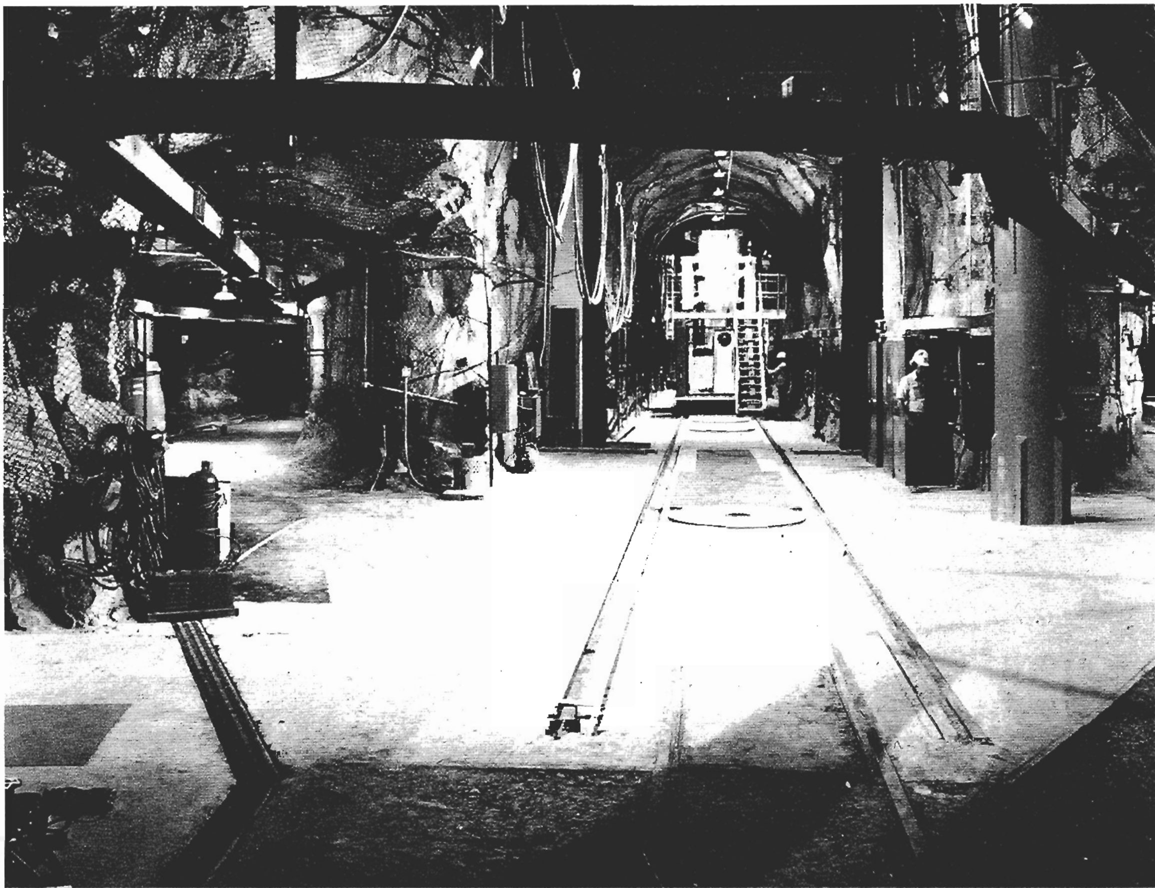

SITING, DESIGN AND CONSTRUCTION OF UNDERGROUND REPOSITORIES FOR RADIOACTIVE WASTES

PROCEEDINGS OF A SYMPOSIUM
HANNOVER, 3–7 MARCH 1986

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1986

GEOLOGICAL ENVIRONMENTS FOR DEEP DISPOSAL OF INTERMEDIATE LEVEL WASTES IN THE UNITED KINGDOM

N.A. CHAPMAN, T.J. McEWEN
British Geological Survey,
Keyworth, Nottingham

H. BEALE
United Kingdom NIREX Limited,
Harwell, Oxfordshire

United Kingdom

Abstract

GEOLOGICAL ENVIRONMENTS FOR DEEP DISPOSAL OF INTERMEDIATE LEVEL WASTES IN THE UNITED KINGDOM.

By 2000 the United Kingdom will have produced about 40 000 m^3 of intermediate level wastes which, because of their content of long lived radionuclides, will be assigned to a deep geological disposal repository, be it on land or offshore. In the paper the authors develop a novel concept of hydrogeological environments for deep disposal which departs from earlier guidelines for high level waste repository site selection by placing increased emphasis on the regional groundwater regime in the vicinity of the potential host formation, rather than simply considering the properties of the host rock itself. This concept has led to the definition of five types of deep environment thought to be most suitable for disposal, and which are considered to be applicable to geological conditions throughout most of northern and central Europe. The authors develop the rationale for the choice of these environments and define those areas of the United Kingdom where they occur. These areas will be assessed in more detail, with a view to producing a short list of sites for thorough investigation and intercomparison as potential repositories.

1. INTRODUCTION

By the end of the century the United Kingdom will have produced about 40 000 m^3 of conditioned intermediate level wastes, containing sufficient quantities of long lived radionuclides to destine them for deep, rather than near surface, disposal [1]. One of the principal options being considered for their disposal is burial in a deep repository on land, or beneath the sea, making use of tunnel access from the land. The main alternative is deep burial beneath the sea-bed using an offshore access point such as a platform structure. The wastes comprise fuel cladding materials, sludges, resins and concentrates, structural materials and plutonium contaminated materials [2]. The conditioning envisaged for the majority of these wastes will involve incorporation into a cement or cement–pulverized fuel ash matrix, and containment in either a steel or concrete package. Any repository design is likely to use large volumes of cementitious material as backfill or structural components. This has the advantage of providing near field conditions which, over very long periods, will minimize both corrosion of the waste packages and concentrations of radionuclides eventually entering solution in pore waters or groundwaters. Calculated near field release concentrations are so low that for the majority of radionuclides the near and far fields can be assumed to act as independent barriers to release [3]. This indicates that waste package design and the performance of the host environment can to all intents be decoupled. although the selection of a host formation with adequate hydrogeological properties nonetheless remains an essential requirement of this concept.

A deep geological repository for such wastes would be a simple mined facility, probably designed to allow waste emplacement in excavated tunnels or rooms, rather than in boreholes as frequently envisaged in high level waste disposal concepts. The depth of the facility is likely to be about 200–1000 m, depending very much on regional geology.

This paper discusses the choice of suitable geological environments for such a repository, and defines those regions of the United Kingdom where these environments are found, and consequently where interest is currently focused.

