**Cover Illustration.**
Seismograms of the Oban earthquake of 29 September 1986, magnitude 4.2 ML, recorded on the LOWNET seismometer array in central Scotland.
Editorial

We apologise for the late appearance of this “Autumn” issue – and agree that “midwinter” might be more appropriate: every effort will be made to produce the Spring 1987 number on schedule. We can, at least, take advantage of our tardiness and wish you all a happy new year, with thanks to all our contributors – and please keep sending in copy!

Contributions for the next issue should be sent to either of the Editors.

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The Molopo Farms Project –
Mineral Exploration in the Kalahari
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Introduction

Southern Botswana (see Figure 1 for location) forms part of the Kaapvaal Craton, which has been part of a stable continental mass since the high-grade Archaean gneisses and associated metasediments were last deformed 2700 - 3000 million years (m.y.) ago. Since then, several cycles of uplift, erosion and sedimentation, with major igneous episodes, both intrusive and extrusive, have occurred. The major sedimentary and volcanic rocks belong to the Ventersdorp (2600 m.y.), Transvaal (2200 m.y.), Waterberg (1800 m.y.), Karoo (280 - 180 m.y.) and Kalahari (60 - 0 m.y.) Supergroups. Major granite intrusion took place 2400 m.y. ago, and major ultrabasic and basic intrusions, which are the subject of this article, were emplaced 2050 m.y. ago.

These ultrabasic and basic rocks are referred to as the Molopo Farms Complex. They are of the same age as an even larger body of basic and ultrabasic rocks in the northern part of the Republic of South Africa known as the Bushveld Complex, which contains the world’s largest known reserves of chrome and of platinum group metals (PGM).

Figure 1. Location of Molopo Farms and Bushveld Complexes. Solid: complex at outcrop or sub-Kalahari Beds surface. Shaded: Subsurface extent of complex.
Due to the extensive cover of sand, silcrete and calcrete belonging to the Kalahari Supergroup (the Kalahari Beds), the Molopo Farms Complex does not crop out, but by 1979 the existence of both basic and ultrabasic rocks in southern Botswana had been proved during the course of drilling for water, and an unsuccessful programme of exploration for asbestos had been carried out by a small mining company.

However, enough similarity had become apparent between the Molopo Farms and Bushveld Complexes for southern Botswana to be regarded as an area with considerable mineral potential. As a result, a technical co-operation project was set up between the British and Botswana Governments for the assessment of the mineral potential of the Molopo Farms Complex, with particular reference to chrome and PGM. Two geologists (the writer and Dr. P.A. Rathbone, now at Keyworth) were seconded from BGS to the Foreign & Commonwealth Office's Overseas Development Administration (ODA) for residential service in Botswana. Several geophysicists from BGS, Keyworth (Dr. A.J. Burley, Mr. G.S. Kimbell, Mrs. S.F. Kimbell, Mr. M.E. Parker and Mr. K.J. Barton) worked at various times on the project, spending periods of 3 - 4 months in Botswana and doing office work on the project in Keyworth. The project commenced in 1980, field work lasted until mid-1983, and the writing up was largely complete by early 1985. Office accommodation in Botswana, together with field support (vehicle maintenance, and local technical and unskilled staff), and laboratory services in Botswana were provided by the Botswana Geological Survey Department.

The previous work in the area showed that the Molopo Farms Complex intruded Transvaal Supergroup sediments and was probably overlain unconformably by Waterberg Supergroup sediments, in an analogous fashion to the Bushveld Complex. A reasonably detailed aeromagnetic survey of the project area and some partial gravity coverage were available. It was quickly apparent that, due to lack of outcrop, geophysics would play a major part in the project, and a major drilling programme would be required to confirm geophysical interpretations and to obtain samples of the rocks of the complex to enable its mineral potential to be assessed.

**Geophysical Surveys**

The high magnetic susceptibility of serpentinised ultrabasic rocks (due to the secondary magnetite formed during serpentinisation) and the high density of basic and fresh ultrabasic rocks make a combination of magnetic and gravity methods very suitable for delineating the extent of these rock types. Accordingly, the first major work done under the project was a gravity survey of the area at a station interval of 2 km. This involved taking gravity readings at 4800 stations to cover the 17 000 km² of the project area.
Because of the poor road network, a helicopter was used to take the gravity readings. A small 5-seat machine was hired for 8 weeks in 1980 and 6 weeks in 1981 at a cost of about £100 per hour. Each day's flight of 6 to 9 hours used two 200-litre drums of fuel, which was carried over 200 km by road to the base camp. About half of the fuel was transported from the base camp to various convenient points in the bush for mid-day refuelling. The number of gravity stations established per day using the helicopter varied from 50 to 100. On the occasions when the helicopter was unavailable due to breakdown, the areas with good tracks were surveyed by Land Rover, averaging about 25 stations per day.

In order to calculate the gravity anomaly sufficiently accurately for interpretation, the location of each station had to be known to the nearest 100m and the altitude to the nearest metre. Station locations were fixed by use of a Decca navigator system. The helicopter carried a radio transmitter which sent out a signal to 3 or 4 beacons which on interrogation by the transmitter sent back a signal to the helicopter. The delay between the transmission and receipt of the signal was proportional to the distance from the helicopter to the beacon. A processor in the navigator unit calculated the distance of the helicopter from each beacon. Positional fixes were taken when the helicopter was directly above each station. The helicopter then landed and readings were taken with the gravimeter and the altimeters. After some practice, gravity readings were taken every 4 to 5 minutes. The radio beacons were sited at points whose positions were accurately known, usually at concrete survey beacons, some of which were sited for reasons of visibility on brick towers 10 to 15 metres high.

Altitudes were measured by means of altimeters, essentially small aneroid barometers. To allow for variations in barometric pressure due to weather conditions, a pair of altimeters was read at a height base close to the area being surveyed at 5 minute intervals during the day. The height bases were tied in to points of known altitude by simultaneous reading of altimeters at various pairs of height bases and at the few accurately levelled locations in the project area. In order to reduce errors a few levelling traverses, using staff and theodolite, were run from the north to the south of the area. By dint of hard work on the part of the geophysicists, a preliminary Bouguer anomaly gravity map was plotted shortly after the completion of the field work for each part of the survey, but several months' office work was required in Britain before the final version of the map was available.

Magnetic traverses were carried out by parties led by a local Botswana Geological Survey technical assistant along lines selected by the project geologists to cut across the strike of major features on the aeromagnetic map. This enabled the geophysicists to make computer models of the structures
which could cause the anomalies, and were required for detailed siting of the project boreholes. Approximately 800 line kilometres of magnetic traverses were carried out.

