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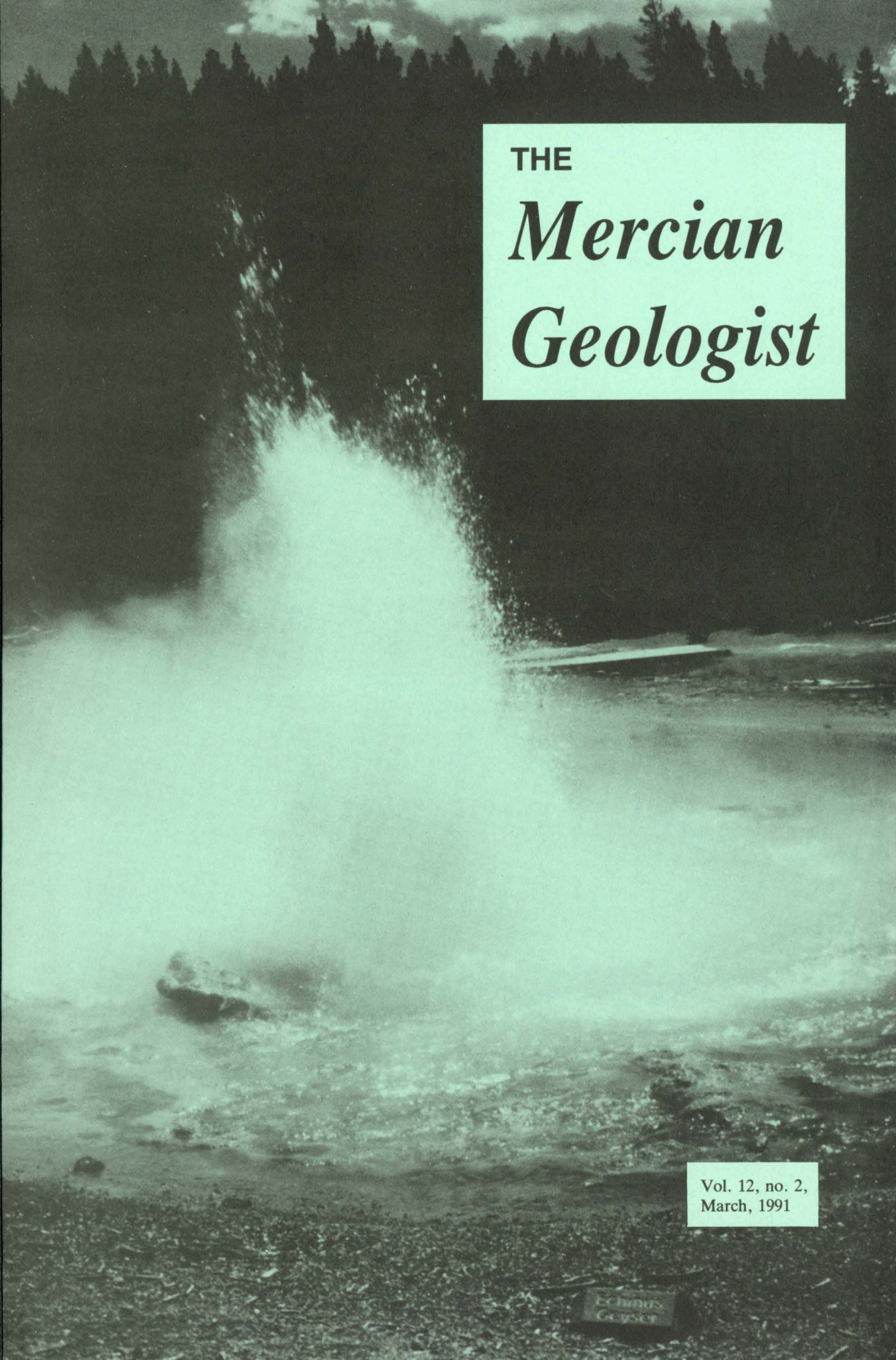

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Front cover: Echinus Geyser, Norris Geyser Basin. The geyser erupting at about half normal strength.

CONTENTS

REVISION OF THE MONSAL DALE/EYAM LIMESTONES BOUNDARY (DINANTIAN) IN DERBYSHIRE

by

Peter Gutteridge

Summary

Carbonate mud buildups which occur in association with the Monsal Dale/Eyam Limestones boundary have been regarded as part of the Eyam Limestones Formation. A sedimentological study of this boundary shows that these carbonate mud buildups are separated from the overlying Eyam Limestones by a stratigraphical break which represents a period of subaerial emergence. The base of the Eyam Limestones is therefore redefined so that the carbonate mud buildups are included within the Monsal Dale Limestones.

Introduction

The stratigraphical boundary discussed is between the Monsal Dale Limestones Formation (below) and the Eyam Limestones Formation (above); both of which are of Brigantian (late Dinantian) age (Fig. 1). According to Aitkenhead & Chisholm (1982) the numerous carbonate mud buildups which occur in association the Monsal Dale/Eyam Limestones boundary are included within the Eyam Limestones. Sedimentological studies of these carbonate mud buildups by Adams (1980) and Gutteridge (1983) have shown that they rest comfortably on the underlying Monsal Dale Limestones and are separated from the overlying Eyam Limestones by a stratigraphical break which represents a period when much of the Derbyshire carbonate platform was emergent. The objectives of this paper are to describe the stratigraphical relationships of these carbonate mud buildups and to revise the base of the Eyam Limestones so that the carbonate mud buildups are placed within the underlying Monsal Dale Limestones.

This revision of the Monsal Dale/Eyam Limestones boundary is concerned only with sections in which carbonate mud buildups are present. The position of the boundary in the four type sections defined by Aitkenhead & Chisholm (1982) is not affected as these sections do not contain carbonate mud buildups.

Stratigraphical position of the carbonate mud buildups

The carbonate mud buildups discussed here have been referred to as knoll-reefs by previous workers (e.g. Smith *et al.* 1967, Biggins 1969, Stevenson & Gaunt 1971, Aitkenhead & Chisholm 1982 and Aitkenhead *et al.* 1985). These carbonate mud buildups were mound-like accumulations of carbonate mud-rich sediment on the former Dinantian sea floor surrounded by a "halo" of crinoid-rich grainstone. Further details of the internal structure and sedimentology of these carbonate mud buildups can be found in Gutteridge (1983, 1990).

This stratigraphical revision is based on evidence from carbonate mud mounds cropping out in Lathkill Dale, the National Stone Centre at Wirksworth and Bradford Dale near Youlgreave (Fig. 1).

(a) Lathkill Dale

Carbonate mud buildups are present at the western end of Lathkill Dale (SK1666) and are exposed around Ricklow Quarry (SK164661), (Fig. 2).

The base of the carbonate mud buildups seen in the sides of Lathkill Dale is marked by a conformable transition from thickly-bedded pale bioclast peloid packstone upwards into medium-bedded bioclast

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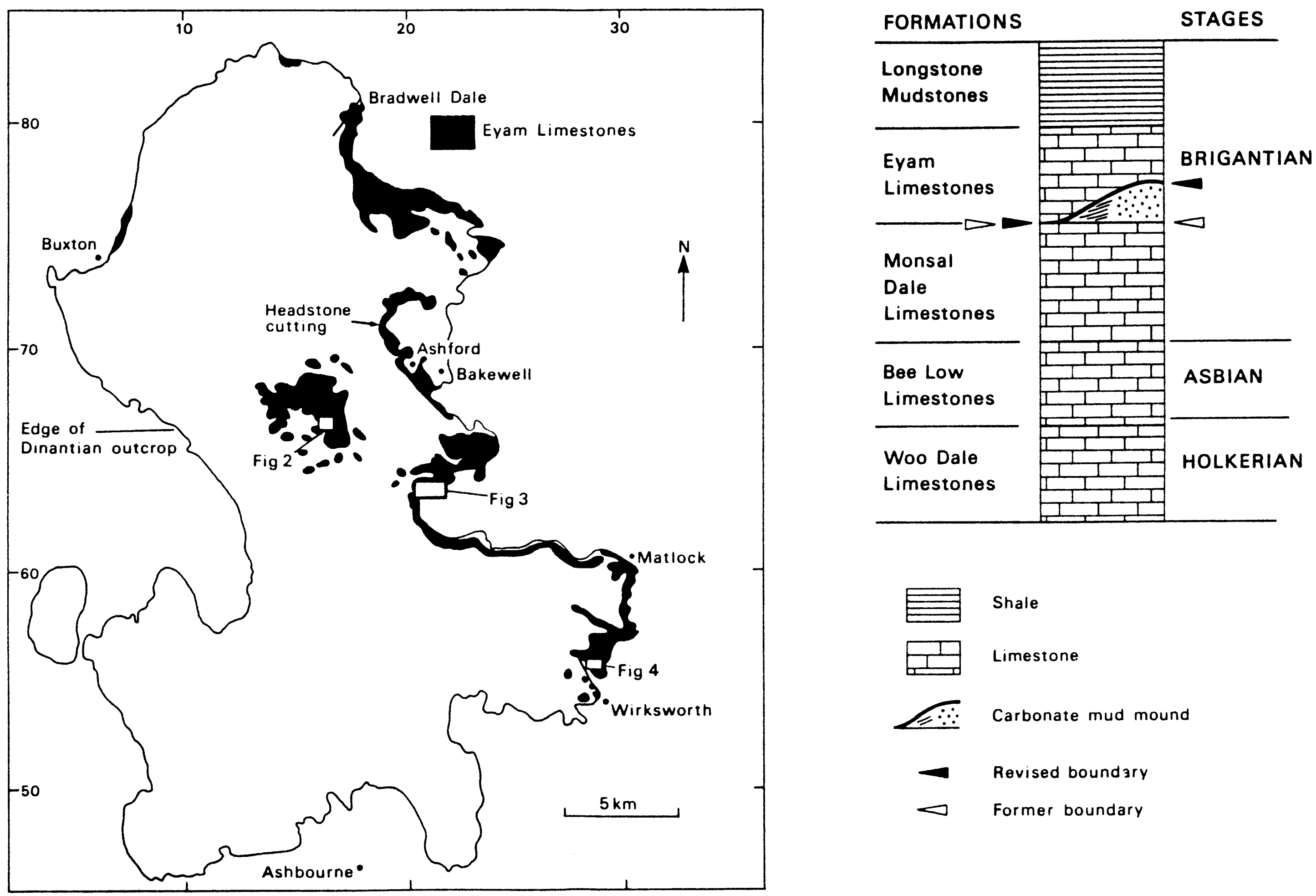

