example.*". The adverb 'finally' implies a time progession in Nirex's 'step-wise methodology', beginning at the regional scale and ending at the PRZ scale. As outlined in the chronology below, the selection of the PRZ did not follow the step-wise progression implied by the quotation.

2.23 The current PRZ at Sellafield was selected in March 1991. Table 1 illustrates the chronology of some of the main surveys, including their scale of coverage. When the PRZ was selected there were only three regional vibroseis seismic reflection lines crossing it (shown as the dashed lines in PE/FOE/3, fig. 4), together with one new borehole to add to the old Boonwood borehole data. These data are far from sufficient to have defined the structure adequately. The structure of the PRZ could only have been defined after the acquisition of the onshore seismic infill surveys of 1992 and 1993 and their subsequent interpretation.

2.24 Table 1 shows that Nirex's survey work was *not* systematically working down from the large area to the small, as alleged by Dr Chaplow, but was *simultaneously filling in* survey coverage of the larger areas and the target zone, the PRZ. It may be seen that a step-wise methodology proceeding from the large scale to the small scale has not been employed by Nirex. Furthermore, it may be seen that the PRZ was selected prior to the availability of site characterisation data.

Site potential

2.25 Dr Chaplow assumes that I, as one of the Objectors, am "*conceding that the site may hold sufficient promise to ultimately justify construction of an RCF and hence, to hold potential as a repository site*". [PE/NRX/14/S1 para. 1.12 and para. 2.11]. This statement may be compared to the relevant text from my proof, which states:

"*I support, in principle, the general concept of a nuclear waste repository sited in the Sellafield area, if a suitable repository zone can be found. I also accept that at some stage within the site investigation programme for repository development it would be appropriate to construct a rock characterisation facility*." [PE/FOE/3 para. 10.1]. Thus it may be seen that Dr Chaplow has misrepresented my position on this issue.

The need for deterministic models

2.26 Dr Chaplow questions the relevance of my argument that accurate geological structure is required as an essential prerequisite for hydrogeological modelling [PE/NRX/14/S1 para. 8.68] within the stochastic modelling approach adopted by Nirex [PE/NRX/14/S1 para. 8.67]. Reliable hydrogeological modelling requires an accurate understanding of the geological structure, sufficient to constrain robustly the major features of the geology. Deterministic characterisation of the PRZ to the cubic metre scale would not be required. This issue is considered in more detail in Section 3 below.

Selective use of information

2.27 Dr Chaplow states [PE/NRX/14/S1 para. 1.28] that I have been "*selectively presenting information*" in order to justify the need for 3-D seismic surveys. [PE/NRX/14/S1 para. 1.28]. In my proof I focused attention on the non-robustness of the present geological interpretation of the PRZ. If the present geological interpretation of the PRZ were robust, datasets indicating non-robustness would not be present. Dr Chaplow has not demonstrated that the examples I considered are invalid.

3. OVERVIEW

Failure by Nirex to address key points

2-D tomographic surveys

3.1 The limitations of these surveys were described in [PE/FOE/3 paras. 6.5-6.10]. The inconsistencies between one tomogram taken as an example and the existing Nirex mapping were discussed in my proof [PE/FOE/3 paras. 6.11-6.18]. A 40 m mismatch in tomogram interpretation and the stratigraphy of BH2 was pointed out. Neither Dr Chaplow nor any of the other Nirex witnesses has commented upon these points.

Preliminary 3-D seismic survey results

3.2 Dr Chaplow has not stated why the results of the 3-D trial survey have not been made available to the Inquiry. He has stated in evidence that, the processing of the 3-D seismic survey was 'inadequate', yet has not stated why. Preliminary results from this survey appear to corroborate independent magnetic and tomographic data.

Premature choice of PRZ

3.3 In addition to the arguments discussed above, I drew attention to the non-scientific methodology adopted by Nirex in its early selection of the Sellafield PRZ [PE/FOE/3 paras. 9.3-9.5]. Dr Chaplow has not commented on this point.