Detailed gravity surveys using surface transport, and resistivity and electromagnetic surveys were carried out by BGS geophysicists to investigate some of the features delineated by the gravity and magnetic surveys.

Drilling programme

Before siting the boreholes to be drilled as part of the Molopo Farms Project, all known water borehole records were compiled and all available samples examined. Similarly all prospecting records, including core samples from the asbestos prospecting programme, were examined. These results were then combined with the gravity and magnetic data into a preliminary interpretation of the geological structure of the project area, which was used to plan the drilling programme.

The drilling programme was divided into a series of shallow boreholes, designed to obtain fresh bedrock from a number of scattered sites to find out the source of the most significant geophysical anomalies, and a smaller number of deep boreholes to drill as continuous a section as possible through the rocks of the complex. Originally the shallow boreholes were to be drilled first and the deep boreholes as much as a year later, once the results of the shallow boreholes had been assessed. However, due to the fact that ODA insisted on using a British contractor, and the time taken in negotiating a drilling contract, the shallow and deep holes were drilled as a single contract, with the deep holes commencing while the shallow holes were being drilled.

A contract was signed with Land and Marine Engineering (Overseas) Ltd. in early 1982 to drill £650,000 worth of boreholes in 14 months from commencement of operations. The company originally planned one 12-hour shift per day on each of two rigs, but due to slow progress in the early months a second shift was worked on one and occasionally both rigs for most of the contract. One rig was a multi-purpose air hammer/coring rig to be used for the shallow holes and to pilot the deep holes through the Kalahari Beds overburden, and the other was a coring rig to do the bulk of the work on the deep holes.

Core was only required when fresh bedrock had been reached. Above that depth, chip samples only were taken. Chip samples were often taken when Transvaal and Waterberg Supergroup sediments were drilled. Up to 100 metres per shift could be drilled with the air hammer in favourable conditions, but the maximum coring rate achieved was 30 metres per shift and the average was approximately 10. Due to difficult drilling conditions in the southern part of the area, particularly the instability of the sand near the surface and the
presence of a waterlogged band of red gritty clay at approximately 100 metres depth in many boreholes, coring of Kalahari Beds sediments or country rock to the complex was occasionally necessary. The drilling conditions also involved extra expenditure on casing to support the borehole during drilling, much of which could not be extracted on completion. As a result, the original contract price of £650,000 proved insufficient to complete the last section through the complex, and a £250,000 extension was negotiated, though at a higher cost per metre drilled. In the end, just over 10,000 metres were drilled, of which 4,500 metres were cored. A total of 46 boreholes were drilled, ranging from 66m to 613m in depth.

During open-hole drilling, one of the project geologists had to be on site or available at a few minutes’ notice in order to determine the point at which to commence coring and to advise the driller in the event of problems related to the nature of the formation being drilled. During coring, the rig needed to be visited less frequently, giving time for the geologist to make a reasonably detailed lithological log of the core, test its magnetic susceptibility and select specimens for thin sections. Throughout the drilling programme, at least one geologist was in the field, working seven days a week until relieved by his colleague at 3-7 week intervals.

Approximately 1250 thin sections were cut in Botswana and after they had been described the lithological logs of the boreholes were amended, and graphic and written logs prepared for publication. Specific gravities of selected core samples were determined, and small cylinders of core cut for magnetic remanence testing. This testing was done by Prof. D.L. Jones of the University of Zimbabwe. Together with the susceptibility measurements, it enabled the magnetic profiles to be modelled in greater detail, helping to define the shape of the rock units proved by drilling. Similarly, the specific gravity measurements were used to refine the gravity models. The Botswana Geological Survey performed over 50 whole rock analyses, and where significant sulphide mineralisation was seen the core was analysed for Cu, Pb, Ni, Co and Zn. Two samples were analysed for Pt and Pd, and further samples were analysed for these elements by a mining company which took up prospecting licences over the area. Rb/Sr and Pb/Pb age dating was carried out on a few selected specimens by Dr. J.M. Barton of the University of the Witwatersrand in Johannesburg.

**Results**

The magnetic and gravity surveys, as confirmed by the drilling programme, show that the MFC underlies an area of 8000 km² within the project area, lying within a synclinal basin where the complex and the Transvaal Supergroup country rocks were folded together before deposition of the overlying
Waterberg Supergroup sediments. Only limited warping, faulting and dyke intrusion have occurred since Waterberg times. A simplified version of the sub-Kalahari Beds geology is shown in Figure 2. Serpentinised ultrabasic rocks give strong magnetic anomalies due to the magnetite formed during serpeninisation, but their density is the same as, or slightly less than that of granite, sandstone or siltstone, so they do not give rise to significant gravity anomalies. Basic rocks and fresh ultrabasic rocks give rise to sizeable gravity anomalies, but in the MFC generally give rise to rather small magnetic anomalies.

![Figure 2. Simplified geological map of Molopo Farms Complex. Kalahari Beds omitted.](image)

Most of the geophysical anomalies tested by drilling were shown to be caused by the complex, but a few boreholes were unsuccessful, either failing to reach the required depth, or penetrating Transvaal Supergroup sediments or volcanics.
The deep boreholes were concentrated in three traverses across the complex. Sections through the complex along two of these traverses, based on a re-interpretation of the geophysics in the light of the drilling results, are shown in Figure 3.

![Figure 3](image)

Figure 3. Sections through Molopo Farms Complex. For locations see Figure 2.

The rocks of the complex have been divided into an Ultrabaic Series, a Layered Basic Series and a Minor Intrusive Suite. The Ultrabaic and Layered Basic Series both consist of cumulates, that is rocks showing, by compositional banding and the planar alignment of tabular and acicular crystals, that they were precipitated on the floor of a large magma chamber. The Ultrabaic Series consists almost entirely of olivine and orthopyroxene, forming rythmic units 1-100m thick showing a gradual transition from an olivine-rich base to an orthopyroxene-rich top, followed by a sharp transition to the olivine-rich base of the next unit. In the northern traverse, a true thickness of 1.85km of dominantly olivine-rich rocks was proved, but in the southern traverse the true thickness of the Ultrabaic Series is estimated to be 600-1000m, and the proportion of orthopyroxene is considerably higher.

The Layered Basic Series only occurs in the southern part of the project area. A true thickness of 1.7km has been proved. At the base it consists of norites and feldspathic orthopyroxenites, but most of the succession consists of gabbros and norites with both clino- and orthopyroxenes. The anorthite content of the plagioclase decreases steadily upwards from 77% at the base to 53% at the top. A short distance to the east of the borehole penetrating the
lowest part of the Layered Basic Series, there is a major fault which cuts out part of the succession. Geophysical evidence suggests that the Layered Basic Series rocks are underlain by approximately 6km of rocks of the MFC which probably include a transition from the Layered Basic Series to the Ultrabasic Series.