Fig. 1. Outcrop of the Eyam Limestones on the Derbyshire carbonate platform (from Aitkenhead & Chisholm 1982). Stratigraphical column indicates position of Monsal Dale/Eyam Limestones boundary (open arrow) defined by Aitkenhead & Chisholm (1982), and the revised position of the boundary where carbonate mud buildups are present (solid arrow). Localities referred to in the text: 1. Lathkill Dale, 2. Ricklow Quarry, 3. National Stone Centre, Wirkworth and 4. Bradford Dale.

wackestone/packstone. The latter facies contains several tabular mud-mounds up to 1 m in thickness which represent the initial stage of carbonate mud buildup growth. There is no evidence of an unconformity between the Monsal Dale Limestones and these carbonate mud buildups as determined by Shirley (1959).

The top surface of the carbonate mud buildups is marked by a calcrete profile (Adams 1980) which can be traced onto the top surface of the laterally-equivalent Monsal Dale Limestones. These carbonate mud buildups contain vadose cements and fissures which are partly infilled with speleothem cements (Adams 1980, Gutteridge 1983). These speleothem deposits contain calcrete clasts and are overlain by sediment derived from the overlying Eyam Limestones. This demonstrates that these vadose cements formed during the episode of subaerial exposure before deposition of the Eyam Limestones.

Where carbonate mud buildups are absent, the top of the Monsal Dale Limestones is marked either by a calcrete horizon or a palaeokarstic surface. At the base of the overlying Eyam Limestones, an impersistent, fenestral wackestone interpreted as a peritidal deposit is present which is overlain by a medium bedded, medium grey bioturbated bioclast wackestone deposited in a subtidal environment (Gutteridge 1983, 1984).

The sequence of events associated with the Monsal Dale/Eyam Limestone boundary in Lathkill Dale is interpreted as follows:

1. Deposition of the Monsal Dale Limestones in marine subtidal conditions.

2. Growth of carbonate mud buildups in a subtidal setting.

3. Subaerial exposure of the carbonate mud buildups and the surrounding Monsal Dale Limestones. This resulted in calcrete development on the carbonate mud buildups and the top surface of the Monsal Dale Limestones together with vadose cementation of the carbonate mud buildups.

4. Deposition of the Eyam Limestones, which initially took place in a peritidal environment which was followed by establishment of a subtidal environment as sea level rose.

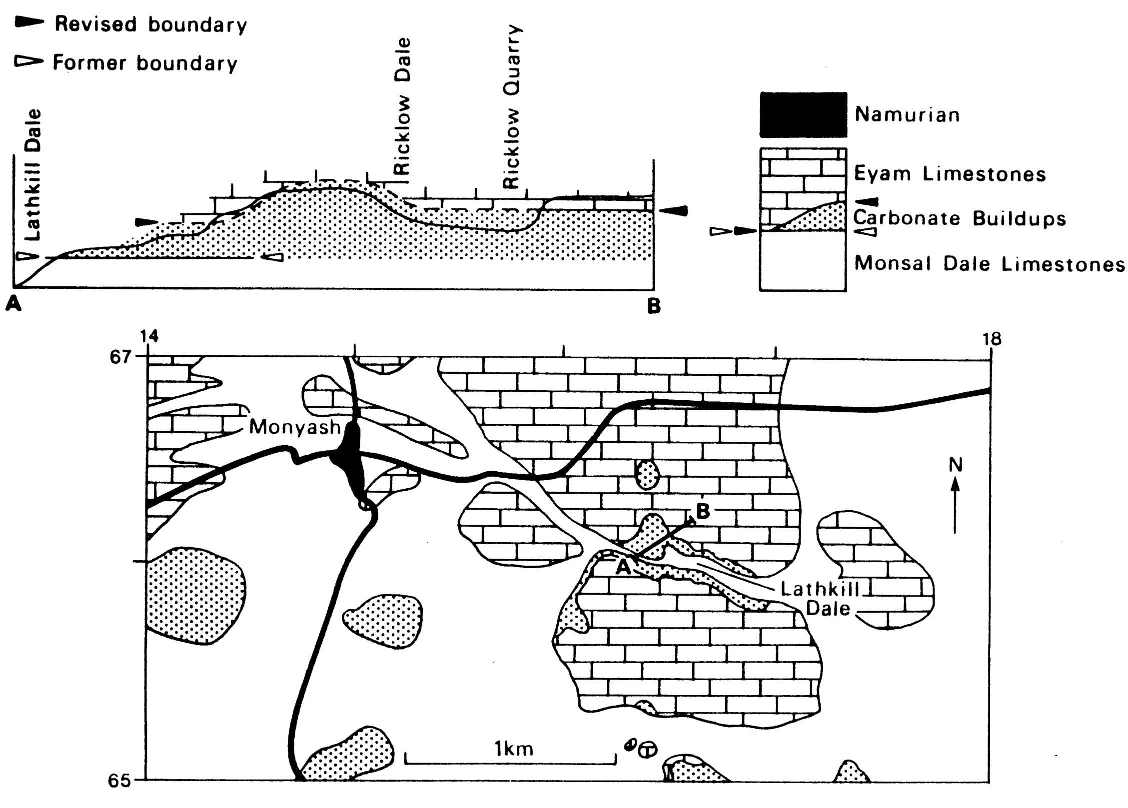

Fig. 2. Stratigraphical relationships in Ricklow Quarry (SK16456615).

(b) Wirksworth

The Monsal Dale/Eyam Limestones boundary is exposed in a series of disused quarries immediately to the north of Wirksworth (the National Stone Centre SK2855). See Fig. 4, p. 77.

The contact between the carbonate mud buildups and the underlying Monsal Dale Limestones shows no evidence of any significant stratigraphical break. These carbonate mud buildups contain vadose cements and fissures which are infilled with speleothem cements similar to those seen at Lathkill Dale. There is also an impersistent calcrete developed on the top of these carbonate mud buildups. The contact between the Monsal Dale Limestones and the Eyam Limestones away from the carbonate mud buildups is not exposed. These carbonate mud buildups are buried by bioclast (mainly crinoidal) grainstone which was deposited in a bioclastic shoal complex associated with the southern margin of the Derbyshire carbonate platform (Gawthorpe *et al.* 1990).

The sequence of events associated with the Monsal Dale/Eyam Limestone boundary near Wirksworth is interpreted as follows:

1. Deposition of the Monsal Dale Limestones in marine subtidal conditions.

2. Growth of carbonate mud buildups in a subtidal setting.

3. Subaerial exposure, which resulted in calcretisation together with vadose cementation of the carbonate mud mounds.

4. Deposition of the Eyam Limestones as a result of relative sea level rise. In this case, the depositional environment was a high energy crinoidal grainstone shoal developed in association with the southern margin of the Derbyshire carbonate platform.

(c) Bradford Dale

The succession across the Monsal Dale/Eyam Limestone boundary, together with several carbonate mud buildups is exposed in Bradford Dale (SK215642), (Fig. 3). The carbonate mud buildups contain vadose cements and fissures which are partly infilled with speleothem cements indicating an episode of subaerial exposure immediately after deposition.

Where carbonate mud buildups are absent, the sequence across the Monsal Dale/Eyam Limestones boundary (e.g. section D, Fig. 3) consists of bioclast wackestone/packstone which was deposited in a low energy subtidal environment on the middle part of a carbonate ramp (Gutteridge 1983, 1984; Currie 1987). This sequence contains a distinctive unit (Unit A, Fig. 3) which is up to 1.5 m thick and which comprises interbedded limestones and shales. The limestones in this unit contain evidence of subaerial exposure in the form of vertical dessication cracks, circumgranular fractures, sub-horizontal sheet cracks and carbonised plant roots. These limestones also contain a full marine fauna. The interbedded shales are unfossiliferous and contain abundant carbonaceous material. A rounded boulder reworked from a carbonate mud buildup is also present within Unit A.

