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THE USE OF DESK STUDIES, REMOTE SENSING AND SURFACE GEOLOGICAL AND GEOPHYSICAL TECHNIQUES IN SITE INVESTIGATIONS

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1. INTRODUCTION

The geoscientific investigations required to characterise a site for the underground disposal of radioactive wastes involve a wide range of techniques and expertise. Individual national investigations need to be planned with a specific geological environment and waste form in mind. However, in any investigation there should be a planned sequence of operations leading through desk studies and surface investigations to the more expensive and sophisticated sub-surface investigations involving borehole drilling and the construction of in situ test facilities.

In 1982 the International Atomic Energy Agency published Technical Report No 215 which reviewed this sequence of operations from the initial development of an overall site investigation plan to the final detailed site confirmation studies [1]. This work was briefly reviewed at the IAEA International Conference on Radioactive Waste Management held in Seattle in May 1983 [2]. Technical Report No. 215 defined four principal steps in the process of site confirmation. The studies described in the present paper principally relate to the second of these steps where an overall plan has already been formulated and the objective is to select areas that have potentially favourable characteristics for a repository and reduce them to a few preferred sites for further study. This is done largely by desk and remote sensing studies supported by surface geological mapping and reconnaissance geophysical surveys. These are all basic techniques within the earth sciences which can be used either in their traditional form or suitably modified for specific application to repository site investigations.

However, for other reasons the techniques described in this paper are particularly important in radioative waste studies. This is because they do not involve disturbing the actual volume of rock earmarked as a potential repository. A long expressed fear is that the detailed site assessment techniques necessary for site confirmation would so change the rock characteristics and groundwater flow patterns that the repository volume would be rendered useless. Thus the development of remote techniques has been a priority area particularly the use of surface geophysical methods to characterise a rock volume at depth, with only a limited number of boreholes for correlation purposes. Thus, some of the methods described in this paper also have application to the more detailed site selection and site confirmation stages in the development of a repository.

2. DESK STUDIES

Desk studies are an important and largely underestimated component of site investigations. Most developed countries have archives of topographical, geological and environmental data within Government agencies, universities, research institutes and learned societies. Industry is another valuable source of information, but here confidentiality can be a problem.

The most obvious sources of information are the geological and topographical maps produced in most countries by national surveys. Thesewill be accompanied by an archive of geological data which, for instance, in the UK goes back to 1835 with the formation of the Geological Survey. Clearly some of this data may be outdated or will lack the detail required for repository site assessment, but a review of such existing information provides a valuable basis for the planning and implementation of more detailed investigations.

Apart from the general geological maps other more specialised maps are often available. Geophysical maps showing variations in the earth'sgravity and magnetic field are typical examples. Such maps can indicate regional and local structural trends in poorly exposed areas and also indicate the shape and distribution of rock masses such as salt diapirs and granitic intrusions, both of which are of interest in radioactive waste disposal studies.

In the UK regional geochemical maps based on stream sediment samples have been used to differentiate between various granitic plutons in the Pre-Cambrian rocks of the Scottish Highlands. These maps may provide direct indications of metalliferous mineral occurrences enabling such areas to be removed from further consideration at an early stage. The regional geochemical map of uranium for North Scotland enabled those granites with high levels of heat producing elements (uranium, thorium, potassium) to be defined. Such granites appear to have more potential as hot rock geothermal sources than as potential sites for radioactive waste repositories and this factor was taken into account when selecting areas for the UK research programme.

The hydrogeological assessment of a site can also benefit materially from an analysis of already available and archived data. Hydrometeorological information , surface water data and geological maps can be used to define areas of recharge and discharge and work out potential recharge rates. First order estimates of permeability and porosity can usually be obtained from models which incorporate topographic information combined with the elevations of the water surface in wells, springs, rivers, lakes and swamps. Such water level information can oftenbe obtained from existing maps and records.

3. REMOTE SENSING

In developing countries and in the more remote regional of developed countries the amount of basic data, which needs to be collected over many decades, will not be very extensive. In such regions remote sensing offers a rapid method of examining large areas regardless of land access, vegetation or geological setting, rapidly and at relatively low cost.

Remote sensing is a general term which refers to the measurement of certain properties of the earth by recording devices carried in satellites or aircraft. Its basis is the detection and recording of various parts of the electromagnetic spectrum coming from the earth. Radiation signals can be recorded by either

electrically digitised impulses or photographic images. For practical purposes the operational modes can be grouped as high altitude, involving orbiting satellites and low altitude, involving manned aircraft. Both utilise multiband sensors plus cameras and radar. With the expansion of satellite derived imagery, large areas of the earth are currently being surveyed and owing to the nature of the orbits of the satellites data for these areas are acquired repetitively. The high altitude sensing has limited resolution but can often show regional structures and major structural discontinuities or lineaments more clearly than can be derived from more detailed low altitude imagery or surface mapping. The low altitude mode has a higher resolution and has been used in a number of radioactive waste programmes to provide detailed information on the fracture zones at selected sites [2].

Over the past decade research in geological remote sensing has focussed particularly on the development of techniques to exploit data obtained in the visible and near infra red region of the electromagnetic spectrum extending from wave lengths between north 0.4 and 2.5 μm. Recently a new airborne instrument, the thermal infra red multi spectral scanner, has been developed [3]. With this instrument it is possible to obtain spectral emittance data in the thermal infra red, that portion of the electromagnetic spectrum which is dominated by thermal radiation from the earth surface. In particular the 8 to 13 μm region contains diagnostic spectral emission features for silicates. Preliminary results show that igneous rock units can be identified from their free silicate contents and that carbonate as well as clay bearing units are readily separable on the digitally processed images. The thermal infra red multi spectral scanner appears to be a powerful new geological remote sensing tool that can provide mineralogical information particularly about silicate rocks that is not available from sensors in other wave length regions. With further development it could become an extremely useful tool in preliminary site investigations.