The Minor Intrusive Suite consists of a number of intrusions ranging in composition from gabbro to quartz monzodiorite, representing basic magma contaminated by the assimilation of varying amounts of arkosic country rock. The intrusions are mostly sills from one metre to several hundred metres in thickness. They have chilled margins against rocks of the Transvaal Supergroup or other rocks of the MFC. From their chemical composition and magnetic remanence characteristics it is likely that some of these minor intrusions may be coeval with the Ultrabasic and Layered Basic Series, but others are probably considerably younger.

No economic mineralisation has been found within the MFC. The fault which cuts off the Layered Basic Series along the southern traverse makes it unlikely that chrome mineralisation occurs in an accessible location within the complex, but small showings of chalcopyrite-pyrrhotite-pyrite mineralisation have been found. In the lower part of the Layered Basic Series, a 0.14m thick band of coarse grained pyroxenite contains approximately 3% of sulphides and contains 0.2% Cu and 0.4% Ni, but no detectable Pt or Pd. Several mineralised horizons up to 0.5m thick in the lower part of the Ultrabasic Series on the northern traverse contain smaller amounts of Cu and Ni but have up to 0.95 parts per million of PGM.

These results, together with confirmation that the MFC is of the same age as, and contains similar layered cumulates to the Bushveld Complex, are promising indications that the MFC could be host to an economic PGM orebody. This assessment is corroborated by the fact that two of the major southern African mining companies have taken out prospecting licences in the project area since the results of the project became known.

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An exciting new phase of geological exploration has begun recently which may prove as interesting as the Deep Sea Drilling Project undertaken from 1968 by the vessel Glomar Challenger. The first ultra-deep boreholes are now going down onshore, deep into the Continental Crust (which averages 35 kilometres in thickness), seeking evidence about the Earth’s origins and the ancient collisions between lithological plates.

Astronomer and meteorologist Alfred Wegener (1880-1930) aroused great controversy in the early decades of this century by propounding a theory of continental-drift, and collating evidence for an old idea long dismissed by most geologists as preposterous. Similarly, many would today dismiss as absurd the possibility of large reserves of methane gas of non-biological origin existing deep within the Earth.

But astrophysical theories of the Earth’s origin state that such methane was abundant at one time, and some known gas-fields are thought to be too deep to have formed by the normally accepted process involving deposition and subsequent geothermal heating of biologically-derived organic-rich sediments. One example is the hydrocarbon reservoir 9 km below Oklahoma in North America.

Thomas Gold of the Centre for Radiophysics and Space Research at Cornell University, N.Y., proposed in 1980 that some gas fields could be traps of non-biogenic hydrocarbons which have been present since the Earth’s origin at 4600 Ma, but were slowly outgassing to the surface. Certainly methane and other hydrocarbons are now known to occur in vast amounts on other planets of the Solar System, notably Jupiter, Saturn, Uranus and Neptune.

Modern views on the Earth’s formation by relatively cool agglomeration of solid matter, followed by gradual heating and density differentiation, permit the possible survival of some primeval methane. Much, however, would have reached the surface long ago, together with carbon dioxide, producing the observed crustal enrichment in carbon, often found now as carbonates.

About 100 tonnes of extra terrestrial matter, mainly dust, enters the earth’s atmosphere every day from space.

One particular variety of meteorites which still accrete onto the Earth, the Carbonaceous Chondrites, gives out methane and some carbon dioxide if subjected to the burial pressures and temperatures envisaged for the early Earth. These are believed to be the most unaltered and ‘primitive’ of all types of meteorites, with a composition closest to that of the primitive solar nebula which gave rise to the Solar System. The widely accepted Chondritic Earth
Model proposes that the Earth has, in fact, evolved from a bulk composition very similar to that of Carbonaceous Chondrites.

Some researchers consider that the increasing proportion of carbonates in sedimentary rocks over geological time indicates that hydrocarbon outgassing has been a continuing process. Recent thermodynamic calculations suggest that under enormous pressures deep in the Crust, hydrocarbons may remain stable at far higher temperatures than previously believed.

Some petroleums show 'optical activity', the preponderance of left-handed or right-handed large molecules. This is typical of molecules produced biologically, since non-biological reactions give equal numbers of both forms. Nevertheless, the eminent Russian chemist Dimitri Mendeleyev (1834-1907) was convinced petroleums were mainly of non-biological origin. That view has been upheld by some Soviet researchers. Organic debris found in oil, including bacterial material, has been dismissed as a contaminant picked up as the oil migrated.

Rich deposits of inert helium gas are often associated with petroleum and methane, but are clearly non-biological in origin. Another puzzle concerns the great variety of rocks, of different geological ages, which serve as reservoirs in hydrocarbon-rich areas like the Middle East. Their only similarity besides porosity and permeability, is a suitable capping of impermeable strata. It has been suggested that they simply trap non-biological hydrocarbons migrating upwards from a deep regional source, along pathways also followed by helium (produced by radioactive decay in deep rocks).

If substantial hydrocarbon reserves can be located in a region where the known geological history precludes their origin in biologically-derived organic sediments, a primeval origin for some of the Earth’s present hydrocarbons may be proved.

Scandinavia's ancient granitic shield has been chosen as the site for an ultra-deep exploratory borehole to test Gold's theory. Research has concentrated upon the Siljan Ring of central Sweden, where Europe’s largest (60 km diameter) meteorite-impact crater, formed at 350 Ma, produced intense fracturing at depth. It left a rock capable of acting as a hydrocarbon reservoir, shown now by anomalously low gravity measurements. Seismic profiles indicate some layers of increased density, possibly caused by mineral solutions recementing and closing the fractures. These layers could act as impermeable traps, sealing in any hydrocarbons migrating upwards from depth. A consortium led by the Swedish state power company has just commenced drilling, and plans to penetrate 4.5 to 6 km into the crust. Existing technology could extend this to 9 km.

Elsewhere, interest in drilling the deep Continental Crust is gaining momentum. Russia has led the field, with the world’s deepest hole now 12 km down on the Kola Peninsula inside the Arctic Circle. Another hole in the
Ukraine is planned to reach 15 km, and a further four down to 7 km are proposed.

West Germany hopes to drill two deep holes by 1988, including one of 14 km in the Black Forest. American universities are proposing a 10 km hole in the Appalachian Mountains to seek the sheet of crystalline rocks thought to have been pushed over the North American continent by its collision with Africa at 280 Ma.