The limestones are interpreted as marine deposits which were modified during subaerial exposure, either in a peritidal setting or as a result of reworking and redeposition on a supratidal setting. The shales are interpreted as former soil horizons. The reworked boulder is inferred to have formed by erosion during this episode of sub-aerial exposure.

The sequence of events associated with the Monsal Dale/Eyam Limestone boundary at Bradford Dale is interpreted as follows:

1. Deposition of the Monsal Dale Limestones in a low energy, full marine subtidal setting on the middle part of a carbonate ramp.

2. Growth of carbonate mud buildups in a subtidal setting.

3. Subaerial exposure resulting in vadose cementation of the carbonate mud buildups and deposition of speleothem cements within fissures. The surrounding carbonate sediments were exposed to desiccation and soil-forming processes. Erosion of carbonate mud buildups also took place.

4. Deposition of the Eyam Limestones in a low energy, full marine subtidal setting on the middle part of a carbonate ramp as a result of relative rise in sea level.

(d) Summary of stratigraphical evidence

These three areas demonstrate a consistent stratigraphical relationship between the Monsal Dale Limestones, carbonate mud buildups and the Eyam Limestones:

1. Carbonate mud buildups rest conformably upon the Monsal Dale Limestones.

2. Features indicative of subaerial exposure, such as calcretes and vadose cements, are present within the carbonate mud buildups.

3. Calcrete profiles, palaeokarsts and palaeosols are present on the top surface of the Monsal Dale Limestones where it is overlain directly by the Eyam Limestones.

4. The sub-aerial features developed at the top of the Monsal Dale Limestones and within the carbonate mud mounds represent the same episode of sub-aerial exposure.

An important stratigraphical break is thus present between the carbonate mud buildups and the Eyam Limestones. The inclusion of these carbonate mud buildups within the Eyam Limestones Formation is therefore inconsistent with the stratigraphical evidence and a modification of the Monsal Dale/Eyam Limestones boundary is proposed such that the carbonate mud buildups are removed from the Eyam Limestones and placed within the Monsal Dale Limestones.

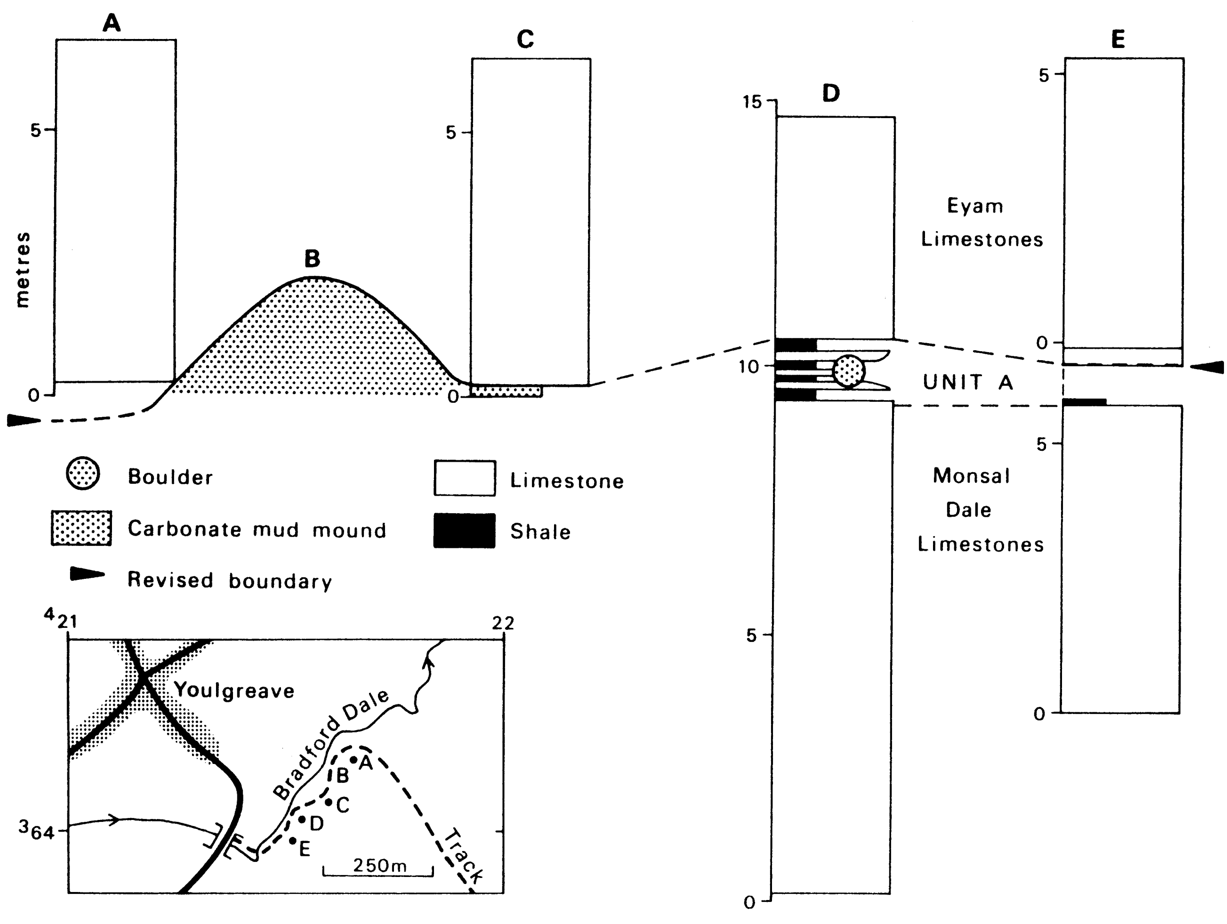

Fig. 3. Stratigraphical relationships of the Monsal Dale Limestones, Eyam Limestones and carbonate mud buildups in Bradford Dale. Solid arrow indicates revised position of Monsal Dale/Eyam Limestones boundary.

The Monsal Dale/Eyam Limestones boundary elsewhere in Derbyshire

(a) Bradwell Dale

At the northern margin of the Derbyshire carbonate platform the Monsal Dale/Eyam Limestone boundary is best exposed in Bradwell Dale (SK173807). Both the Monsal Dale and Eyam Limestones were deposited in a bioclastic grainstone facies (the "flat-reef" facies of previous workers) which developed in a bioclastic shoal complex associated with the northern margin of the Derbyshire carbonate platform (Gawthorpe & Gutteridge 1990).

Shirley & Horsfield (1940) and Stevenson & Gaunt (1971) placed the base of the Eyam Limestones in Bradwell Dale at an inferred erosion surface overlying an E-W trending "anticlinal" structure. This "anticline" was reinterpreted by Gawthorpe & Gutteridge (1990) as the crest of a large-scale sedimentary bedform. The overlying discordance is thus inferred to have been produced by sedimentological factors which influenced bedform development and is unlikely to be of stratigraphical significance. Further work is needed to determine the precise position of the Monsal Dale/Eyam Limestone boundary in this section.

(b) Ashford/Bakewell area

This area represents a former intrashelf basin within the Derbyshire carbonate platform in which dark-coloured limestones were deposited in a relatively deep-water, sheltered setting (Butcher & Ford 1973, Aitkenhead *et al.* 1985 and Gutteridge 1989). Aitkenhead & Chisholm (1982) drew the Monsal Dale/Eyam Limestones boundary at the base of a dolomitised laminated limestone (the Headstone Laminite of Gutteridge 1989) in Headstone Cutting (SK188714). This laminite was interpreted by Gutteridge (1989) and Fowles (1989) as a tidal flat deposit and is inferred to be the time-equivalent of the emergence surface described previously in this paper which developed over the surrounding shelf and shallow ramp areas.

Sedimentation around the Monsal Dale/Eyam Limestones boundary

The Derbyshire carbonate platform was differentiated into a series of shelf, intrashelf basin and ramp environments during deposition of the Monsal Dale Limestones (Gutteridge 1983, 1984, 1987, 1989, Currie 1987). Towards the end of deposition of the Monsal Dale Limestones numerous carbonate mud buildups developed in shelf, shallow ramp and platform margin settings. The carbonate platform became emergent which resulted in the development of calcrete profiles, palaeosols, palaeokarstic surfaces and vadose cementation of the Monsal Dale Limestones and carbonate mud buildups. At this time, carbonate tidal-flat sediments were accumulating in the intrashelf basinal areas. This implies that the magnitude of the relative sea-level fall was not great enough to expose the intrashelf basin. The Eyam Limestones Formation was deposited during a relative sea level rise resulting in progressive burial and onlap of the top surface of the Monsal Dale Limestones and the carbonate mud buildups.