2. DEFINITION OF SUITABLE ENVIRONMENTS

Although the wastes concerned essentially do not emit heat, their radionuclide inventories indicate that in all other respects their geological containment requirements are similar to those for high level wastes (HLW). Over the last 8–10 years the United Kingdom, in common with many other countries, has gone through the exercise of defining suitable host rocks for HLW disposal, using well established and well advertised guidelines which incorporate such factors as:

- Thermal stability of the host rock
- Low permeability of the host rock
- Avoidance of areas of high seismo-tectonic activity, susceptibility to erosion, etc.
- Minimum depths of burial, particularly in relation to glacial effects.

Application of these factors tended to put great emphasis on the properties of the host rock itself, and very little emphasis on the regional groundwater flow regime in which it lay. In other words, near field physical properties had assumed too great a significance in comparison with a knowledge of long distance transport pathways, which might often be in entirely different rock formations to the host. However, as a result of our increased understanding of low flux regimes, and greater confidence in modelling them in both fractured and non-fractured rocks, it has become apparent that the 'site selection' exercise needs to be primarily based on defining what are considered to be suitable large scale hydrogeological environments. In some senses this reduces the emphasis on the host rock itself, and places it much more on the larger scale geological environment.

Thus, while the old approach to HLW disposal resulted in the definition of the now widely known and accepted group of host rocks (salt, crystalline rocks and clays), largely on the basis of their low permeability and their thermal stability, the approach we advocate here could well lead to selection of other host rocks whose containment properties are based on the overall nature of the environment in which they are found, rather than any intrinsic property they possess in isolation.

At the outset, however, the approach we discuss is firmly based on well understood guidelines, some of which were mentioned earlier. Since these guidelines have been described many times, and in most cases are largely a matter of geological common sense, we shall not discuss them further in this paper. The approach we adopt here differs from earlier exercises, however, in that it is the requisite features of the geological environment (rather than simply the host rock alone) which are considered. In the simplest terms these features will be characterized by:

- Predictable groundwater flow paths, preferably long and resulting in progressive mixing with older, deeper waters or leading to discharge at sea;
- Very slow local and regional groundwater movements in an area with low regional hydraulic gradients;
- Ease of construction to allow for economic repository design;
- Conformity with the many accepted restrictions regarding seismicity, depth, etc.

While this approach inevitably finds us looking again at clays and salts, it considerably restricts what might be considered suitable crystalline rock terrains, and introduces new possibilities where the host rock type may be subordinate to the flow regime (e.g. small island environments, discussed below).

By drawing upon experience gained in various field investigation programmes and desk hydrogeological reconnaissance surveys carried out in the United Kingdom, it has been possible to use the growing body of knowledge on the deep geology to define environments which might fulfil these requirements, and then to map their occurrence. The environments now considered most suitable for disposal of long lived wastes in the United Kingdom are listed below, together with the rationale behind their choice:

(a) *Inland basinal environments:* Deep sedimentary basins containing mixed sediments with a high proportion of low permeability formations (mudstones, evaporites, volcanics, etc.). Regional groundwater movement would be mainly confined to any aquifer (or high permeability) units and would tend

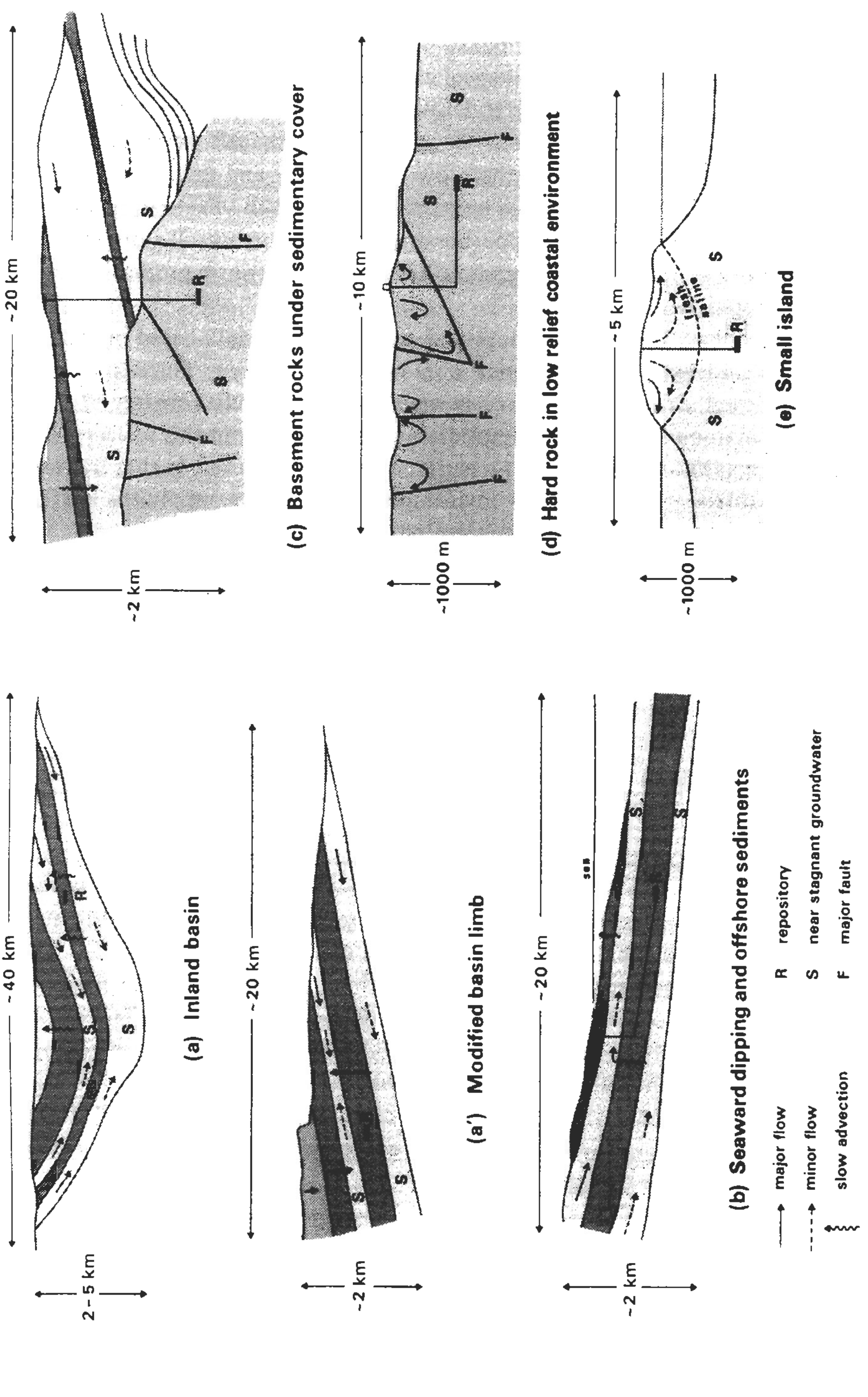

FIG. 1. Geological environments considered most suitable for deep disposal of long lived intermediate level wastes in the United Kingdom.

to be downwards, following the dip. Vertical fluxes would occur across the low permeability units, connecting the aquifers, at very low advection rates, or where there is little or no advection, at rates dominated by diffusion. Further down-dip into the basin, fluxes would become progressively less, and near stagnant conditions would be expected to develop, with varying degrees of mixing of waters from one formation to another, either by diffusion, or by very slow vertical advection in response either to pressure variations between formations or to thermal buoyancy of groundwaters, depending on regional heat flows. The most appropriate location for a repository would be on the limb of the basin, in one of the low permeability units, where groundwater fluxes in adjacent high permeability units would be expected to continue down-dip, thus increasing the path length and any consequent migration times. This concept is shown in Fig. 1(a), together with Fig. 1(a′), a very similar situation, common in the United Kingdom, where local structure and topography may emphasize one limb of a basin, or cause somewhat modified flow.