Whatever the fate of Gold's methane theory, these ultra-deep drilling projects promise a wealth of new information on the processes operating deep within continental crust. Until now these processes have only been inferred by detailed analysis of the physical and mineralogical evidence preserved in rocks exhumed from such depths by aeons of tectonic movement and erosion.

Sources:
Throughout geological history the earth's crust has been shaped and deformed by the violent energy release of the earthquake. The popular concept of an earthquake is that of devastation associated with large earth movements in the highly active areas of the world. It is true that the great majority of destructive earthquakes occur in these zones where the lithospheric plates grind slowly past, over and under each other like large rafts of pack-ice. However, areas of lithospheric plate well removed from any plate boundary are still highly stressed and earthquakes do occur there. For example a series of earthquakes struck New Madrid in the centre of the North American land mass, during 1811-1812 causing considerable damage, the largest being felt from coast to coast across North America.

Britain, being in an intra-plate area, should not expect the intense activity of the plate boundary regions but, as we have seen above, the possibility exists and should not be discounted. In fact modern seismometers detect over one hundred events each year in the British Isles and in some years up to 50 are felt by people.

Historical Seismicity of Britain

A seismologist may use a file of earthquake data to study the geotectonics of a region or the seismic risk. In either case he is studying a process on a geological time scale using only a snapshot of information; this snapshot may be twenty years or less if he is using instrumentally determined epicentres. In Britain, we are fortunate in having well documented reports in newspapers, journals and monastery records dating back one thousand years. This extended time base gives much greater confidence to statistical analysis of the earthquake file.

On April 6, 1580, what is probably the biggest earthquake in recent British history occurred in the Straits of Dover. It was felt across Northern France, Britain as far north as Edinburgh, the Low Countries and Germany beyond Cologne and Duisburg. A church spire collapsed in Leicestershire, Ely Minster lost some stones from the roof, Westminster Abbey, St Paul's and the Temple church were all damaged. The tower of St Peter's near Broadstairs in Kent was cracked from top to bottom and still bears the marks of the repairs today. Contemporary records mention two deaths in Britain and more on the Continent. Recent research at BGS has re-mapped the felt effects and damage (the macroseismic effects) using modern techniques and has been able to estimate a Richter magnitude of over 6.
Rather smaller, with a magnitude around 5.0, was the earthquake which wreaked havoc in the town of Colchester, Essex, in 1884. Being more recent, this event is better documented and even sepia-tinted photographs bear witness to the collapsed chimneys and roofs. And as recently as 1931 an earthquake of magnitude about 6.0 on the Dogger Bank caused damage down the east coast of Yorkshire and was felt in Ireland, Scotland, Holland, Belgium, Denmark and Norway.

There is scarcely an area of Britain which has not experienced a tremor at some time although some areas appear to have been more active and some less so. The Great Glen, northern England west of the Pennines, and a diffuse area from South Wales through Herefordshire into the north Midlands, appear more often in the records; areas with lower than average activity are the Eastern Highlands, south-west Scotland and the Borders, north-east England, Central Wales and large areas of southern England.

Comrie in Perthshire is noted for its localised swarms of intense activity which occurred there from 1789-1801 and 1839-1846 resulting in the first use of instruments to study British earthquakes. Indeed, the secretary of the committee formed by the British Association, David Milne, coined the word 'seismometer'. Similarly, the Ochil Hills have been a centre of sporadic activity continuing to the present day.

Useful though historical records are, we must use them with care, remembering that they often reflect the distribution of centres of learning and population as much as the true seismicity.

**Instrumental seismic monitoring**

Following renewed activity at Comrie in the 1840s attempts were made to develop a sensitive seismometer but it was not until John Milne returned from working in Japan in 1895 that an effective instrument emerged. It was this same instrument which was deployed in a worldwide network of stations and led to great advancements in knowledge of seismology and world seismicity.

The influence of war caused the interest in seismology to wax and wane in the first half of the 20th century. However, observatories were established at some 13 sites including Aberdeen, Paisley, Edinburgh and Eskdalemuir in Scotland, as well as in England, Ireland and Jersey. These early instruments were insensitive by modern standards and were designed to respond to the long-period waves of the distant global earthquake.

A Milne-Shaw horizontal pendulum which initially started life at Eskdalemuir in 1915 was transferred to the Royal Observatory, Edinburgh in 1919 where it recorded until 1962 before its removal to the Royal Scottish Museum where it can be seen today.

In the early 1960s, it was recognised that underground nuclear tests could be monitored from remote seismic stations. America donated a standard
photographic recording seismograph, both long and short-period, to over one hundred stations throughout the world, one being installed and working today at Eskdalemuir. This was a spring-board for modern seismology and the results were quickly able to confirm and refine the exciting new theories of continental drift and plate tectonics.

At the same time, the British Ministry of Defence installed an array of short-period seismometers, recording on magnetic tape, in the hills near Eskdalemuir Observatory. Similar development was being carried out by a research group at the Royal Observatory in Edinburgh and this was to form the basis for the Institute of Geological Sciences’ (now BGS) modern seismograph networks throughout Britain.

The instruments are small, portable and extremely sensitive, detecting ground motions of less than one millionth of a millimetre. In fact this lower limit is dictated by the background noise from waves, wind, traffic etc and not by the seismometer itself. The tiny signals are amplified, converted to a tone (FM) and telemetered up to 100 km by small UHF radio transmitters. Recording has conventionally been continuous on FM magnetic tape recorders but the most recent systems record on digital tape or cassette only when a microprocessor recognises an earthquake from the incoming station signals.

Seismologists in Edinburgh process these tapes on computers to extract the arrival times of the different seismic waves at stations across the network. Epicentres, depths and magnitudes are calculated and catalogued. Further analysis for the larger events can even reveal the strike, dip and displacement on a causative fault up to 30 km beneath the earth’s surface.

Readings for global earthquakes are contributed to World Data Centres in Britain and America where the data from stations world-wide is collated. The accurate locations and magnitudes produced are telexed back to contributing stations often within an hour or so of a large event.

Macroseismic surveys of felt effects are carried out for the larger British earthquakes. A questionnaire, usually in a local newspaper, asks observers to describe the shaking, for example “did the windows or doors rattle?” The replies are then assigned an intensity - a point on an internationally agreed scale (the MSK Scale) between 1 (unobserved) and 12 (total destruction). Contours joining the points of equal intensity are known as isoseismals. The spacing of the isoseismals and the areas they enclose are related to the magnitude and depth of the earthquake and these parameters can be determined for historical earthquakes by comparing their isoseismal pattern with that of recent events in the same region.