Conclusions

An important stratigraphical break occurs after deposition of carbonate mud buildups which follow conformably on from the deposition of the Monsal Dale Limestones. The previous definition of the Eyam Limestones which includes these carbonate mud buildups is thus at odds with the stratigraphical evidence. A modified definition of the base of the Eyam Limestones is proposes which excludes the carbonate mud buildups and places them in the Monsal Dale Limestones.

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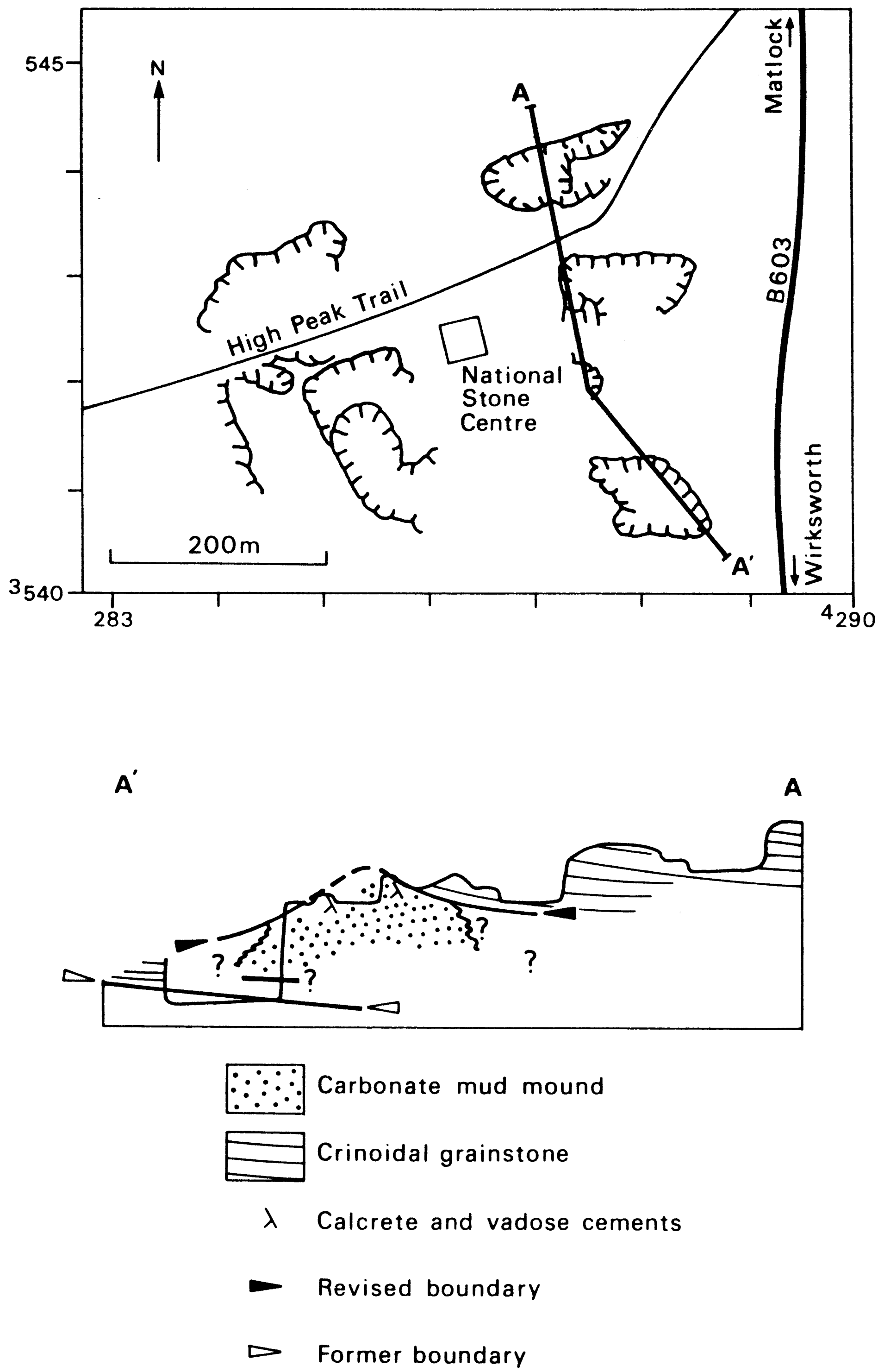

Fig. 4. Stratigraphical relationships of the Monsal Dale Limestones, Eyam Limestones and carbonate mud buildups in National Stone Centre near Wirksworth. Figure modified from (Gawthorpe *et al.* 1990). Solid arrow indicates revised position of the Monsal Dale/Eyam Limestones boundary.

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GEOLOGICAL INFLUENCES ON RADON IN HOUSES IN NOTTINGHAMSHIRE

by

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Summary

In the Gedling area, northeast of Nottingham, 85 houses were monitored for indoor radon levels. No value exceeded the Notification Level of 100 Bq/m^3. House construction and room ventilation are important influences on the radon levels. There are local radon concentrations in houses on fissured Permian limestones and on some horizons within the Triassic mudstones. High radon levels also occur in some of the artificial caves in the Triassic sandstones of Nottingham.

Introduction

Radioactivity is the emission of particles generated by the atomic disintegrations of the unstable isotopes of certain elements. It is a natural phenomenon of the world in which we live. Sources of radioactivity include outer space and various nuclear industries (contributing less than 1% of the total), but most originates within the ground. The major primary source is uranium-238 which is widely distributed, generally in small proportions, in some granites, some hydrothermal veins and some shales, and may also be present, but less abundant, in almost any other rock. Uranium-238 is an unstable isotope which decays through a chain of daughters until it eventually stabilises as lead (Fig. 1). This decay chain is dominated by solid, and hence generally immobile, elements, but radon-222 is a gas. Even though its half-life is short, radon can easily seep from the ground. Most radon diffuses into the atmosphere where it is diluted to irrelevantly low levels, but it can accumulate in poorly ventilated spaces—such as caves, house basements and even the living rooms of houses with leaky floors and sealed, double-glazed windows.

Radiation presents a threat to all forms of life, including man. The decay of radon-222 produces highly destructive alpha particles, which are only capable of travelling a few millimetres or centimetres; the danger to man from atmospheric radon is therefore infinitely small. But, the radon decays rapidly to polonium-218 and a chain of other daughters (Fig. 1). These solid particles attach to aerosols and dust particles and may get breathed in by man. They then may lodge in the lung lining. From there, the few milimetres travel of newly generated alpha particles is enough to let them enter the body tissue. The hazard is that these particles can fracture the DNA chains within cell nuclei, to a point beyond effective enzyme repair, so that cell mutations are produced—and these are the starting points for malignant cancer growth.

The absolute scale of radiation hazard to health—by radon or by any other factor—is open to medical debate, and many long-term effects remain unassessed. It is however beyond dispute that significantly improved health prospects are gained by reducing the total dose of radiation received from any source; this includes the unavoidable, natural, outdoors radiation dose, any dose received at work (limited to a small proportion of occupations, all tightly controlled by industrial regulations), and the dose received at home. The importance of house radiation levels was emphasized by the case of the Pennsylvania nuclear power plant worker who set off the site radiation detectors, not as he left work, but when he arrived from home in the morning (Brenner, 1989). His house proved to be unusually radioactive, due to radon migration, and since then house radon levels have been recognised as the source of a significant component of most peoples' radiation dose.

The standard unit of radiation measurement is the Becquerel, which is equal to one radioactive disintegration per second. Atmospheric radon can produce radioactivity levels of tens, hundreds or thousands of Becquerels per cubic metre of air—and this is how radon levels are expressed. The numbers may sound high, but a typical jar of coffee will have an activity level of 100 Bq. Alternative units of radon measurement are Working

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Levels (based on a concept of what is acceptable) and Curies (the older unit, still used in America). The approximate conversion factors are:- 370 Bq/m^3 = 0.1 WL = 10 pCi/l.

Man is affected not just by the level of radiation, but by the accumulated dose gained from all sources. The dose is the product of radiation level and time, and is measured in either Sieverts or Working Level Hours.

Geological distribution of radon

The two primary factors influencing radon emissions from the ground are the concentration of parental uranium and the rock or soil permeability. Uranium content is normally high in granite, though there are considerable variations in level between different granites. Uranium characteristically migrates into the hydrothermal environment with consequent concentrations in mineralised veins, locally to the level where it may be economically mined. In the sedimentary environment, uranium is precipitated under reducing conditions, and is consequently enriched in some shale horizons and phosphatic limestones. The national surveys of house radon in Britain have identified the high radon levels in Cornwall and Devon, with the highest values on some of the granites, their mineralised peripheral zones and some areas of mine waste (Wrixon *et al*, 1988; O'Riordan, 1990). The same surveys have revealed other areas of high radon levels, on the mineralised limestones of Derbyshire, around some of the Scottish granites and on some Jurassic phosphatic sediments in Somerset and Northamptonshire; in all these areas radon levels are above the national average but are still orders of magnitude lower than those on the granites of Cornwall and Devon. The relationships of radon with granite and black shales is also clearly recognised in America (Hand and Banikowski, 1988; Brenner, 1989; Wilson, 1984).