(b) *Seaward dipping and offshore sediments:* Similar in concept to (a), with groundwater movements expected to be very slow towards and under the coast (Fig. 1(b)). Very slow groundwater fluxes are expected to prevail at depth, and in the offshore environment the only potentials for movement will be through very slow upward advection caused by: (i) any remnant heads present, although these, resulting as they do from onshore topographic effects, will decay markedly with distance from the coast; or (ii) any thermal buoyancy, which will be dependent on regional geothermal patterns. Otherwise the lack of head variations in sub-sea-bed formations will result in almost zero flow.

(c) *Low permeability basement under sedimentary cover:* Basement rocks of low intrinsic permeability (principally hard shales, mudstones, slates, quartzites or volcaniclastics, with some hard crystalline rocks) occurring under more recent sedimentary cover (Fig. 1(c)). Groundwater movement will dominantly occur in the cover, with little anticipated connection to the basement rocks. These hard basement rocks also have the advantage of making construction relatively easy. In the United Kingdom the most suitable basement rocks may be the shales, mudstones, slates, quartzites and volcaniclastics.

(d) *Hard rocks in low relief terrain:* Hard rocks have the advantage of making the construction of underground facilities easier. Low relief environments (Fig. 1(d)), such as those being developed for waste disposal and storage facilities in Sweden, have little driving potential for groundwater movement, although the scale of groundwater flow systems is small compared with that of the environments described previously, owing to control by frequent major fracture zones. As with case (b), a coastal location would be preferable, to give access to an offshore repository, and higher coastal relief could be tolerated in this case, since any transmitted heads would decay rapidly offshore owing to the barrier effect of major fractures.

(e) *Small islands* are worth investigating, almost regardless of rock type, since a deep repository could be sited below the sea water–fresh water interface, where groundwater conditions are thought to be essentially stagnant. The simple concept portrayed in Fig. 1(e) would of course be considerably modified by local structure (e.g. faults), and by proximity to shore and any consequent hydraulic connection with permeable formations on the mainland, but in principle this category is attractive if the availability of ultra-low flow conditions combined with the massive dilution potential of the sea can be assumed.

3. LOCATION OF SUITABLE ENVIRONMENTS IN THE UNITED KINGDOM

3.1. Types (a) and (b): Inland basinal environments and seaward dipping and offshore sediments

Five stratigraphic intervals have been considered: the Permian throughout its complete sequence, including the basal clastic sediments, the Mercia Mudstone Group (including the Penarth Group), Lias, Oxford Clay and Kimmeridge Clay (including the upper Corallian and Ampthill Clays). These formations were selected as their lithologies are mainly argillaceous or evaporitic. Areas of interest which may prove potentially suitable have been defined for each interval using boundaries which are the vertical projections to the surface of the following structural contours:

(i) Where any part of the formation is more than 200 m below the surface
(ii) Where the base of the formation is 1000 m below the surface
(iii) Where the formation thins to less than 50 or 100 m thick, depending on the formation.

These factors are clearly convenient rationalizations of somewhat arbitrary depth and thickness guidelines, which in the event would be very site specific, but are nevertheless a useful and conservative means of narrowing down the areas of interest. The boundaries derived produce areas which are intentionally rather larger than those which would eventually be chosen for more detailed study. This is a result of the geometrical difficulty of combining depth, dip and thickness data in formations which frequently have non-uniform geometries. Other cut-offs are defined by tectonic boundaries, such as major fault zones, and also zones of structural complexity. A further, but much less significant, cut-off is the unconformity reflecting the level of the pre-Cimmerian erosion, although this only affects the Oxford and Kimmeridge Clays to a limited extent, and the boundary is not differentiated on the relevant figures.