Seismic hazard

Isoseismals can also be approximately equated to values of ground motion, that is displacement, velocity and acceleration. It is these values that an
engineer needs when he sets out to design an earthquake-resistant structure such as a dam, refinery, nuclear power station, or offshore oil platform. BGS maintains computer files for British and world earthquakes and, as a service to consulting engineers, can statistically estimate the peak values of ground motion likely to be experienced at a site over the design life of the building.

Recent British earthquakes

Residents of northern England and southern Scotland were rudely awakened from their post-festive snooze on Boxing Day 1979 by a magnitude 4.8 earthquake at Longtown near Carlisle. Chimneys and roof-tiles were brought down with the felt area exceeding 200,000 sq km. Over 90 aftershocks, some exceeding magnitude 4.0, were detected over the next two years.

On 19 July 1984 seismologists were awakened by telephone calls from the press seeking explanations for reports of shaking and damage from Liverpool to Dublin and Swansea. A fast drive to the office revealed one of the largest British earthquakes for 100 years. Hurried calculations between a flurry of press, radio and TV interviews gave an epicentre on the Lleyn Peninsula, North Wales, and a magnitude of 5.4. The depth was estimated at 18 km although the uncertainty was large as the nearest seismic station was 80 km distant. A dense network of local seismometers was rapidly installed and has detected almost 400 aftershocks to date. Plots of aftershock locations reveal a cluster only a few kilometres across at 20 to 24 km depth, confirming the main shock estimate. Damage was generally confined to plasterwork, chimneys and roof-tiles: a fortuitous consequence of the profound depth.

In Scotland a small event shook Dumfries and the surrounding area on 16 February 1984. No physical damage was caused but the event was strongly felt and two computers crashed, this being a consequence of the relatively shallow depth of 3 km for a magnitude 2.6 earthquake. A slightly larger event (magnitude 3.5) caused genuine public alarm when it shook the homes of residents near the Clyde nuclear submarine bases at Coulport, Faslane and Holy Loch on the evening of 16 September 1985. An examination of the seismograms in Edinburgh was able to confirm within an hour that this was a genuine earthquake and not an explosion. The epicentre was only 2 km from Coulport under Loch Long and minor damage was sustained over a radius of a few kilometres.

Such earthquakes are not rare in Britain and we normally experience about ten each year like the Dumfries event or greater.

Offshore, in the North Sea, there is even greater activity than on land and BGS has developed and installed specialised sea-bed seismometer packages which transmit via an anchored spar-buoy to recorders on nearby oil platforms. A system is currently monitoring activity in the northern North Sea on the Statfjord A oil production platform. Five offshore structures and a standby
vessel were shaken by a magnitude 4.0 earthquake on 10 June 1985 in the Danish sector; the first time, to our knowledge, that an event has been felt on a North Sea platform.

Not all tremors are truly tectonic in origin. The seismometers respond equally well to quarry blasts and weapons testing or disposal. The seismologist

Figure 1. British earthquakes above magnitude 1 in the period 1969 to 1985.
is often called upon to give evidence in such cases to support a complaint or claim for damages. Sonic booms from Concorde and military aircraft are another frequent source of complaint, the felt effects often being indistinguishable from an earthquake, even to the trained observer. As well as confirming the sonic nature of the event the seismological data may be used

Figure 2. Earthquakes in the North Sea detected by BGS and Bergen University 1980 to 1985. Major faults are shown and the activity can be seen to correlate with the Viking and Central Grabens. Another band of activity lies parallel to the Norwegian coast.
by RAF Flying Complaints to track down the offending aircraft.

Falling between the categories of man-made and natural events are the earthquakes induced by man's activities. In the coalfields of Britain small tremors are triggered above, or below, the workings as the coal extraction increases the stresses in surrounding rock-strata. The shallow nature of these tremors gives a characteristic high intensity over a very small area - typically one or two houses or a few streets.

In a current experiment in Cornwall two wells have been drilled 2.5 km deep into the granite to examine the feasibility of extracting geothermal energy. Using oil production techniques, water at a pressure in excess of 2000 psi was injected into the wells to crack the rock and form an interconnecting pathway, exposing a large heat transfer surface. Over a period of a few months 11,000 small earthquakes were generated, again a seismic monitoring network was able to distinguish these from quarrying, weapons disposal, sonic booms and natural earthquakes in the area.

Further research

Years of instrumental seismic monitoring in Britain and research into the historical archive have amassed a databank of earthquake parameters for further research. Perhaps the most obvious line of research is to look for a correlation of epicentres with tectonic features. The interesting outcome is that, so far, there does not appear to be any, although the uncertainties of fault locations at depth blur the issue. Exceptions arise for the North Sea where activity correlates with the fault-bounded graben structures.

Recent theories on rock properties propose that the composition and temperature of the crust in intra-plate regions cannot support brittle fracture below 12 to 15 km; rather, the theories state, the rocks must flow plastically under the stress. The events on the Lleyn Peninsula in 1984 at depths of over 20 km cast some doubt over the assumptions unless the area is one of very low thermal gradient or unusual composition.

Earthquakes which are recorded on a number of well-distributed stations can yield not only the direction of slip on the causative fault, but also an approximate direction for the maximum ambient stress. Stress directions have been obtained for earthquakes from Kintail, Carlisle, Lleyn and Cornwall. The results agree with independent measurements in Cornwall: Britain is under compression, roughly NW-SE, possibly caused by the mid-Atlantic spreading centre to the NW and the Alpine orogeny to the SE.

Seismic waves radiated from earthquakes may be used like echo-sounders to probe the depths of the Earth. Shear-waves (those oscillating perpendicular to the direction of propagation) are now recognised to contain a wealth of information about the medium through which they have travelled. In
particular, they can become aligned, or polarised, by cracks in the rock which themselves are aligned by the ambient stress field. It is now thought that these cracks are ubiquitous and fluid-filled and knowledge of their size, density and alignment is of great interest to the oil engineer, hydrologist or geothermal prospector. Furthermore, the stress pattern immediately before an earthquake is thought to change quite rapidly; the detection of this by examining shear-wave polarisation may be useful in earthquake prediction.

Assessment of seismic hazard continues and becomes more refined as the earthquake file increases year by year. Eventually it may be possible to define seismic zones of different degrees of hazard; a pattern for this is already becoming apparent in the North Sea after only six years of instrumental monitoring. The difference between a maximum likelihood magnitude of 5.5 and 6.0 can make millions of pounds difference to the construction of an offshore platform.

Finally, to place British seismicity in perspective: it is an area of low to moderate seismicity with a maximum likely magnitude somewhere just over 6. This should not present significant problems for buildings and equipment correctly designed for the relevant ground motions involved. However, parts of Agadir in Morocco, an area of low seismicity, were virtually destroyed by a magnitude 6 in 1960. The earthquake was very shallow and the buildings were not designed for the loadings imposed, consequently 12,000 people lost their lives.