Highly permeable rocks permit radon to migrate more rapidly from its rock source either into the atmosphere or into the confinement of a house. The greater fracturing of the Cornish granites may be partly responsible for radon levels being higher in houses on them than in houses on the less fractured Scottish granites. Any karst limestone may permit rapid radon migration through its fissures, to create anomolously high levels in overlying houses (Hawthorne *et al.*, 1984; Hand and Banikowski, 1988). This role is further demonstrated by the very high radon levels found in some sections of poorly ventilated limestone caves (Yarborough *et al.*, 1976). In part of one cave in the Derbyshire Peak District a radon level of over 80,000 Bq/m^3 has been recorded (Gunn *et al.*, 1989); the cave is the radon carrier, while the source may be either hydrothermal mineralisation, black shale horizons or interbedded phosphatic limestone. Soil permeability also has a significant influence on radon migration (Nazaroff and Nero, 1984), though the relationship between soil radon levels and house radon levels is complex (Nason and Cohen, 1987).

Even though bedrock properties have a clear influence on radon production and emission, household radon levels cannot simply be predicted from a geological map, because equal or greater influences are imposed by a wide range of other parameters, notably those related to house construction.

Radon in houses

Radon levels in household air depend on a range of factors including the bedrock sources of radon and the construction and ventilation of the house. The highest radon levels may be anticipated where radon may diffuse through a porous floor and then become trapped in poorly ventilated rooms. A multitude of factors within the house construction have very complex influences on the ultimate radon levels. Nationwide surveys within Britain have recognised that higher radon levels are more likely in houses with solid floors, double glazing, draught proofing and a lack of open windows (Wrixon *et al.*, 1988; Courtis, 1988). Also, radon levels are significantly lower in upper floors of houses, so that inhaling radon while asleep is usually less of a hazard than while awake. Conversely, radon levels are usually higher in basements, especially those cut into solid rock and left unlined, such as the sandstone 'caves' of Nottingham. House radon levels vary with the season, normally being reduced by open window summer ventilation, and are also influenced by pressure variations, set up by wind or forced heating, which can cause more radon to be drawn from the ground.

With respect to the hazard to human health, the main concern is with radon levels in the ground floor living areas. These are therefore the normal sites for measurement. If the radon level is high, remedial action may be appropriate. This may range from the sealing of floors and points of soil air entry, to forced, underfloor ventilation (DoE, 1990; Brenner, 1989). Such work can cost over £1000 per house; government grant aid is discretionary, with rather poorly defined limits (O'Riordan, 1990; Chevin, 1990).

The Action Level in Britain is 200 Bq/m^3 (reduced in 1990 to half its previous level in response to clearer perceptions of radiation hazards to health). This figure is based on 6 hours per day spent in the house ground floor living area giving an annual dose of 10 mSv, which is regarded as undesirable. A Notification Level of 100 Bq/m^3 warrants further monitoring, and a Priority Action Level of 800 Bq/m^3 warrants remedial action within one year. Less than 1% of houses in Britain exceed this Action Level, though their distribution is not uniform and rises to 12% of the houses in Devon and Cornwall (O'Riordan, 1990). Remedial action will involve substantial total costs, and modification of house construction methods is highly appropriate in certain parts of the country.

It is important to put the risks of household radon into a wider context. It may be estimated that the average dose of normal, unavoidable, natural radiation, of which about 40% is from radon, causes cancers which kill about 60 people per year out of a population of one million (ICRP, 1987; O'Riordan, 1990). The additional radiation dose received in a house with a radon level of 100 Bq/m^3 roughly trebles this death rate. In comparison, this risk is about equivalent to that of driving a car; and cigarette smoking increases the cancer hazard more than a hundred-fold. (The radon level in the house of Pennsylvania worker referred to above was over 100,000 Bq/m^3).

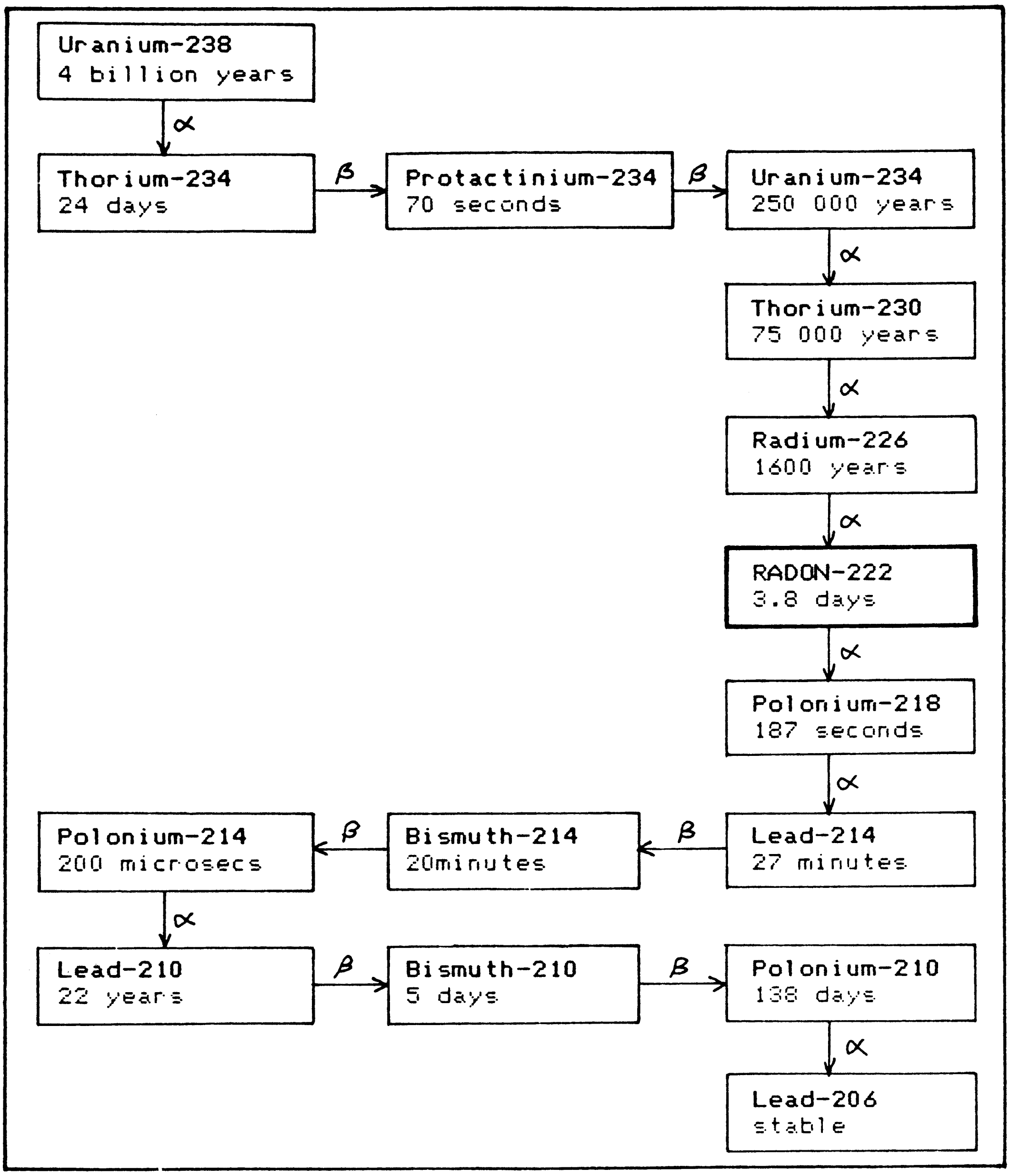

Fig. 1. The radioactive decay chain starting from naturally occurring uranium-238 and including radon-222 and its daughters (after Brenner, 1989). The half-life of each isotope is the period of time necessary for half the surviving mass to decay to its daughter. An alpha decay produces a free helium nucleus consisting of two protons and two neutrons. A beta decay produces a single free electron.

The limited local data from the national surveys showed that mean house radon levels in Nottinghamshire were low, and slightly below the national average. However, appreciable local variations do exist. The Environmental Protection Officer of Gedling Borough Council recognised his responsibility to monitor radon levels in a larger sample of houses in the borough, to better ascertain the potential of any health hazard. A pilot survey in 18 houses was carried out in 1989, followed by a main survey of 70 houses in 1990. After accidental losses these gave a total of 85 results.