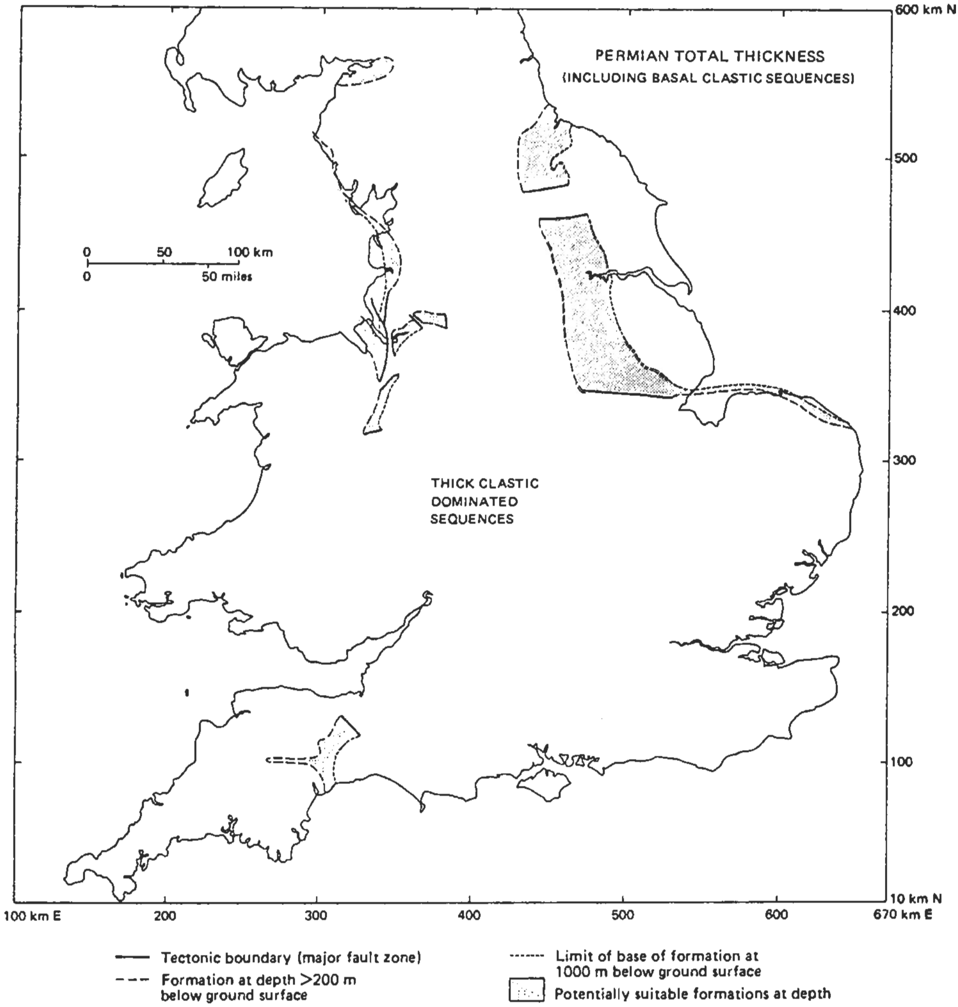

FIG. 2. Type (a) and (b) sedimentary environments: areas containing potentially suitable Permian rocks.

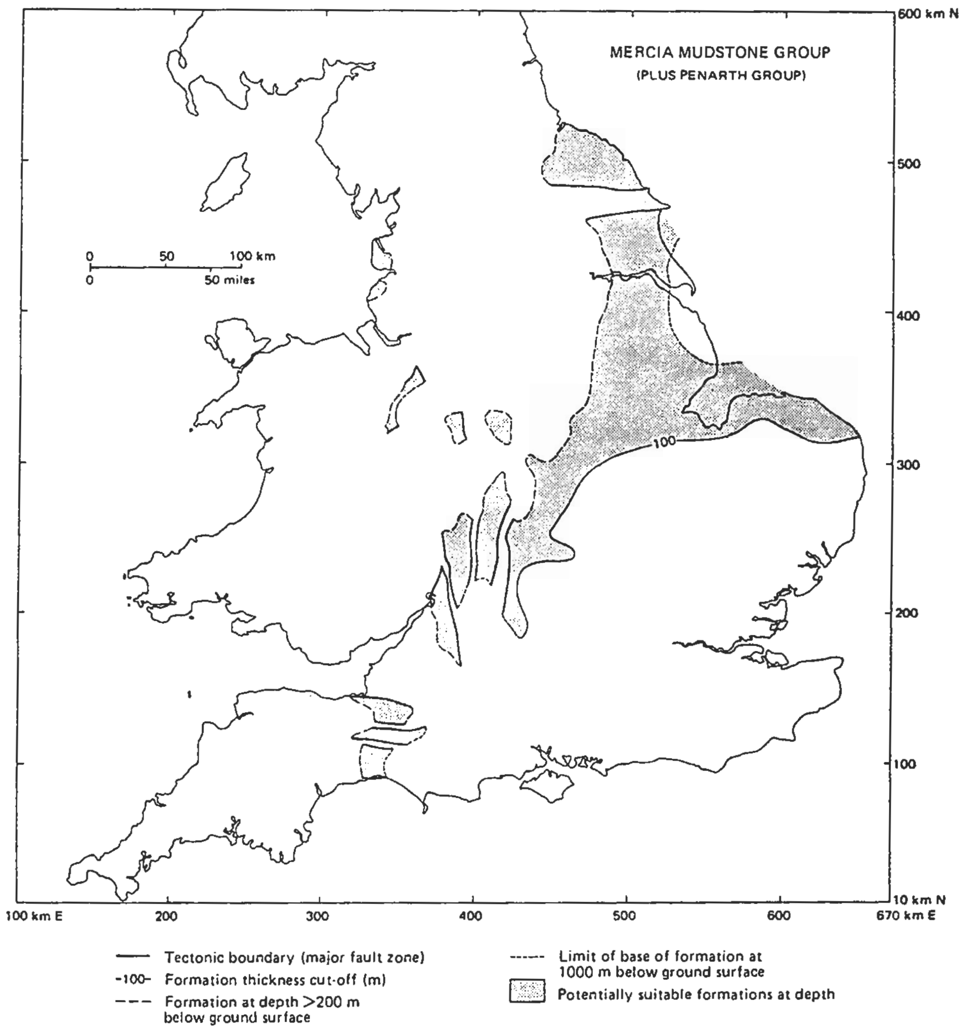

FIG. 3. Type (a) and (b) sedimentary environments: areas containing potentially suitable Mercia Mudstone Group rocks.

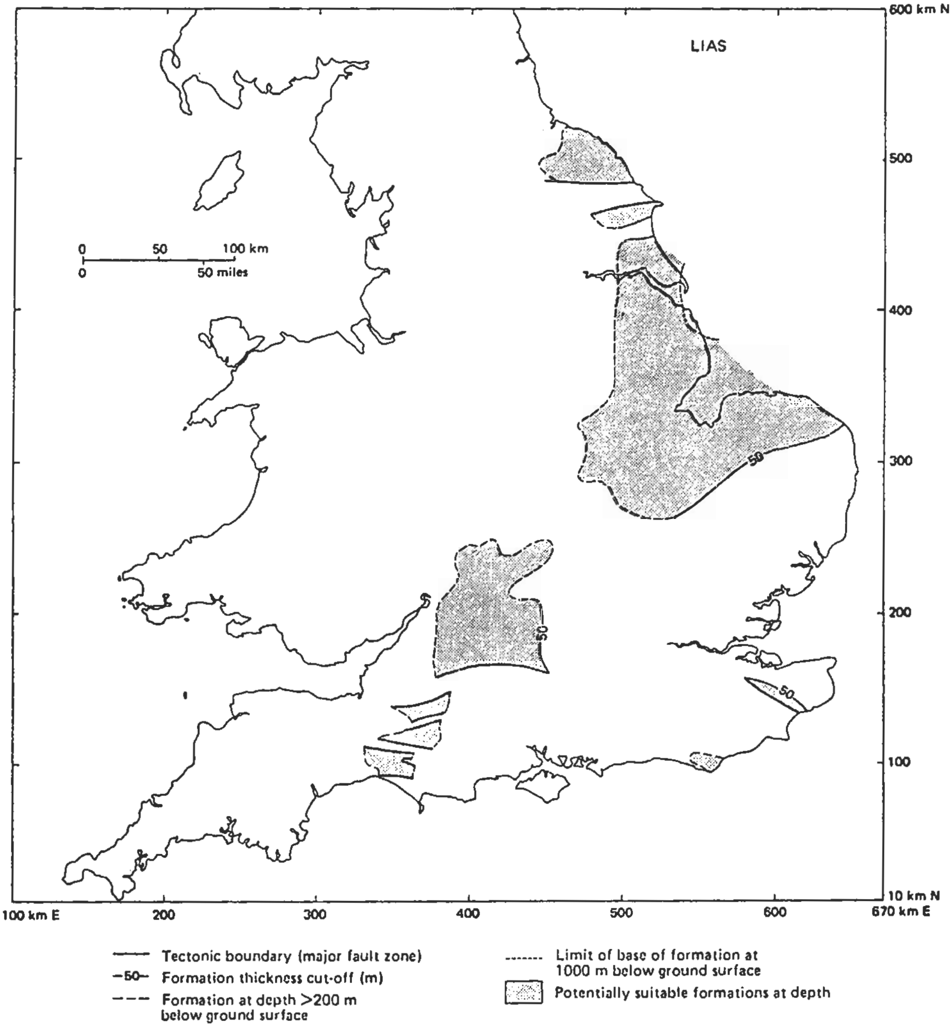

FIG. 4. Type (a) and (b) sedimentary environments: areas containing potentially suitable Lias rocks.