Remote sensing is also useful in hydrogeological mapping. In studies of sedimentary sequences groundwater discharge points can to some degree be predicted from a knowledge of outcrops, hydraulic heads and relative permeability. However, the groundwater circulation patterns in fractured crystalline rocks are much more difficult to predict. At Altnabrec in Caithness in North East Scotland, temperature differences in groundwaters and surface waters have been used to locate groundwater discharges from crystalline rocks which emerge through overlying deep faults and glacial sediments. This work will be discussed by one of my colleagues in a later paper at this seminar.

4. GEOLOGICAL MAPPING

Field mapping is probably the most fundamental technique employed by geologists and serves two main functions. Firstly, it is used to determine in more detail than is provided by remote sensing techniques the areal distribution, structure and spatial relationships of bedrock, unconsolidated materials and glacial deposits. Secondly, it enables samples to be systematically collected for subsequent detailed laboratory work.

Geological mapping involves a careful study of the surface outcrops of rocks together with interpretations of rock structures using features in overlying superficial sediments and soils. Surface excavations created to recover industrial and metalliferous minerals and for engineering structures are also examnined and shallow trenches or auger holes are made specifically to obtain samples of the underlying strata from shallow depths. Mines or other subsurface excavations can also be examined.

If geological mapping has not been conducted over areas of possible interest it must be done at an early stage in any site investigation programme in order to properly understand other relationships. Data obtained are illustrated in maps, crosssections or special three-dimensional diagrams. Lithological differences, bedding plains, folds, faults, other discontinuities such as joints and shear zones and unconformable relationships are the principle mappable features.

The preparation of geological maps has been completed at an early stage in all national research programmes whether the potential host rock be granite, basalt, bedded salt, dome salt or argillaceous strata [2].

Detailed stratagraphic mapping is of particular importance in the analysis of salt domes. Their recent geological history can be established through a detailed analysis of the overlying formations affected by the salt intrusion. This precise dating of the history of salt movement is important in predicting future trends.

5. GEOPHYSICAL PROSPECTING

The methods that have been discussed so far will have provided an indication of the surface distribution of different rock types and of their structure. Geophysical techniques have the capacity to extend this picture into the third dimension with a minimum number of penetrations of the potential repository volume by drill holes and exploratory shafts. In many respects geophysical studies of potential repository sites involve an unconventional use of geophysics. Usually geophysicists are looking for faults, secondary minerals, areas or zones of hydrothermal alteration and other anomalies rather than for the absence of such features.

Geophysical surveying depends on measurements of the earth's magnetic, electromagnetic and gravitational fields, or on measurements of electromagnetic, electrical or acoustic energy induced into the earth to modify and enhance or override these natural fields. Airborne, surface or subsurface operational modes provide the measurements which need to be supported by a programme of laboratory measurements of rock physical properties to enable the field data to be interpreted.

Ground based and airborne geophysical surveys use similar techniques although some methods are only applicable to ground based surveys. Gravity measurements can be used to give an indication of the three-dimensional shape of rock masses of different density. For example they have been used in the British programme to provide a three-dimensional picture of the Strath Halladale and Cheviot Granites and in the Danish programme to evaluate the structure of the Mors Salt Dome. Measurement of the total magnetic field can detect structural trends and lithological variations and can also provide an

assessment of the economic mineral potential of an area. Seismic reflection can determine the thickness and structure of stratified rocks such as bedded salt at the Waste Isolation Pilot Plant (WIPP) site in New Mexico: indicate the form of plutons and diapiric salt structures and detect faults and other discontinuity systems. Seismic refraction can be used to determine the thickness of overburden and give an indication of bedrock structure.

Electrical methods are also useful in the characterisation of potential sites. Many features such as zones of abnormal fracturing or alteration which are important in site selection are good targets for electrical methods. Electrical resistivity measurements are particularly useful to show the presence of good conductors such as fracture zones and zones containing metalliferous minerals, and to provide data on groundwater conditions. They have also been used to detect solution features at the WIPP site in New Mexico. Electromagnetic measurements which utilise induced magnetic fields can be used in the detection of faults and fractures and also in the assessment of mineral potential. A third electric technique the magnetotelluric method uses natural electric currents and can be used in the assessment of major subsurface structures including the configuration of basis and layered sequences. They can also give an indication of the presence of highly saline groundwaters and or of geothermal anomalies.

None of the geophysical methods is capable of producing a fully accurate interpretation of geological or hydrogeological conditions. Some borehole information is required to calibrate geophysical techniques and they need to be interpreted in the light of the complementary information which is available.

6. CONCLUSIONS

Desk studies and surface investigations act as a valuable screening mechanism and if they are carried out correctly can enable adverse characeristics of the site to be identified at an early stage before large sums of money have been invested in detailed assessment. Once this screening has been carried out and sites for further detailed examination defined they can then be used to provide the basic data for the planning and execution of the more detailed subsurface investigations which will then be required. These more detailed investigations will involve a large capital outlay on borehole drilling and the provision of subsurface facilities for more detailed hydrogeological and geomechanical investigations. These preliminary studies are therefore exceedingly important in that they enable the most effective site survey to be planned and executed.

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