Acknowledgements

The Global Seismology Research Group of BGS is a team of scientists and this article describes the work of that team.

Mobile Exploration (Norway), the Camborne School of Mines, The States of Jersey Meteorological Office, The Universities of East Anglia, Leeds and Leicester and other individuals assist with station operation. Data is exchanged with the Dublin Institute of Advanced Studies, the University of Bergen, NORSAR and other European agencies through the International Seismological Centre.

The work is funded in part by the Department of Energy, The Jersey New Waterworks Co, Renfrew District Council and the Department of the Environment and is supported by the Natural Environment Research Council. It is published with the approval of the Director of BGS (NERC).

Further Reading
BGS, Murchison House, sell a whole series of booklets, reports and catalogues of British earthquakes.
The Foss Baryte Mine, Aberfeldy

Rosalind Garton
12 Main Street, Strathkinness, Fife

A high spot in the 1986 season of excursions was the visit on July 5th to the Foss Baryte Deposit near Aberfeldy. About 40 people and a bicycle made their way to the hills south of Loch Tummel - beautiful walking country but unlikely looking mining terrain. Mining is not new to this area, however. Nearby is the Tomphubil limestone quarry and its recently restored kiln, built about 1865 to provide lime for local bog and moor reclamation, and there is also evidence of 17th and 18th century lead mining in the area.

Crammed into Land Rovers borrowed from a variety of sources we bumped our way up the side of Meall Tairneachan to about 2000 feet, along a road specially built by the mine owners, Dresser Minerals. Our guides for the day were Alan Burns, the site geologist, and Graham Smith and Mike Gallagher from BGS. The first of the day’s wonderful views was admired before we set off on foot. This one was of some historical interest, as it included Schiehallion (location of early attempts at determining the Earth’s mass), and the line of the Loch Tay Fault in Glen Tilt, where the geology inspired James Hutton in the late 18th century.

The remoteness of the site helps explain why this huge deposit of barium-rich rocks went undiscovered for so long. It was found by the Geological Survey in the late 1970's, following a survey of the chemistry of stream sediments draining the area to trace known copper mineralisation. Little copper was

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Figure 1. The geology and location of the Foss Baryte Deposit
found, but anomalously high values of barium, zinc and lead were. Further surveys led to the identification of the Ben Eagach Schist (a formation in the Middle Dalradian or Argyll Group) as the host of baryte (barium sulphate) with sphalerite and galena (zinc and lead sulphides respectively). The deposit lies at the top of the formation, near its contact with the overlying Ben Lawers Schist (Figure 1).

Most of the Ben Eagach Schist is made up of dark grey schists displaying original bedding, the rest comprising mica schists, quartzites, thin limestones and metamorphosed igneous rocks, and the mineralised zone. This zone is 300 feet thick and contains some unusual barium-rich rocks, including a bedded baryte rock, a quartz-celsian (barium feldspar) rock, barian muscovite schist and fragmented rocks. A carbonate rock is also found in the zone, and although a minor constituent, contains high concentrations of zinc and lead. The deposit is stratabound, that is it sits within strata as an ore body.

The baryte rock itself comprises about 90% baryte with quartz and carbonate. It occurs as bands and lenses that vary in thickness from less than an inch to about 60 feet. The structure of the rocks was extremely complicated. Caledonian deformation having produced folds on plunging folds and thinning and pinching of the baryte. It wasn’t long before I was stratigraphically completely disorientated, and was relieved to be assured by Alan Burns that many eminent geologists had been similarly confused on visiting the locality!

The unpredictability of the baryte rock causes problems when extracting it, as an adjacent bed is very soft. When the succession is overturned slumping and underground washouts can result. Geological structure aside, the problems associated with mining at such a remote and elevated site seemed formidable. Extraction, using both mining and opencast techniques, takes place only in the summer, and the rock is stockpiled at the mine gates. During the winter the baryte is taken by 20 ton lorries to Aberdeen, the lorries crossing the tiny Wallace bridge at Aberfeldy which had seemed barely wide enough for our bus! Twenty tons may sound a lot, but when the cargo has a specific gravity of about 4.2 the volume isn’t large!

The baryte is used for making up drilling “muds” for the oil industry. Muds are needed to lubricate and cool drill bits, and they must be made up to different densities depending on the depth and pressure found in each drill hole. Baryte is a soft mineral (hardness 3), so does not abrade a drill bit, and its high specific gravity means it can be used to blend muds of different densities. We were told that there is enough baryte rock in the Aberfeldy deposit to last until North Sea oil runs out! The expected life of the Foss deposit which we visited is about 10 years, and there is an estimated 15 million tons more in the nearby Ben Eagach Prospect. In 1984 and 1985 50,000 tons of baryte rock were extracted, and at the time of our visit about 3,500 tons were
being removed each month. In spite of the scale of the mining, the impact on
the local environment seemed very small.

Another interesting aspect of the visit was the hunt for unusual minerals. A
darian chert contained about 50% celsian, making it one of the largest
concentrations of celsian in the world. Other minerals were hyalophane
(another barium aluminium silicate), cymrite - a very rare hydrated BaAl
silicate which has retained the water in its structure despite metamorphism and
folding, and the chrome mica, fuchsite. Some of the baryte samples were
encrusted with pyrite and were very beautiful. However, pyrite can cause
problems because of it hardness (about 6) if it is too abundant.

The origin of this enriched zone of rocks is still being debated. The scarcity
of clastic material suggests that the baryte and carbonate rocks are the result
of rapid chemical precipitation. The deposit is believed to be of
synsedimentary origin from a metal-rich brine introduced into a black shale
environment near the sea floor. The environment prevalent at the time the Ben
Eagach Schist was deposited was one of basins interrupted by higher areas.
Black, organic-rich muds (the precursors of the graphitic schists) accumulated
in the basins while calcareous sediments were deposited on the highs.
The enrichment in barium, zinc, lead and other metals may be of hydrothermal
origin, and it has been suggested that it is the result of "black smoker" activity
- the eruption of hot, mineral laden waters near spreading ocean ridges into
cold, deep sea water. In this case it may have occurred at the time of the
opening of the Iapetus Ocean. There is no direct evidence of hot spring activity
in the area, but metamorphosed igneous rocks do occur in the Ben Eagach
Schist and in the overlying Ben Lawers Schist.

Many of us returned laden with heavy and interesting mineral samples with
which to adorn our mantlepieces. The scenery and rocks were most
spectacular, and combined to make a very enjoyable excursion. Thanks are
extended to all those who organised the visit and who explained the geology.
Special thanks go to Dresser Minerals for permission to visit the site.