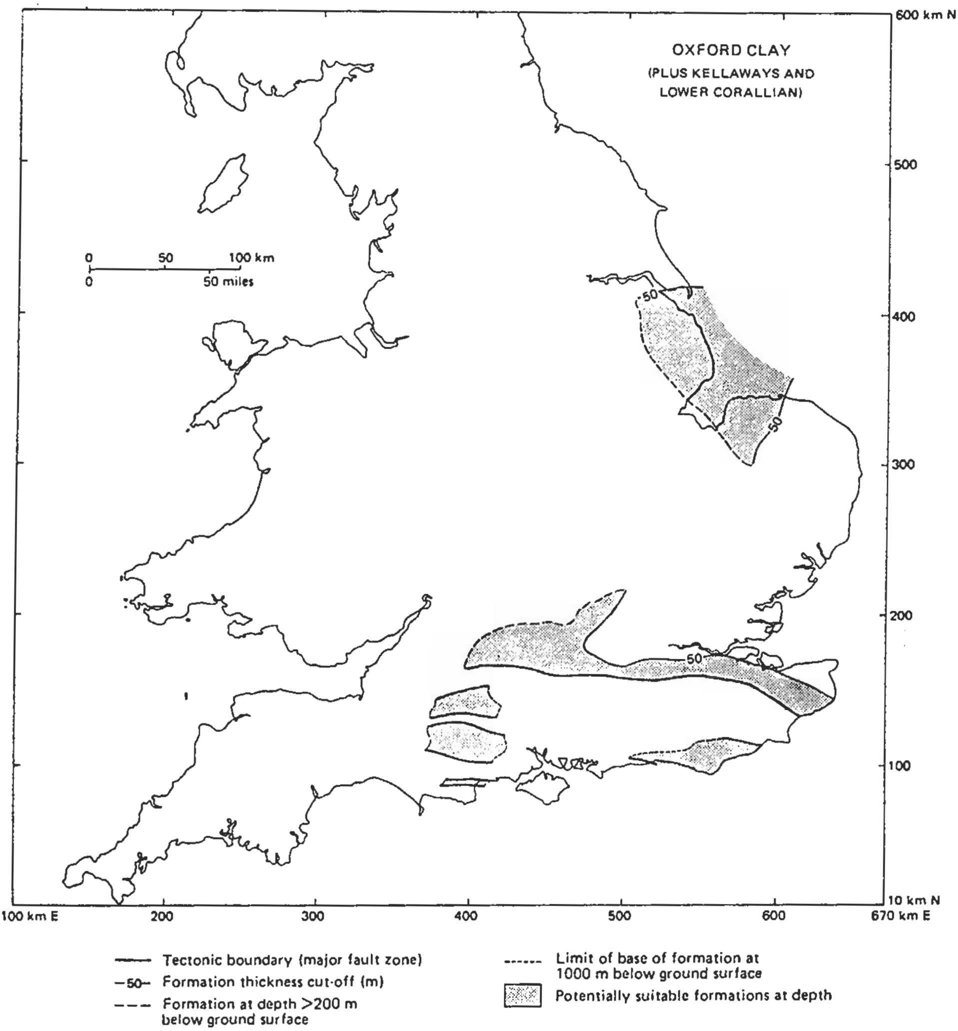

FIG. 5. Type (a) and (b) sedimentary environments: areas containing potentially suitable Oxford Clay and associated rocks.

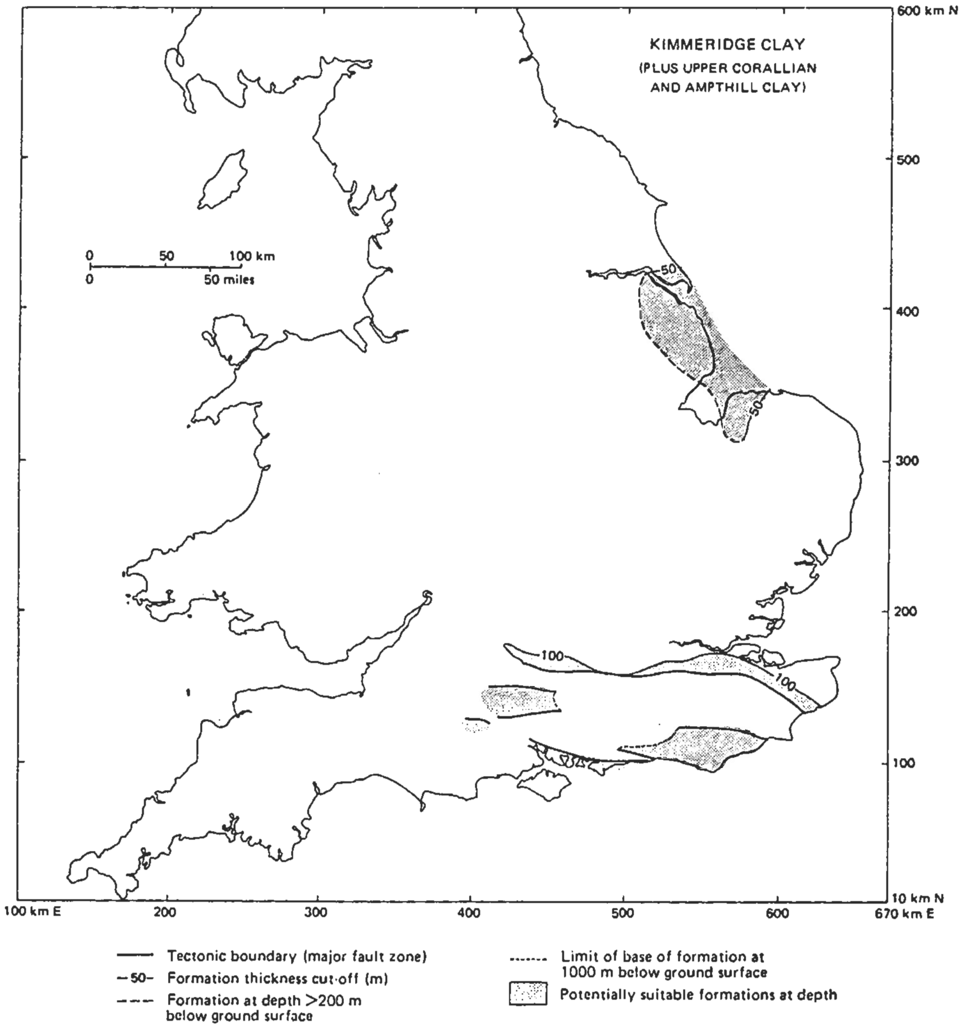

FIG. 6. Type (a) and (b) sedimentary environments: areas containing potentially suitable Kimmeridge Clay and associated rocks.