Table 1. Chronology of major geological and geophysical investigations

Survey type	Date of acquisition	Scale	Comments
Onshore seismic surveys 1-3	1988-90	District	Reconnaissance surveys
Boreholes 1/1A-3	1988-91	Site	Only BH2 is within PRZ
	(March 1991)		(PRZ selected)
Offshore seismic survey	1991	District	
Gravity and magnetic surveys	1992	District	Reconnaissance exploration
Transition zone seismic survey	1992	District	
Onshore seismic infill surveys	1992-93	Site	
Boreholes 4-5	1992-93	PRZ	
Boreholes 7-14	1993-94	Site	Outside PRZ
RCF and RCM boreholes	1993-94	PRZ	

3-D characterisation of the PRZ

3.4 Dr Chaplow has not commented upon the discrepancy in BVG structure between the interpretations obtained from geophysical surveys and the structure interpolated from borehole data [PE/FOE/3 paras. 8.4-8.7].

The reliability of the current structural interpretation of the PRZ

3.5 Dr Chaplow has stated several times that any revisions required of the geology of the PRZ will be matters of 'detail' or of 'refinement'. This will be considered below.

3.6 The dimensions of the proposed RCF (phases 1 and 2) are of the order of 100 m in two horizontal dimensions. In my opinion an 'accurate' model of the RCF volume would require that the geological structure within this volume be known to less than 10% error in each dimension at the relevant depth, i.e. an error of about 10 m or smaller. Thus, for example, all faults with throws of 10 m or greater should be mapped, and also located in three dimensions to within about 10 m. At this scale we therefore require a deterministic model. The smaller geological scales could be estimated by stochastic methods. Against this criterion, the accuracy of Nirex's location of faults F2, the largest fault in the PRZ, is considered below.

The interpretation of fault F2

Introduction

3.7 Fault F2 is the most prominent fault cutting the PRZ. It has the largest throw (displacing the Base St Bees Sandstone horizon by about 150 m), and cuts at a shallow angle right across the PRZ.

Correlation of F2 on tomogram BH5-RCF3

3.8 Nirex states that the location of fault F2 is confirmed through a tomogram transecting the two boreholes BH5 and RCF3 {S/94/007} [COR/513]. Thus the PRZ geological structure report of July 1995 states:*"Fault F2 is correlated with features on the BH5-RCF3....tomogram(s)..."* {S/95/005, p. 13, para. 3.4} [COR/508]. F2 is identified on the left-hand side at BH5 at 385 mbRT (below Rotary Table), corresponding to the red fault feature shown in the uninterpreted tomogram with borehole logs on each side {S/94/007, Fig. 38}. F2 is identified on the right-hand side of the tomogram at 525 mbRT in RCF3, at the base of the Brockram, but with three subsidiary strands found up to 74 m deeper.

3.9 Dr Chaplow has said in evidence that the thickness of the fault zone is not necessarily a guide to which of the 'strands' is the main one; however the uppermost one at 525 mbRT is the thickest of the four, and also the one that has been used in all Nirex's current structural maps. Nirex's interpretation of F2 in RCF3 is summarised in Table 2 below. I have re-named the five strands with a suffix A to E for clarification.

3.10 Figure 1 herein shows Nirex's preferred version of the several possible interpretations of the tomogram {S/94/007, fig. 14} [COR/513]. I have projected onto it the position of F2, derived from the borehole data and also from the seismic and other interpretations used to construct the current Nirex structural maps. Details of the projection method are given in the figure caption. The projection method results in a similar but more precise projection than may be derived from the small-scale F2 surface contour map {WA/95/47C, fig. 3.2}.

3.11 The depth scale on Figure 1 is in mbRT of borehole RCF3 {S/94/007, para. 2.1.4}. Since the rotary table of RCF3 was 3 m higher in elevation above sea level than that of BH5, 3 m must be added to the mbRT (BH5) depths, so that they correspond to mbRT (RCF3) elevations. In practice this difference is trivial. Thus in Figure 1 any 'F2' feature should cut BH5 at 388 m (=385 + 3 m) and RCF3 at 525 m (both bRT of RCF3).]

Table 2. Correlations of fault 'F2' at RCF3

Nirex label	FoE label	Depth (mbRT)	Depth (maOD)	Dip azimuth	Comments
F2 strand 1	F2A	525	-437	005°	F2 as contoured on Nirex structure maps. Thickest fault logged in core.
F2 strand 2	F2B	533	-445	010°	
F2	F2C	577	-489	350°	
F2	F2D	599	-510	305°	
(F2)	(F2E)	(~613)	(~ -525)	(305°)	Cut out by F201. Brackets indicate approx. values if throw of F201 is restored. Tomogram feature 'A'.