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My thanks to Wendy Garton and Richard Batchelor for drawing the map of
the locality.
The tenth E.G.S. long excursion was held in Argyll: an attempt to reach the Garvellachs on a previous week-end excursion had been frustrated by the weather, so it was hoped that a week in the area might allow a successful landing. It had been suggested that a visit to the disused lead mine at Tyndrum should be made before proceeding to the Forestry Commission cottages at Dalavich later in the afternoon. Thus the party, dressed for the field and laden as usual with all that was deemed necessary for the week, left Edinburgh in rapidly deteriorating weather. When the time to evacuate the vehicles arrived - after a short detour to see the local sewage works - it was raining heavily and therefore several decided to forego the experience and start the excursion the following day with dry boots and clothing. On arrival at Dalavich the cottages were found to be relatively spacious and comfortable, reasonably well equipped but not identically so, leading to unsuccessful bartering for specific items between groups. Situated among the pine trees on the shores of Loch Awe we were glad that the midge season had not started; this fact was made very apparent by many entries in the Visitors Books, kindly provided for each house by the Forestry Commission with a request for comments of any sort; it is possible that the variety and content of some may even have exceeded the Forestry Commission's expectations, but they certainly gave the participants of the excursion many hours of amusement!

The main purpose of the trip, of course, was to look at the geology of the area - mainly the Dalradian. For that end, on the Sunday morning, a rather subdued party (partly due to the rain and partly to the rather poor roads which induced varying degrees of queasiness in some members) gathered near Kilmory village. After a short introduction to the geology, the sedimentary and structural features of the Crinan Grits that are exposed in the Kilmory Bay syncline were examined; these included excellent graded bedding and textbook examples of bedding/cleavage relationships developed in a series of spectacular plunging folds. Later in the day the Ardrishaig Phyllites were seen, and at the most southerly point reached (locality 10, Roberts, 1977) thick epidiorite sills. Before returning to the buses the ruined church at Kilmory village was visited to look at the collection of ancient carved Celtic slabs and crosses kept there.

On Monday morning, after an equally bad journey on the road west from Dalavich, the party assembled at the car park for the Kerrera ferry. They walked south, past an intrusion displaying excellent columnar jointing, until access to the shore was obtained. Old Red Sandstone conglomerates and some
extremely weathered dykes, hardly recognisable as such, were studied before lunch was taken at a locality where fossil fish (?)singular) had been found in the past. Despite enthusiastic hunting only one dubious indication of ancient life was found, but the frailties of modern life were brought home by a slip resulting in a broken bone in the hand of one of the party. At this point the party was forced to retreat due to access problems, and therefore headed for Dunollie Castle to the north of Oban, where more conglomerates and basalt lavas were studied on the shore for the rest of the afternoon.

Weather permitting, a trip to the Garvellachs had been planned for the following day. The incompatible sizes of the boat and number of mariners meant that the party had to be divided into three, the first party leaving Dalavich at about 6.30am! Luckily the weather was kind, as regards sea conditions, and a safe landing was achieved - the idea of repeating the early start was not popular! Although the sea was fairly calm for the half-hour crossing the rain continued, and very heavy showers were experienced by all parties during the morning. The island visited was Garbh Eileach, the largest of the group, where the Port Askaig Tillite is well preserved; this was described by Spencer (1971) and later discussed by Eyles and Eyles (1983). The formation consists of a variety of sandstones and mixtites (a non-generic term used to describe the boulder beds) and, particularly in the lower member, subordinate siltstones and dolomite. The mixtites near the jetty were spectacular, and included granite boulders possibly from as far afield as Czechoslovakia; moving down the sequence the proportion of granite boulders decreased and those of dolomite increased. Other interesting features included sandstone wedges, where sand had filled crevices in the top surface of the mixtites, and the Great Breccia with blocks several metres across; stromatolites were found in the Islay Limestone below the mixtites. The first two parties to leave the island had time to visit the quarry in the Easdale Slate at Cullipool before everyone had to evacuate Luing Island before the last vehicle ferry at 6.00pm.

On Wednesday the party visited Tayvallich. As expected, soon after leaving the vehicles a heavy shower sent everyone scurrying for cover. The morning was spent on the peninsula south of Keillmore (locality 3, Gower, 1977) where the rocks consisted of a limestone containing fragments of epidiorite resting with sharp contact on the Loch na Cille Boulder Bed, with pillow lavas below. After lunch features in the pillow lavas and associated hyaloclastite breccias and tuffs were examined in a kilometre-long strike section on the coast to the north west of Keillmore; a bed of “porphyry breccia” is also exposed here, containing boulders more than 1 m in diameter. By late afternoon the party had only reached locality 5, and at this point it was decided that the optimism displayed in leaving one vehicle at the end of the section was unfounded, and the entire party returned to the start. In the evening a party, complete with
cake, was held to mark the occasion of the tenth long excursion of the Society: certificates were presented to the few that had survived them all!

On Thursday it was planned to visit three geographically separate localities: we only managed to get to two! The first stop was the south western end of the Craignish peninsula, where the Craignish Phyllites show negligible deformation, protected by the close proximity of thick epidiorite sills (Anderton, 1975); sedimentary features are well preserved, as well as excellent gypsum pseudomorphs up to 4 cms long. A non-geological point of interest at this locality was the distant view of the white water marking the position of the Corryvreckan whirlpool between Jura and Scarba. After lunch the party moved northwards to the peninsula north of Asknish Bay, where extremely deformed examples of the Craignish Phyllite were seen, together with diorite and granite intrusions. Some copper mineralisation was found.

On Friday the party split. A small group, feeling that they had suffered the local roads for long enough decided to investigate the area around Dalavich, whilst two bus loads headed for the shores of Loch Fyne. The first short stop was in the Erin Quartzite (locality 16, Roberts, 1977) before moving south to the main section near Barmore Island. The Stonefield Schists, Loch Tay Limestone, Glen Sluan Schists and Green Beds were to be examined, as well as exposures of epidiorite that were not mentioned in the guide (plus the delights of Tarbert by a splinter group). Particular features of interest were the development of albite porphyroblasts, tourmaline and graded bedding showing that the beds were inverted. The intricacies of the structure described in the guide were difficult to grasp on first acquaintance (see later). This turned out to be one of the most energetic sections of the week, for despite being a short shore section it did not lack interest for those who enjoy scrambling!