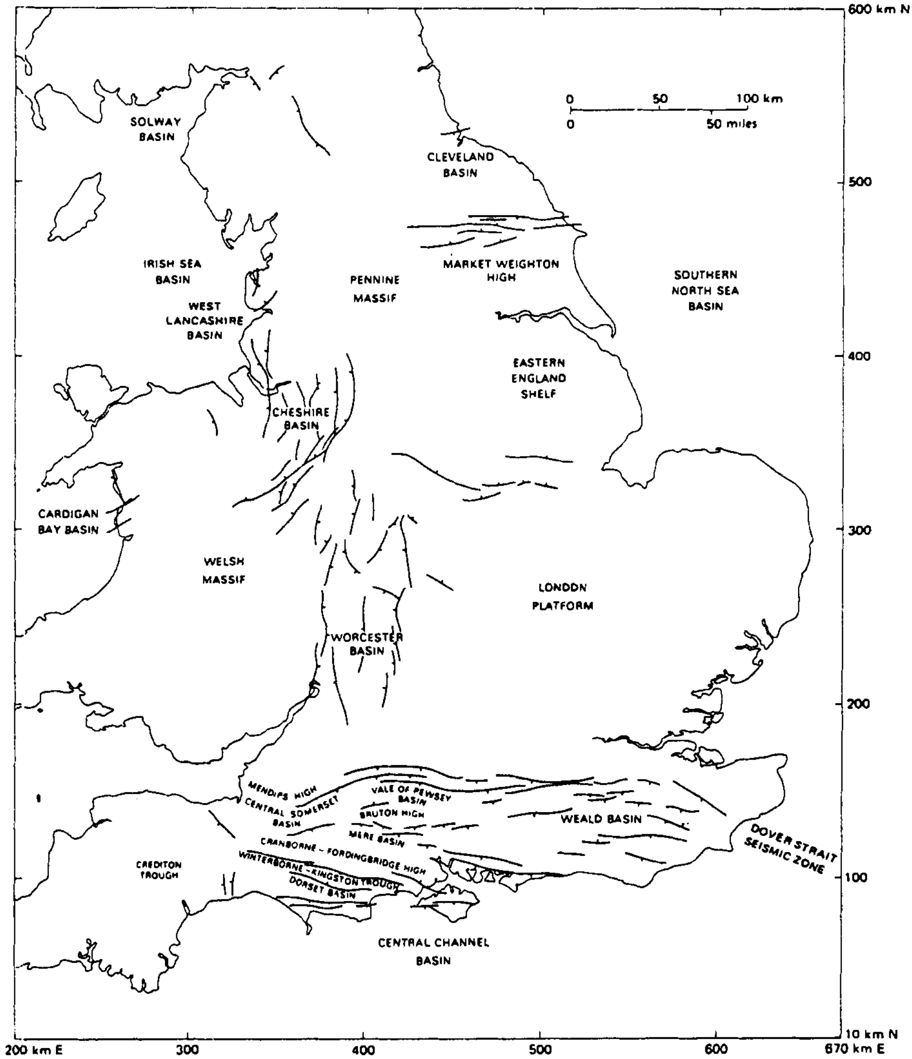

FIG. 7. Major relevant structural features of England and Wales.

The resultant areas of each formation which meet these depth and thickness criteria are shown in Figs 2–6, and Fig. 7 shows the disposition of the major Permian and Mesozoic basins of England and Wales. It can be seen that much of the southern and eastern portions of England contain potentially suitable disposal environments. Of particular interest is the area known as the Eastern England Shelf, where all the stratigraphic intervals considered are represented, and where the geological complexity is minimized by the absence of significant folding and faulting. Other potentially interesting areas are the Wessex Basin (comprising all structures between the Crediton Trough and the Dover Strait Seismic Zone) and the Worcester Basin.

The Wessex Basin is a complex of elongate sub-basins and structural highs, bounded by major normal growth faults, and overlies a Variscide basement cut by major east–west Palaeozoic thrusts. The result is a considerably more complex disposition of the Mesozoic sediments of interest than in eastern England. Similarly, the Worcester Basin is bounded by large north–south growth faults, and has numerous cross-faults, adding to its structural complexity.

Three other major sedimentary basins were considered: the Cheshire, West Lancashire and Cleveland Basins. The first two contain thick sequences of Permian strata, and thick Mercia Mudstone Group sediments are particularly well developed in the Cheshire Basin. The latter is complicated by numerous large north–south to south-west–north-east trending normal faults, and much of the Permian thickens rapidly offshore from Lancashire and the Lake District into the Irish Sea Basin. Owing to its sedimentation history the Cleveland Basin contains large areas of Permian, Mercia Mudstone Group and Lias, although there are no suitable areas of Oxford or Kimmeridge Clays.

All five of the stratigraphic intervals of interest are present in seaward dipping or offshore environments along the whole coastal section of the Eastern England Shelf and the Cleveland Basin, and into the Southern North Sea Basin. The Weald Basin also extends offshore under the English Channel, and the Mesozoic sediments of the Dorset Basin extend offshore into the Central Channel Basin. On the west coast the West Lancashire and Solway Basins extend offshore into the Irish Sea Basin.

Most of the areas of interest of types (a) and (b) are also licensed for oil and gas exploration and production, and the Eastern England Shelf, the Cleveland Basin, their extension into the Southern North Sea Basin, the Worcester and Cheshire Basins, and parts of the Wessex Basin (in particular the Dorset Basin) are considered to be potential geothermal fields. The implications of these resources are considered in the conclusions.