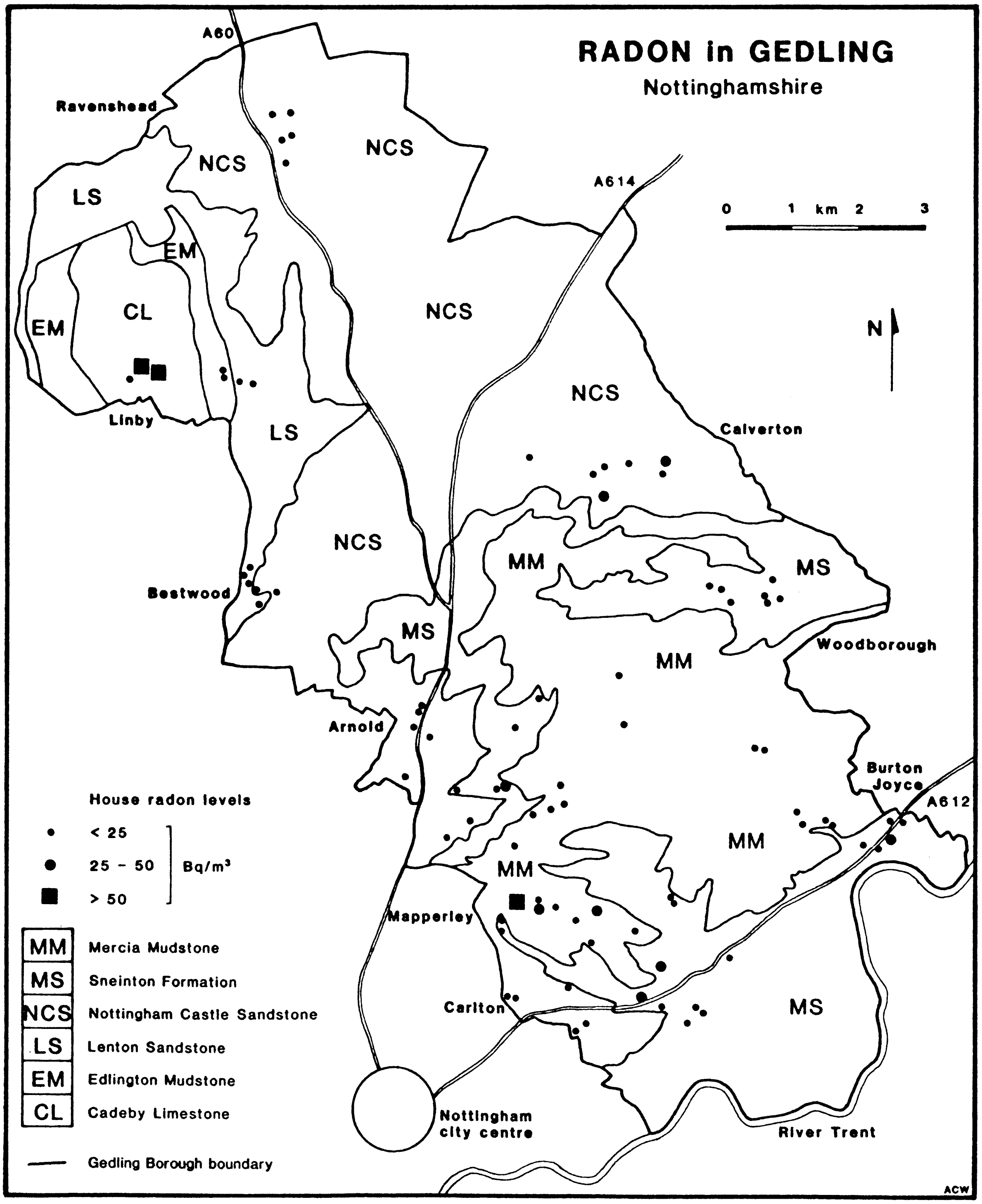

Fig. 2. Simplified map of solid geology and house radon levels in the Gedling Borough area (geology based on published B.G.S. 1:10,000 maps). Mercia Mudstone includes those formations above the Sneinton Formation; the stratigraphy and lithology are summarised in table 1.

Both surveys used passive detectors (Wrixon *et al.*, 1988). These record alpha particle impacts on prepared samples of plastic; after being in place for three months, they can, by calibration, yield the mean radon level in becquerels per cubic metre of air over that period. All the detectors were placed in ground floor living rooms of the sample houses. The pilot survey samples were random, using the houses of available council staff. The main survey was designed to sample a cross section of the geology of the borough, with a weighted distribution reflecting the spread of population (Gibbs, 1990). Small areas to be sampled were identified from the geological base map; within these areas the sample selection was random, except that houses with double glazing and without basements were chosen, where apparent, when a simple choice had to be made. This procedure was designed to encompass a "worst case scenario" within the limited available sample size, and may have produced a very small bias towards higher recorded levels in the overall survey results. Houses were identified only by approximate grid reference, and are only crudely located on Fig. 2, to respect the confidentiality of the data concerning householders who cooperated in the survey. Only summary statistics are published, while the full data remain in an unpublished report (Gibbs, 1990) which can be made available, through the writer of this paper, for any future research.

Both surveys covered three winter months between November and March. The measured radon levels are therefore enhanced due to the usual reduction of house ventilation through the colder months (Wrixon *et al.*, 1988). The raw values have been multiplied by a factor of 0.8 to approximate to the more meaningful annual average radon levels—and these deduced annual figures are considered in this paper.

The mean radon level in the samples houses of Gedling is 17.0 Bq/m^3. This compares with mean values of 20.0 and 24.2 Bq/m^3 obtained by two national surveys (Courtis, 1988; O'Riordan, 1990) each based on a sample of over 2000 houses. The Gedling area therefore has generally normal radon levels in its houses, just below the national averages which are elevated by the inclusion of data from localised hot spots such as on the Cornish granites. However the Gedling mean value does encompass three house radon levels in the 50–100 Bq/m^3 range, though none has yet been recorded which reaches even the Notification Level of 100 Bq/m^3. These higher values are of some interest, but they are fortunately of no real concern with respect to any potential health hazard.

Correlations of the survey results with details of the house construction and room conditions were limited by the sample size, which was small in comparison to the number of parameters involved, but revealed patterns which could be anticipated from the data obtained by the national surveys. Room ventilation was described as good or poor, based on an overall subjective assessment which covered draught levels, open windows and doors, and the presence of chimneys and double glazing. Radon levels were nearly 30% higher in the poorly ventilated rooms; mean values were 16.7 and 12.9 Bq/m^3 in poorly and well ventilated rooms respectively, in the sample of 82 houses on all rocks except the Cadeby Formation limestones. There was no significant difference between the mean radon levels in rooms with solid or suspended floors. Only the degree of room ventilation, or conversely the extent to which the house was sealed against the weather, provided a recognisably consistent factor which had to be taken into account during the further considerations of the parameters relating to ground conditions and geology.

House radon and the Gedling geology

Bedrock outcrops within the Gedling borough area comprise a sequence of Permian and Triassic rocks mostly dipping very gently to the southeast (Fig. 2). The Permian rocks are divided into the Cadeby Formation which approximates to what is better known as the Lower Magnesian Limestone, and the overlying largely argillaceous Edlington Formation, previously known as the Middle Permian Marl. The Sherwood Sandstone Group is divided into the underlying mottled sandstones of the Lenton Sandstone Formation, and the thicker, massive sandstones of the Nottingham Castle Sandstone Formation, which includes pebble beds in its wide but thinly populated outcrop. The exposed Mercia Mudstone Group is divided into the Sneinton, Radcliffe and Gunthorpe formations; the Sneinton Formation is a sequence of micaceous siltstones and mudstones (the old waterstones) and interbedded sandstones, while the Radcliffe and Gunthorpe formations are lithologically similar red mudstones with thin siltstone and sandstone skerries (Dean, 1989; Lowe, 1989). Drift is thin and patchy except for the Trent alluvium which covers much of the southern outcrop of the Sneinton Formation siltstones. Coal Measures underlie the whole area at depth, and have been extensively mined, but nowhere do they come to outcrop.

The variations in house radon levels across the main lithological units are summarized in table 1, and the distribution of sample sites is shown in Fig. 2. Except for the few high radon levels in houses on the Cadeby limestones, the contrasts between mean house radon levels on different rock units are small, and the limited sample size reduces their statistical significance. The lower three rock units have few samples as they have very few houses on them, and one detector was unfortunately lost in a house fire on the predictably significant limestone outcrop.

Table 1. Stratigraphical column of the main lithological units at outcrop in the Gedling Borough area, correlated with the means and ranges of radon levels recorded in houses.

Rock type at outcrop	House radon concentrations		
	Mean Bq/m^3	Range Bq/m^3	No. samples
TRIASSIC			
Mercia Mudstone Group			
Radcliffe and Gunthorpe formations (mudstones with skerries)	17.9	0–83.6	25
Sneinton Formation (siltstone, sandstone and mudstone)	16.7	4.6–43.8	28
Sherwood Sandstone Group			
Nottingham Castle Sandstone Formation (sandstone with pebble beds)	11.8	0–31.4	21
Lenton Sandstone Formation (sandstone and clayey sandstone)	13.4	6.2–3.3	6
PERMIAN			
Edlington Formation (mainly mudstone)	10.9	3.5, 18.3	2
Cadeby Formation (mainly dolomitic limestone)	58.9	9.7, 70.7, 96.3	3

Cadeby Formation limestones

Erratic house radon levels on the dolomitic limestones of the Cadeby Formation are compatible with those on any fissured limestone. Open fissures in the sub-soil bedrock permit rapid migration of radon and create the potential for high house radon levels, whereas a house sited wholly on a single block of limestone, or over clay-filled fissures is likely to have a low radon level. While there is no indication that the Cadeby limestones are a significantly high density source of radon, these results show the importance of fissures in permitting migration of radon from a larger mass of rock.