The now traditional Friday evening gathering was held. The hosts on this occasion decided that the mental processes had not been overtaxed during the week, and hence invited everyone to solve a cubic equation to discover the venue - everyone turned up at the right place! Entertainment was provided by extracts read from the Visitors’ Books. Thanks were expressed to all those involved with the organisation and execution of the excursion, particularly leaders, drivers and the Catering Committee, and certificates were presented to other sundry individuals for nefarious contributions and/or misdeeds. Two of these were for statements made during the week, the first made at locality 22 of the last itinerary, where one member was heard to say “I think we are baffled by the significance of these structures” and also, at the same locality, “the subtleties of this escape me”. The second statement - “never have so many travelled so far to see so little” was a reference to the fact that we never actually reached the end of any of the itineraries. The Strontian Hammer for 1986 was awarded to Ian Hogarth for organising everything so well, especially the trip to the Garvellachs, in the face of so many problems (namely, thirty-five
participants). The citation is too long to quote.

The final day would normally simply be a return to Edinburgh, but with such a short drive it was decided that two buses would visit Lismore on the way back. After a short, but choppy, crossing from Port Appin, the party walked round the coast, crossing the Lismore Limestone (Hickman, 1975), to an intrusion of diorite and its associated mineralisation; pyrite and pyrrhotite were found.

And so ended another enjoyable and interesting excursion. A week when not even a single toe was deliberately dipped into the sea and when the normally ubiquitous cuckoo was only rarely heard; one when the number of good days were not enumerated by the number of bare knees that blossomed but by the number of days when waterproof overtrousers were not a necessity; one marred by sickness (several members had succumbed to a mystery bug) and injury, and compared to the previous nine excursions, bad weather - but it could have been worse. Let us hope that next year we can expect, and experience, our usual brilliant weather.

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Review:
Andrew A McMillan
British Geological Survey

When Down to Earth appeared on the scene in November 1985 just in time

to celebrate the 150th birthday of the Geological Survey, our erstwhile

President was heard to comment that it should have been entitled 'Rock

bottom'! For those of us aware of the parlous state of geology in this country

and of the Survey’s plight in particular, this sounded about right and it is a

theme to which the author of this entertaining book returns on several

occasions.

The publication is a ‘personal account’ and once or twice, the opportunity

is taken to let rip. The NERC (and its biologists) in particular amongst parent

bodies of the Survey comes in for a fair amount of stick.

The book consists of eighteen thoughtfully titled chapters some of which

have amusing chapter head sketches. I particularly like the ‘Mandarins’.  

Although each chapter describes aspects of the Survey’s life and work in some

sort of chronological order, there is no chronological continuity from chapter
to chapter. I like this approach because it breaks up an otherwise lengthy string

of dates and facts but it is difficult to use the book for reference purposes

especially as there is not even a brief index (cf. E.B. Bailey’s ‘History’, 1952).

It is inevitable in any history that dates, acronyms and names predominate.  

There is, of course, little one can do with the former two subjects except quote

them sparingly. Names, on the other hand, evoke characters. Brief character

sketches are given of some notable geologists but it would have been

interesting to read more of post-World War II staff, most of whom the author

must know personally.

Much of the earlier history has, of course, been treated before by Sir John

Flett (1935) and Sir Edward Bailey (1952) but, like different biographies of the

same individual, each book portrays the author’s style and prejudices, and

highlights different events as being significant.

I have a suspicion that the “plate-tectonic” (post-1960’s) years have seen

more changes in the Survey in relation to its size, scope, objectives and

relevance to society and industry than ever before, saving possibly the

inaugural period under De la Beche. Somehow I feel the author has not done

justice to this fast moving modern phase: perhaps that is because, just as it is

sometimes difficult to appraise the merits of contemporary music, it is equally

hard to stand back from the present and place current events in the context

of the past. Actually, geologists who adopt the axiom that the “Key to the Past

is the Present” ought to be in their element!

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The sort of criticism I have is epitomised by the section on computing entitled ‘The Numbers Game’. It is hardly a chapter and all it does is to chronicle the exasperating history of the introduction and implementation of computing in the Survey. A brief reference to Read and Dean’s early statistical work is the only indication of the use and practicability of computing in geology until a rather inadequate mention of the National Geosciences Data Bank is made in the pessimistic final chapter. I cannot believe that there has been so little progress in the last 20 years.

The author has chosen this low key approach to describe other fields of modern geological activity. On the marine side, for example, I regard the Survey as more than ‘a collator of data from diverse sources’. Although recognition is given to the development of techniques and the value of mapping the continental shelf in terms of benefit to the offshore engineering industry and assessment of hydrocarbon prospectivity, I think the scientific worth of the programme needs to be fully stated as well. This is pioneering work which in its own way is as exciting as the discoveries of Clough, Peach and Horne. Equally, the importance and use of regional geological surveys, environmental geology and other forms of modern geological mapping need to be highlighted. Few readers, who are not geologists, will know how these approaches differ from ‘traditional’ mapping. The brief mention of the fascinating Aberfeldy baryte-base metal discovery fails to convey the importance of studying stratabound sulphides and the implications for future work in the Grampians.

In essence, I would have liked to see the author singing the praises of scientific achievement and highlighting what the Survey is good (and bad) at. Progress or otherwise in the science goes hand in hand with bureaucratic change. Yet the latter, a dull succession of unit name changes, regrouping of staff and alterations to management structure (not unique to the Survey), is given precedence. Notwithstanding these observations I found the book a good read. I certainly think that the pre-war years are treated better than the post-war years. Sometimes the author leaves the reader in mid-air, presumably to let him draw his own conclusions. Other matters are covered more extensively. Hercules, for example, receives a full frontal chapter all to himself. On the subject of work returns I would suggest there was little or no need to illustrate four separate examples of those wretched forms! Anecdotes are amusingly recounted. The reference to J.E. Richey in Mull and the ‘load of old stones’ reminds me of a similar account in Lilian Beckwith’s delightful novel ‘The Hills is Lonely’. Errors appear to be few: the most amusing that I found was the startling revelation that Dr J.D. Peacock was an enthusiastic scuba diver (p.172). He assures me that he has never been a scuba diver! Poems are reproduced both in the text and in an appendix, and include ‘The Aged Palaeontologist’ which readers of this magazine will recall was published in the March 1978 issue. The illustrations are well produced and clear, although the
splendid artwork of the scroll presented to Dr G. H. Mitchell on his retirement is lost in the black and white reproduction.

I can certainly recommend the book to anyone with an interest in the Survey, the history of geology, or QUANGOS. However, I think it unlikely it will have wide appeal and I contend that geologists in general still have a long way to go to influence public and governmental opinion of the value of the science. I feel the author should have fully grasped the opportunity to emphasise how geology and the Survey have, to poach a phrase, served the nation.

Further reading
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