3.12 It may be seen that F2 does not correlate with any features of Figure 1. F2 cuts across features at either side of the tomogram, and runs directly across a central featureless area.

3.13 At the left-hand side (at BH5) feature A, with an apparent dip of 43°, cuts BH5 at 388 m {as described in S/94/007, p. 23, para. 4.3.7} [COR/513] corresponding to F2. However, feature A is clearly dipping at about double the angle of F2. Furthermore, where feature A intersects RCF3 it correlates precisely with F201 at around 605 mbRT of RCF3. Thus tomogram feature A starts on the left as F2 but appears to end up on the right as F201.

3.14 At the right-hand side of Figure 1 (at RCF3), Nirex states that the principal strand of F2 (≡F2A) is at the base of the Brockram, at 527 mbRT {S/94/007 para. 4.3.1}. However, there is no feature on the tomogram which links F2A in RCF3 to F2 in BH5.

Coincidence of faulting at RCF3

3.15 In addition to the lack of correlation between F2 and features of the tomogram, the complexity of faulting at RCF3 also calls into question Nirex's structural interpretation of the PRZ.

3.16 Fault F201, which has been identified from borehole data at RCF3, is so steep that it has not been imaged directly on the tomogram. Feature B on the preferred interpretation {S/94/007, p. 23 para. 4.3.7. and fig. 14}[COR/513] intersects RCF3 at exactly the same depth as feature A. Feature B is interpreted by Nirex as a fault. Although feature B is also at the same depth as F201, it cannot be correlated with F201 as Feature B has too shallow a dip, by a factor of about 2 (see {WA/95/47C fig. 3.5}). The structural characterisation of feature B remains unresolved.

3.17 Thus it may be seen that the Nirex interpretation implies that there are *three* faults all intersecting each other at around 605 mbRT in RCF3:

- The flat-lying continuation of F2 (≡F2E), interpreted on the tomogram,
- Fault feature B, also interpreted on the tomogram, and
- F201, recognised in the borehole.

This concidence of faulting indicates the complexity of the PRZ.

F2 and the F2E strand

3.18 Nirex states that the lowest strand of F2 (≡F2E) is missing at RCF3 because it has been has been cut out by F201 {S/95/007 fig. 5.2}. F2E appears to match the BH5-RCF3 tomogram correlation better than the Nirex mapping of F2 at F2A (88 m above F2E).

3.19 A revised mapping of 'F2' over the PRZ, using F2E rather than F2A would create its own problems, due to the implications it would have for the variety of trends of F2 over the PRZ. Correlation of the three lowest strands of F2 between the trio of boreholes RCF3-RCM2-RCM1 {S/95/007} suggests that the three strands dip steeply north (F2C) or NW (F2D and F2E). The correlations are illustrated in Figure 2. This three-way borehole correlation would require F2 to swing anticlockwise through 90°, and then back again to account for the faulting in the area of RCF3. This would be highly unusual behaviour for a normal fault such as F2.

Conclusion

3.20 This example illustrates the highly complex three-dimensional structure of the PRZ. It is clear that, to date, Nirex interpretations have completely failed to resolve this structure satisfactorily. The tomogram report itself states that this tomogram *"suggests a complex structure that is difficult to interpret with confidence"* {S/94/007, p. 20, para. 4.3.2}. This is evidently true. Thus the statement quoted above *"Fault F2 is correlated with features on the BH5-RCF3....tomogram(s)..."* {S/95/005, p. 13, para. 3.4} [COR/508] is incorrect. The tomogram does not in any way corroborate the mapped interpretation of a single fault 'F2'.

3.21 The oversimplification found within current Nirex mapping is not simply a question of 'detail', or of 'refinement', as stated by Dr Chaplow. Fault F2 has been interpreted as the biggest fault in the PRZ, with a throw of around 150 m. The possible location of F2 extends vertically over a distance of about 100 m in the proposed south shaft location, and extends horizontally over distances of several hundred metres away from RCF3. These dimensions are of the same order as those of the proposed RCF. The implication is that there is no single 'F2', but in its place there are probably some five or six faults within the PRZ, some striking NW-SE, and others striking NE-SW. Nirex has unsuccessfully tried to map these as a single, simple surface labelled 'F2'.