3.2. Type (c): Low permeability basement with Mesozoic sedimentary cover

Figure 8 shows a large area of Precambrian and Palaeozoic basement which is present at relatively shallow depth as part of the London Platform. Its boundaries

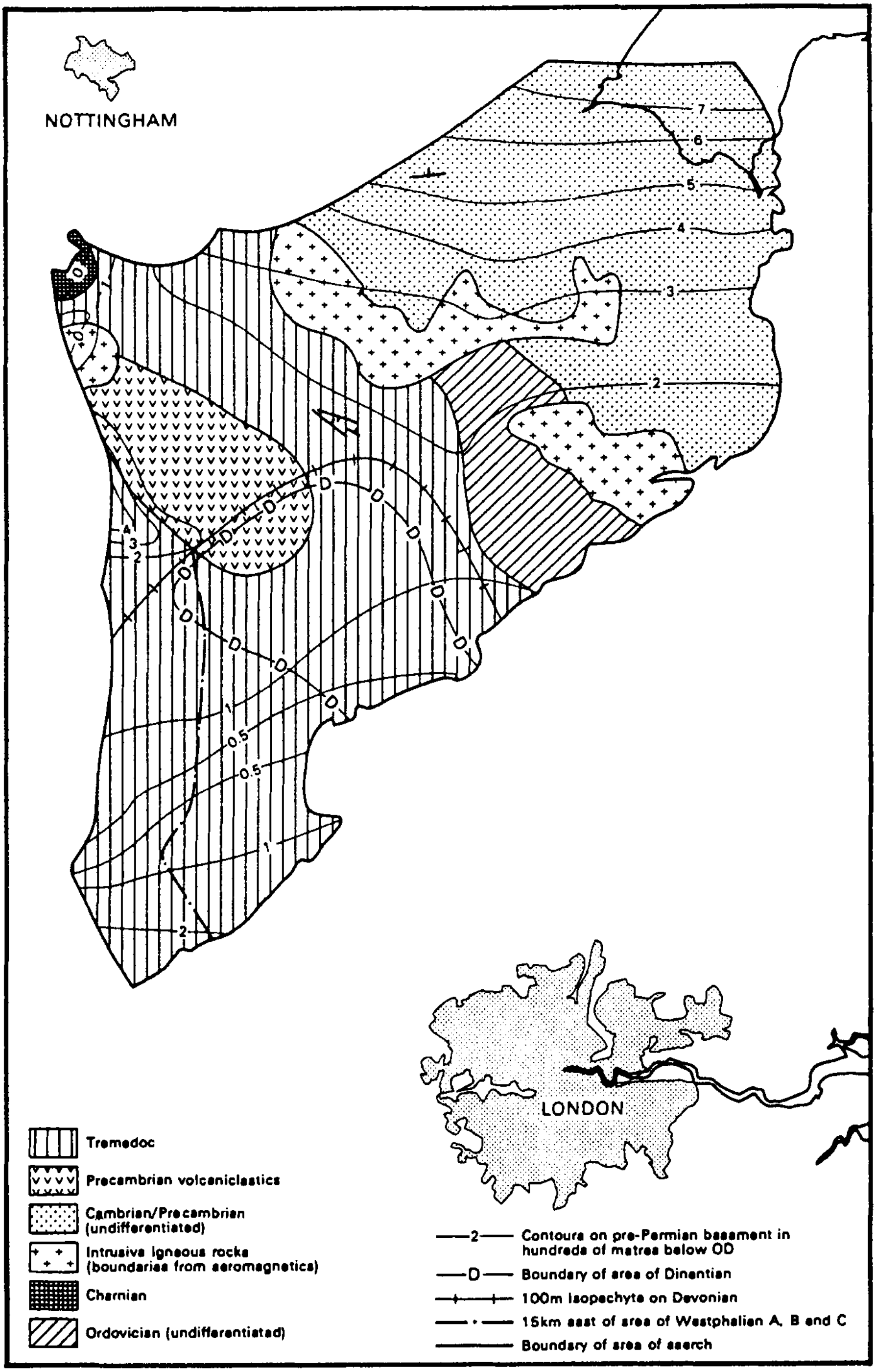

FIG. 8. Area of potentially suitable buried basement rocks.

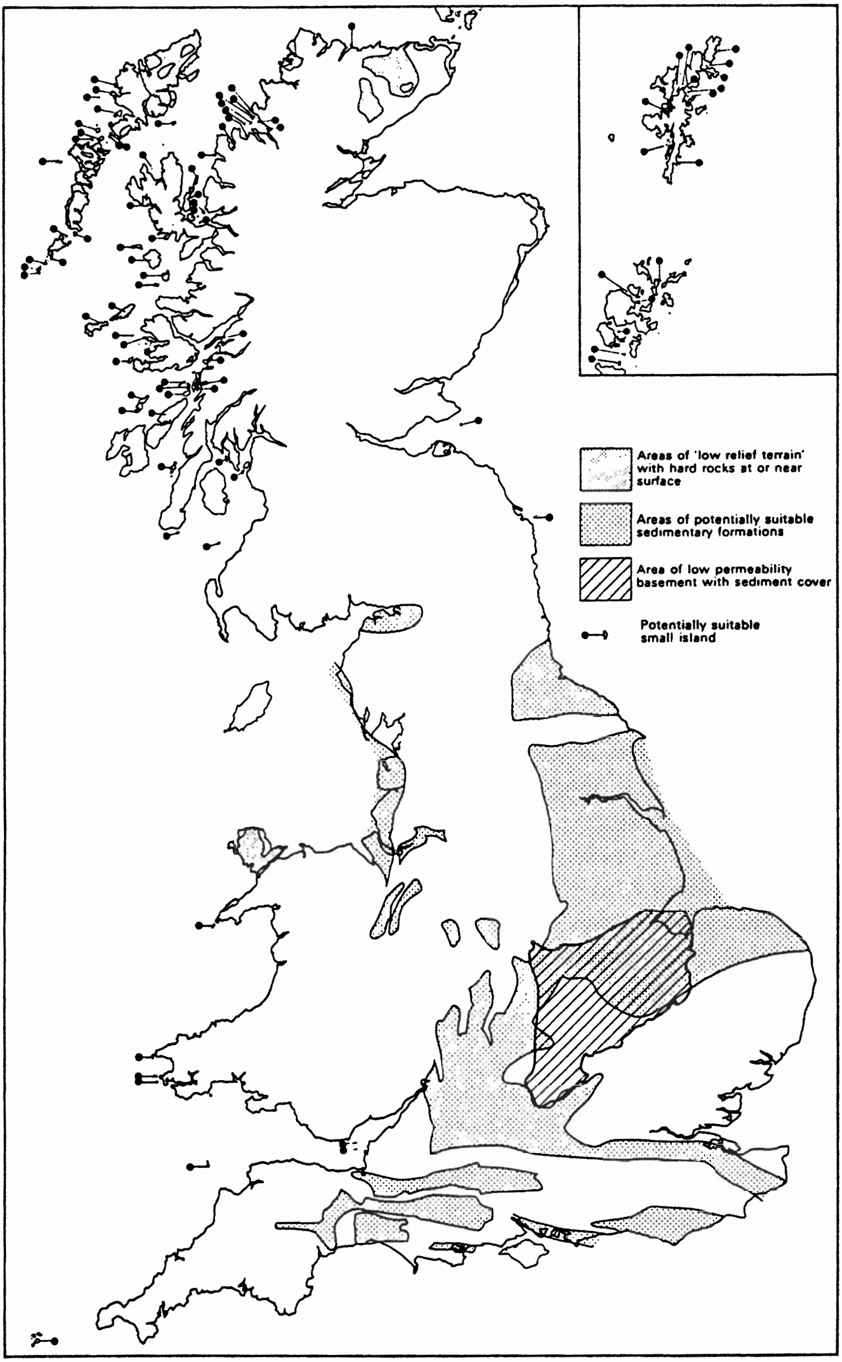

FIG. 9. Compilation of areas containing all the geological environments considered suitable for deep disposal of long lived intermediate level wastes.