Nottingham Castle Sandstone Formation

The Nottingham Castle sandstones have a low mean value of house radon, even though they are very permeable rocks. Both they and the Sneinton Formation have log normal distributions of house radon levels, which suggest that open fissures are not significant in radon migration. The many artificially-cut 'caves' in the Nottingham Castle sandstones, mostly beneath the older parts of the Nottingham city centre (Owen and Walsby, 1989), are almost ideal radon traps. They are unlined, cut in the permeable bedrock, and most are poorly ventilated since they have only a single entry, commonly serving as the sub-basement of a single building. Spot samples of air from a number of the less well ventilated and rarely visited caves have been tested for radon; measurements were made with a radon decay products monitor (Wrixon *et al.*, 1988). Radon levels in the caves ranged between 160 and 900 Bq/m^3. Contrasts within the ten samples can be related to differences in ventilation, both between separate caves and between different parts of the same cave systems. Buildings over any of the caves have not yet been monitored for radon; there are few caves in the Gedling Borough area, and none lies beneath the houses tested in this survey.

Mercia Mudstone Group

The mudstones of the Radcliffe and Gunthorpe formations have a mean house radon level only slightly above the means of the other main rock units, but the mean hides a slightly skewed distribution with a small number of higher values. It is likely that the highest values are, at least in part, due to greater emissions of radon from the ground, as opposed to being purely a function of house parameters. A widespread marker horizon of high gamma radiation has been identified in borehole surveys at the stratigraphic level of the Radcliffe/Gunthorpe formational boundary (Balchin and Ridd, 1970). This may be a source of radon. Through the Mapperley area, this thin band of rock has a long winding outcrop which does correlate with the distribution of some of the higher recorded house radon levels, including the single highest level of 83.6 Bq/m^3. A second lithological contrast is provided within the mudstones by the sandstone and siltstone skerries, which may act as radon pathways due to their highest permeability. Table 2 summarizes the survey data from houses on the Radcliffe and Gunthorpe Formations of the Mercia Mudstone. Though the sample numbers are small, poorly ventilated houses on or close to either the Radcliffe/Gunthorpe boundary marker horizon of one of the skerries do appear likely to have higher radon levels.

The Sneinton Formation consists of a more varied sequence of siltstones, sandstones and mudstones; this could be expected to produce stratigraphically guided variations of radon distribution, as a function of bed permeabilities and perhaps with respect to the distribution of detrital mica. These factors may partly account for the range of house radon levels on this formation (table 1), but they have not been identified sufficiently for any correlation with the survey data.

Table 2. Mean radon levels in well and poorly ventilated houses correlated with their locations on or close to stratigraphical horizons within the Radcliffe and Gunthorpe formations of the Mercia Mudstone Group.

Room ventilation	Mean house radon concentrations (Bq/m^3) (Number of samples)		
	Good	Poor	All
On or close to the Radcliffe/Gunthorpe gamma marker horizon	5.0 (4)	32.6 (5)	20.2 (9)
On or close to any skerry band	7.4 (2)	48.2 (6)	22.3 (8)
Close to neither	11.6 (4)	10.1 (4)	10.8 (8)

Other geological factors

Alluvium is only extensive along the Trent valley where it covers part of the Sneinton Formation outcrop. The seven houses on it had a mean radon level of 15.5 Bq/m^3, while the mean level of those houses on the same rock without any alluvial cover was 17.1 Bq/m^3; the difference is not significant. Garden soils were subjectively described as either clayey or sandy, with a consequent contrast in permeability, but the survey revealed no clear correlation with house radon levels.

Deep coal mining has taken place beneath most of the Gedling borough area. Ground strains developed within the subsidence profiles over longwall mines include an inner zone of compression and a peripheral zone of extension (Waltham, 1989); these are known to affect rock permeability in many situations, and so could influence radon migration. The Gedling survey therefore included subsidence data, as interpreted from the British Coal plans of mine workings. The results were not conclusive. Table 3 summarizes the data for the 35 houses monitored on undermined areas of outcrops of the two major rock units. The high mean value on the Mercian mudstone suggests that more radon may emerge not from a rock of increased permeability, but may be squeezed out of a rock of reduced porosity. In nearly all cases, the ground strain is residual, and not active, as mining beneath has ceased more than 5 years previously; monitoring of houses in areas of active subsidence may reveal more useful data.

Other geological influences could not be recognised from the limited data available. Faults may be radon sources or pathways, but too few were identified for sampling. Enhanced radon emission could occur from the margin of a permeable, valley floor, inlier, beneath an impermeable caprock. However this effect is likely to be very limited, as most radon will only travel a few metres in soil or unfissued rock. Survey data was inconclusive, and differences could have been masked by the lower radon levels in more windswept hilltop houses.

Conclusion

In conclusion, the Gedling survey demonstrates that some features within the bedrock geology have significant influence on the amounts of radon in houses, and can be responsible for undesirably enhanced levels in poorly ventilated rooms. Though no recorded radon levels are high enough to provide any significant health hazard, further monitoring on the fissured limestones may be appropriate.

Mining ground strain	Mean house radon concentrations (Bq/m^3)	
	Mercian mudstone (Radcliffe and Gunthorpe formations)	Sherwood Sandstone (Nottingham Castle formation)
Extension	14.7	13.5
Neutral	8.2	7.2
Compression	29.5	10.7

Table 3. Mean radon levels in houses on Mercian mudstones and Nottingham Castle Sandstone subjected to tensile or compressive ground strain induced by mining subsidence. Based on sample of 35 houses, evenly distributed across the six fields, and with no significant bias created by the states of house ventilation.

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AN EXTENSIVE MARINE VERTEBRATE FAUNA FROM THE KELLAWAYS SAND [CALLOVIAN, MIDDLE JURASSIC] OF LINCOLNSHIRE

by

David S. Brown and John A. Keen

Summary

Vertebrate bones and teeth, hitherto scarce in Kellaways Beds, have been recovered in relative abundance from temporary exposures of the Kellaways Sand east of Lincoln. The fauna includes eleven taxa of sharks including *Lissodus leiodus, Palaeospinax* and a hemiscylliid genus; nine taxa of bony fishes including *Heterolepidotus*; plesiosaurs referable to the families Elasmosauridae [*Muraenosaurus*], Cryptoclididae [*Cryptoclidus*] and Pliosauridae [*Liopleurodon*]; and the marine crocodiles *Metriorhynchus* and *Steneosaurus*. The mostly fragmentary material extends the British and World Callovian faunal list and indicates that some new species may be present. The reptile specimens and some of the fishes occur as associated disarticulated skeletons.

Introduction

The Kellaways beds extend from Dorset through the Midland counties to the Yorkshire coast virtually unseen, since they fail to form exposed topographical features, are of little or no industrial use and therefore not currently quarried. Fossil faunas are sparsely recorded, and only a small number of temporary exposures have yielded vertebrate material.

This paper records the finding and collecting [by John Keen] of a rich vertebrate fauna from temporary exposures in the Kellaways Sand of Lincolnshire. The specimens, except for one plesiosaur skeleton, have been gleaned from residual blocks of sandstone and piles of unconsolidated sand found on the surface after temporary exposures have been filled in. The extensive list of fish and reptilian taxa is compared with that of the Lower Oxford Clay.

The figured specimen (Fig. 2; Plate 1), together with associated remains, have been donated to Scunthorpe Museum (prefix: SCUNM).

Stratigraphy

The Kellaways Formation is a component of the Lower Callovian Substage [English Middle Jurassic], and in Southern England comprises Kellaways Clay and Kellaways Sand Members. In a recent review of English Lower Callovian stratigraphy, Page (1989 p. 368; figs. 4, 10) states that the Kellaways Clay facies progressively thins northwards and is partly replaced through lateral passage into the overlying Kellaways Sand. Thus in the Lincoln area the Formation comprises only the Kellaways Sand Member, perhaps 5 m thick, which rests upon the Cayton Clay Formation [Cornbrash] and is overlain by Lower Oxford Clay.

Typically, the Kellaways Sand consists of yellow or grey sands which may be uncemented or poorly cemented with calcareous sandstone bands, and represents two ammonite zones: *Proplanulites koenigi* and *Sigaloceras calloviense*. There are no natural exposures in the Lincoln area: it lies immediately beneath farmland in a narrow strip striking north-south some 5 or 6 km east of the Lincoln Edge escarpment. In consequence, it is seen only occasionally when it is disturbed by building work or the laying of drainage pipes.

Mercian Geologist, vol. 12, no. 2, 1991, pp. 87–96 and one plate.

Arkell (1933, p. 356) noted that a thickness of 25 feet (= 7.62 m) had been proved in the nineteenth century at Sudbrooke, 7 km north east of Lincoln. More recently (Richardson, 1979) a thickness of 6.43 m was proved by a borehole core from Worlaby, South Humberside (43 km north of Lincoln), at which location the Kellaways Sand is divisible into 3 beds: a thin basal bed consisting of a fine argillaceous calcareous sandstone containing grey limestone pebbles; a topmost bed, 0.53 m thick, of medium-grained firmly cemented calcareous sandstone with abundant pyritous patches; and between these a wide bed of fine light grey uncemented quartz sand with carbonaceous and clay patches.