3.22 It may be seen that there are likely to be very serious errors in the interpretation of the major faulting in the PRZ. The work required to remedy these deficiencies is described below, with reference to BGS Technical Report{WA/95/47C}, which became available in September 1995.

3.23 The authors of the report {WA/95/47C}, Nirex's Geological Integration Team, state in their recommendations that:

"*The magnitude of structural changes between seismic lines only hundreds of metres apart ... and indeed boreholes only tens of metres apart ... emphasises the meso-scale complexity of the Sellafield Site and PRZ.*" {WA/95/47C, Appendix I, p. 34}.

3.24 These authors thus appear to concur with my concerns with respect to the complexity of the geology. The authors further state that:

"It is the considered opinion of the authors of this report that only a 3D seismic acquisition program (of appropriate extent) with full pre-stack depth migration will ever be capable of supplying an adequately predictive 3D subsurface model for the PRZ area". {WA/95/47C, Appendix I, pp. 34-35}.

3.25 Thus it may be seen that Nirex's contractors identify the same key problem, and recommend the same solution that I outlined in my proof of evidence.

Time required for further work

3-D seismic surveys

3.26 Dr Chaplow states that new field acquisition work is provisionally programmed for 1996 [PE/NRX/14/S1 para. 6.15]. If it is assumed that pre-qualification procedures are already complete, and that an outline specification of the survey is ready, the time required for further work may be assessed. The times outlined below are the *minimum* times required for a 3-D vibroseis survey of seven to ten square kilometres in area (i.e. only 15-20% of the Site):

Acquisition phase
Tendering process - 1 month
Planning: access, surveying, etc. - 3-4 months
Acquisition field work - 4 months

Processing and interpretation
Processing - 3 months minimum from end of acquisition
Interpretation and QA - 6-9 months
Integration with existing data - 1 year or more

3.27 Only the summer period (June-October) is possible for the fieldwork. The above very tight timescale assumes that acquisition can be successfully completed by the end of October 1996. These estimates assume that processing is put well in hand during acquisition, and that no problems arise to delay the fieldwork. The figures above can be compared with the actual time taken to date on the various phases of the 3-D trial survey undertaken in 1994, covering about one square kilometre:

Tendering process, planning access, surveying, etc. - 4 months (April-July 1994)
Acquisition field work - 1.2 months (August - early September 1994)
Acquisition factual reporting - 2 months (September-November 1994)
Processing, interpretation and QA - Not yet reported.

3.28 It may be seen that it is difficult to envisage a properly validated interpretation being available before mid-1997 at the very earliest, i.e. 18 months from now. Given the oil industry experience that the acquisition of 3-D seismic data results in a complete revision of all previous structural models, a phase of integration with borehole and other data is likely to be required before the model can be said to be robust. This stage might be realistically achieved in, say, 30 months from now, or mid-1998.

Possible implications of additional survey work

3.29 After the revision of the structural interpretation that is likely to be required following completion of the 3-D seismic survey, it may be deemed appropriate to relocate the site of the proposed RCF. Furthermore, due to the dependence of the hydrogeological model on the interpretation of the geological structure, it will not be possible to generate a reliable hydrogeological model until the interpretation phase of the 3-D survey is complete. This modelling work may require one to two years of further work subsequent to completion of the 3-D survey interpretation.