are defined by the −800 m contour on the pre-Permian basement [4], and the presence of Coal Measures (Westphalian A, B and C) has been used as a cut-off or exclusion factor. Consideration of the properties of the overlying Mesozoic sediments then resulted in a further reduction of areas thought suitable. The eastern boundary is thus defined by the first presence of overlying Lower Greensand or Chalk, and the western boundary by the presence of the overlying Sherwood Sandstone Group. These are three of the major aquifers in the region. In addition, the discovery of gas, thought to derive from the nearby Coal Measures Basin, in the Tremadoc of northern Buckinghamshire and Oxfordshire, led us to include a further, rather arbitrary cut-off boundary, 15 km east of the eastern edge of the source basin. The gas deposits are not commercially viable.

Figure 8 also shows the general geology of the basement within the area of interest now defined [5]. Within this area, thick Dinantian limestones and Devonian clastics are to be avoided. Extensive alteration of the rather poorly understood igneous intrusions (during the Caledonian orogeny) may make these unsuitable as well. The remaining potentially suitable formations, which are present over large areas, include Tremadoc shales, siltstones and sandstones, Cambrian and Precambrian volcaniclastics, and undifferentiated Cambrian and Precambrian, mainly phyllitic tuffs and quartzites.

3.3. Type (d): Hard rocks in low relief areas

Crystalline, igneous and metamorphic rocks, well indurated argillaceous rocks and some clastic sediments are to be found mainly in the north and west of the United Kingdom (Fig. 9). Hard rocks in low relief areas are not found in England, and in Wales are only found in Anglesey and the Lleyn Peninsula. In Scotland such areas are mainly restricted to the north-east and parts of the Outer Hebrides, where they can be quite extensive (up to several tens of kilometres inland, such areas normally being coastal).

The geology of these areas varies considerably, from peneplained Lewisian gneiss in Northern Lewis to Caithness Flags in the area around the Dornoch Firth and in Caithness, and granites intruded into Moine metasediments in Caithness and Sutherland. Smaller subareas of interest need to be defined using similar techniques to those employed in Sweden by the Swedish Nuclear Fuel and Waste Management Company [6], which use major faults and discontinuities as boundaries.

3.4. Type (e): Small islands

Figure 9 shows offshore areas of the United Kingdom containing small islands of potential interest. Eighty-seven islands have been identified. Excluded from this group were islands of less than about 0.5 km^2, those with extreme topography, and those not sufficiently far from the mainland to necessarily have independent hydrogeological regimes. Above a certain areal size or level of geological complexity, or within a certain proximity to the coast, the simple principles of Fig. 1(e) may not apply. However, parts of a larger island may have suitable hydrogeological characteristics in that they are essentially coastal regimes similar to type (b) or (d), and some have been included in the 'small island' category.

The majority of the islands lie off the west coast of Scotland, or in the Orkneys and Shetlands, although a few are to be found around the coasts of England and Wales.

4. CONCLUSIONS

The application of fundamental hydrogeological concepts has enabled us to define what may be the most generically suitable geological environments for deep disposal of long lived radwastes in typical northern and central European areas. Applying these concepts to the United Kingdom, we have been able to define the areas of occurrence of these environments quite precisely. It is interesting to note the difference between the areas consequently defined (Fig. 9) and those selected in 1979 as potentially suitable for disposal of heat emitting wastes [7]. The approach advocated here includes more (and more diverse) sedimentary environments and fewer areas of crystalline rock. There is a greater weighting towards southern and central England, rather than northern England and Scotland.

The next step must be a more detailed desk appraisal of specific zones within these areas, to define subareas with greater potential. In many areas an essential first step in this process would be the acquisition or reanalysis of detailed seismic and deep borehole data. In other, simpler areas it is feasible to begin assessing specific subareas, or even specific sites, which have been nominated on non-geological grounds, such as availability of land, construction feasibility, and transport or non-nuclear environmental factors. In this respect the east coastal and contiguous inland area of England defined by the Eastern England Shelf to the Cleveland Basin appears to be one of the least complex, most predictable regions in which to focus the initial search for specific sites for more detailed assessment.

Such assessments in these sedimentary areas must take account of the regional geothermal potential, although at this level of analysis it seems unlikely that either the regional heat flows or any future exploitation of warm aquifer groundwaters would adversely affect a deep repository sited in intervening low permeability formations. In addition, the factor common to almost all thick sedimentary sequences, that of the possible patchy occurrence of hydrocarbons, must be borne in mind.

In conclusion, we are now in a position to take advantage of the wide variety of suitable geological environments present in the United Kingdom to mount a comprehensive programme of selection of different types of site for more detailed study and comparison.

REFERENCES

[1] GROVER, J.R., The management and disposal of low and intermediate level radioactive waste in the U.K., Radioact. Waste Manage. Nucl. Fuel Cycle **4** (1984) 269–283.

[2] FLOWERS, R.H., "The packaging of intermediate and low level radioactive wastes", Radioactive Waste Management (Proc. Conf. London, 1984), British Nuclear Energy Soc., London (1985) 61–68.

[3] CHAPMAN, N.A., FLOWERS, R.H., Near-field solubility constraints on radionuclide mobilisation and their influence on waste package design, Proc. R. Soc. (London) (in press).

[4] SMITH, N.J.P., et al., Contours on the Top of the Pre-Permian Surface of the United Kingdom (South). 1:1,000,000 Scale Map, British Geological Survey, Keyworth, UK (1985).

[5] SMITH, N.J.P., et al., Pre-Permian Geology of the United Kingdom (South). 1:1,000,000 Scale Map, British Geological Survey, Keyworth, UK (1985).

[6] DIVISION KBS OF SWEDISH NUCLEAR FUEL SUPPLY COMPANY, Final Storage of Spent Nuclear Fuel – KBS 3, 4 vols, SKBF/KBS, Stockholm (1983).

[7] MATHER, J.D., GRAY, D.A., GREENWOOD, P.B., Burying Britain's radioactive waste: The geological areas under investigation, Nature (London) **281** (1979) 332–334.