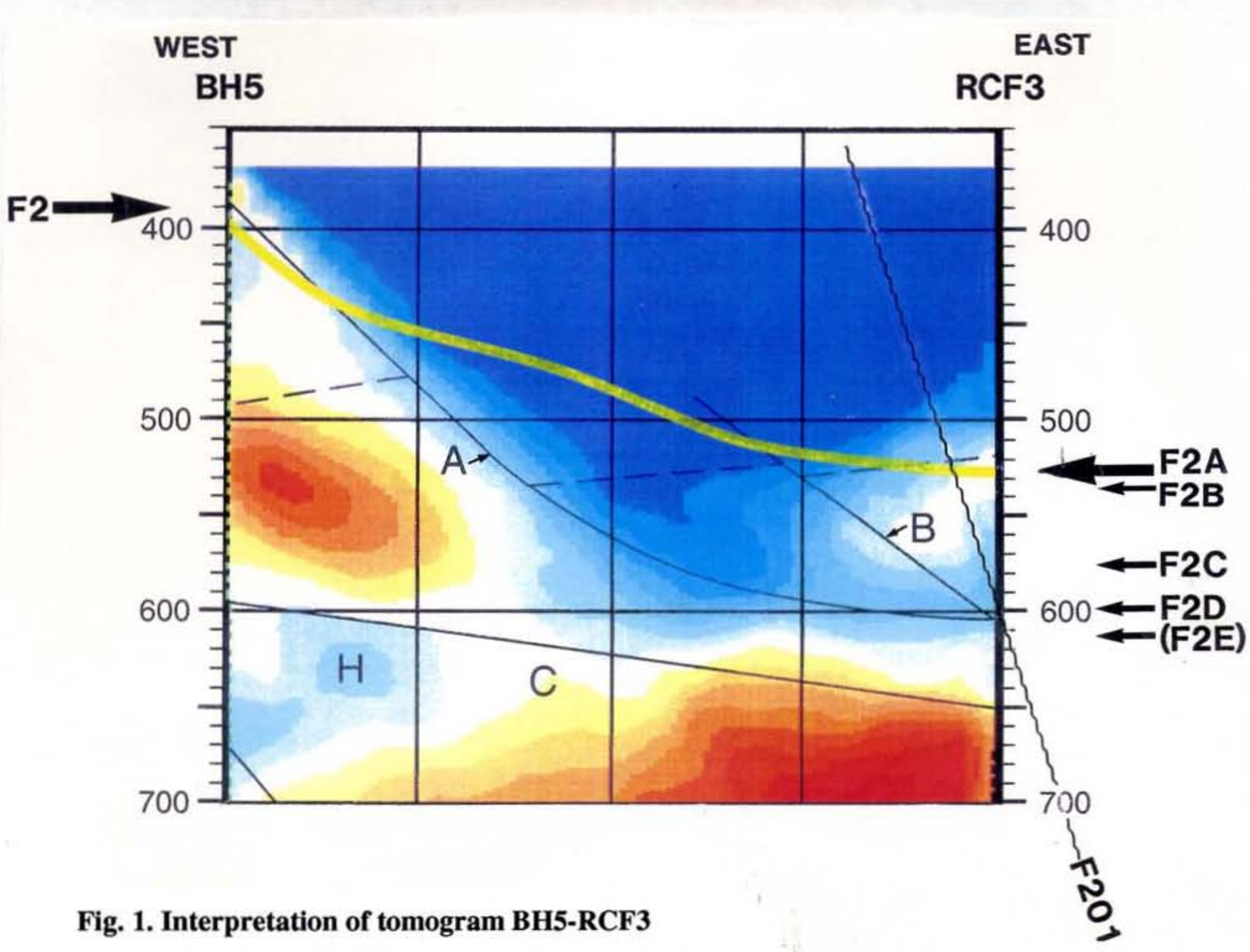


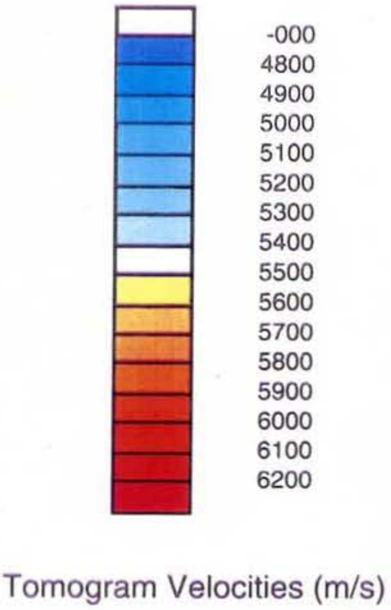
Fig. 1. Interpretation of tomogram BH5-RCF3

Reproduced from (S/94/007 fig. 14}, with additions. Vertical scale is metres below RT of RCF3. Vertical and horizontal scales are identical.

F2 as identified in BH5 is marked with large arrow, This is mapped to the uppermost of five strands of F2, labelled here F2A-F2E (see also Table 2).

The interpolated yellow line is the fault projection, compiled by picking the depth values at the top and bottom of the fault from relevant structure maps {SA/95/002} [COR/518], and from depths in boreholes, then gridding and contouring the picks. The plane of the tomogram is then extracted from the contoured F2 surface map, which is similar to that shown in {WA/95/47C Vol. 1, fig. 3.2}, but more precise.

F201 is indicated schematically by the wavy line. It is too steep to be imaged on the tomogram. Arrow labelled (F2E) is the approximate depth of the lowest strand of F2 (cut out by F201 at the borehole) after removing the throw of F201.



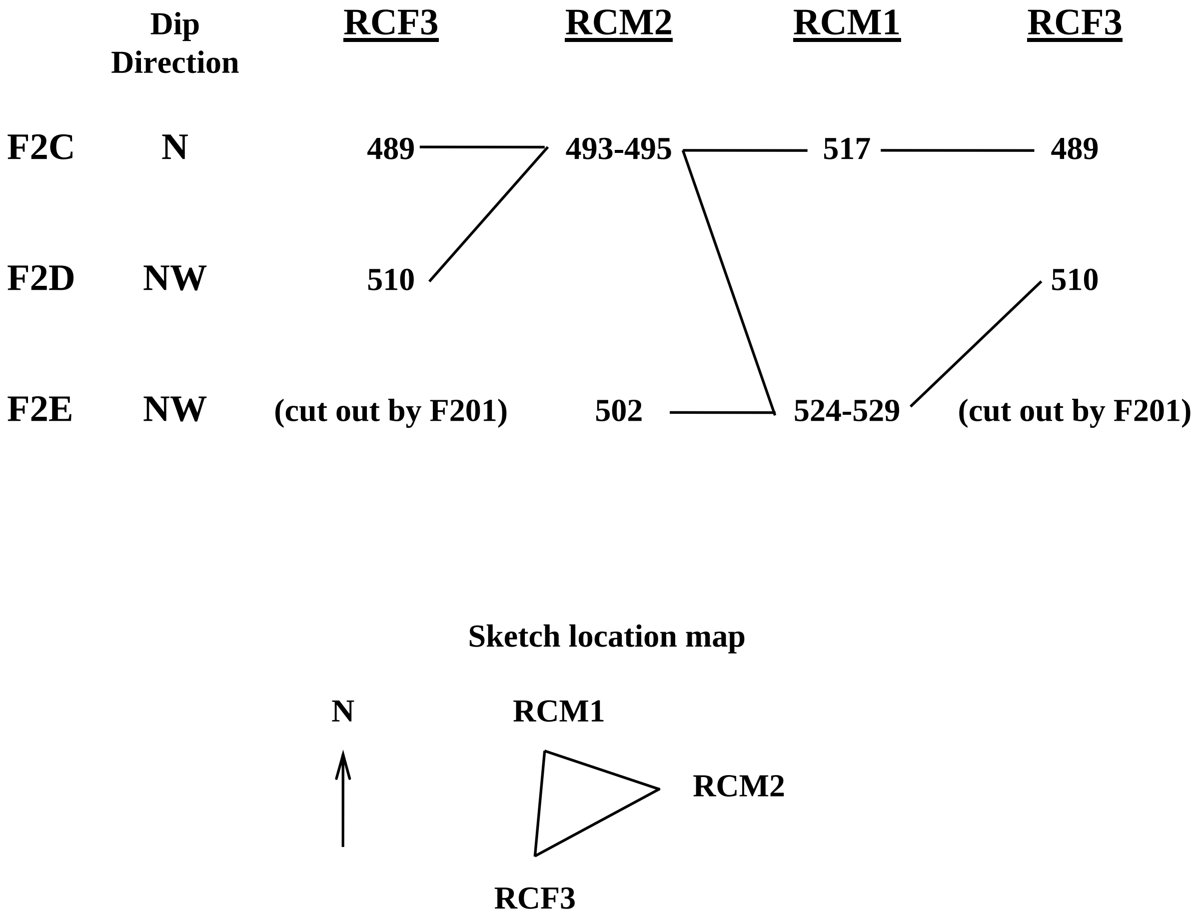


Fig. 2. Correlation of lower strands of F2 at south shaft location.

Nirex's correlation of the three strands of F2 (F2C, F2D and F2E; cf. Table 2 herein) between the three boreholes RCF3, RCM2 and RCM1 is shown. The numbers in each column correspond to depths of each strand in metres below OD.

The diagram illustrates why only two faults strands are apparently found in each borehole (see tables 3.1, 3.3 and 3.2 of {S/95/007}). F2E is cut out by F201 at RCF3; F2C and F2D are assumed to converge at RCM2; and F2D and F2E are assumed to converge at RCM1.