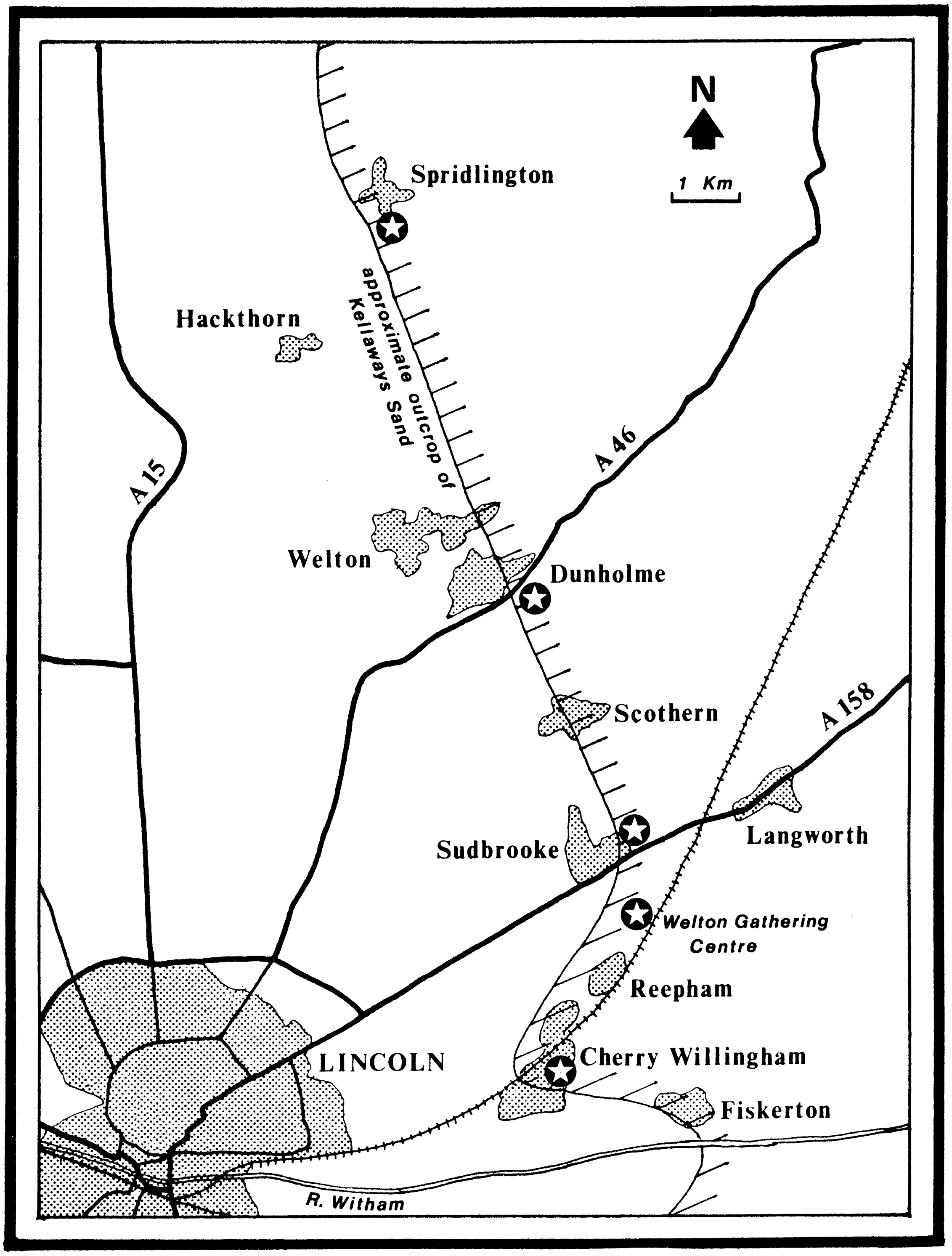

Fig. 1. Sketch-map of the area north-east of Lincoln, showing approximate outcrop of the Kellaways Sand beneath farmland. Stars indicate positions of temporary exposures.

Review of English Kellaways vertebrate fossil record

Finds of vertebrate remains in the Kellaways Beds have hitherto been scarce, and the only records of significance come from North Humberside and Peterborough.

In 1900, Sheppard found plesiosaur bones in a quarry in 'Kellaways Rock' (= Kellaways Sand: Page, 1989) on Mill Hill at Elloughton, near Brough [grid ref. SE 942278 given by Walker, 1972]. Detached bones were recovered and traced back to associated remains of a tail occurring in soft coarse-grained ferruginous sand easily worked by hand. The specimens, which include vertebrae, ribs, paddle-bones and the anterior half of a toothless mandible were referred to the genus *Cryptoclidus* by E.T. Newton of H.M. Geological Survey.

Sheppard (1903 p. 186) noted that just below the remains in Mill Hill Quarry the sand became much finer and whiter. It may be hypothesized, therefore, that if the lithology of the quarry and the Worlaby borehole are comparable then Sheppard's plesiosaur horizon corresponds to the base of the topmost bed seen at Worlaby.

Sheppard subsequently found plesiosaur remains in a 'Kellaways Rock' exposure in Drewton railway cutting, 5 km north of Mill Hill. These and the Mill Hill specimens were given to Hull Museum (Drake and Sheppard, 1909 p. 63), which was destroyed by enemy action during the Second World War.

Further plesiosaur bones, again referred to *Cryptoclidus*, were recorded by Stainforth and Sheppard [1931] from South Cave Station Quarry [to the West of Drewton], together with scales and bones of the halecostome fish *Lepidotes latifrons*. The horizon was not stated, and so may be from below the type section of the overlying Cave Rock Member exposed in this quarry (Page, 1989) and therefore Kellaways Sand.

Martill (1986), discussing the stratigraphic distribution of Callovian vertebrates, noted that macro-vertebrate remains occur frequently in Kellaways Sand of Cambridgeshire and Lincolnshire, usually as isolated worn bones encrusted with epibionts; this material is mostly sauropterygian but some ichthyosaur material is known. His information was based on undescribed fragmentary remains mostly taken from drainage ditches in the floors of brick-pits in the overlying Lower Oxford Clay.

Martill (1988) also drew attention to a sauroped dinosaur from this horizon. The specimen (B.M.N.H. R. 1985–8) consists of a pelvis, ribs and part of a dorsal vertebra which Seeley (1889) described under the name *Ornithopsis leedsi* Hulke, 1887. It was collected by Alfred N. Leeds from a well-shaft sunk at the Peterborough Gas Works: four further dorsal vertebrae described with the specimen by some authors probably are not associated (Leeds, 1956: p. 35). Seeley recorded that the shaft passed through 24 feet of grey clay recognised by Leeds as Oxford Clay and well known to him from nearby brick pits. Below this the shaft passed through 12 feet of sand, mostly light grey in colour, before again reaching a grey clay; and the dinosaur specimen came from 36 feet down, at the junction of the sand and lowermost clay bed. The grey sand can only have been the Kellaways Sand with, underlying it, either a silty clay band within the Kellaways Sand Member or the top of the underlying Cayton Clay Formation [see Page, 1989].

Discovery and extraction of specimens

The finding around Lincoln of detached Kellaways vertebrate fossils, and the search for their origin, began on 7th April 1985 with the discovery of a block of cemented ferruginous sandstone containing a plesiosaur mandible, tooth and phalanges on a tip of rock and other building site rubble in Lincoln. A close search produced further plesiosaur bones; a crocodile tooth; and fish bones, scales and teeth representing about 15 genera.

The sandstone matrix and the specific presence of the oyster *Gryphaea bilobata* amongst the invertebrate fossils indicated the Kellaways beds; and so, with the aid of a geological map, a systematic search for the building site was made along the narrow area of supposed Kellaways outcrop beneath farmland. Three weeks later this site was found 1 km north-east of Reepham (grid ref. TF 04597474), where British Petroleum had almost completed several small buildings and equipment installations comprising the company's Welton Gathering Centre. The foundation trench for a final building was seen cutting into the underlying Kellaways Beds, and upon entering this trench the associated bones of a plesiosaur specimen were discovered exposed on the outer side. This specimen was later collected and removed to Scunthorpe Museum in numerous blocks of the sandstone. It was established that some of the rock and overburden from the site had been dumped at the tip in Lincoln from which the mandible and other specimens had earlier been removed.

Top soil and drift to a depth of about 1 m had been cleared from the area prior to building, and the trench section then showed about 0.5 m of unconsolidated yellow sand beneath which was a band of cemented grey sandstone rock about 1 m thick, with an unconsolidated grey sand beneath. The associated plesiosaur bones occurred about the middle of the rock band.

Two poorly-preserved ammonites (SCUNM.P2908, P2894) taken from the rock with the plesiosaur skeleton have been identified tentatively by Mr. Simon Knell of Scunthorpe Museum as *Sigaloceras enodatum*; this indicates that the horizon is probably *S. calloviense* zone, *S. enodatum* subzone.

Further vertebrate specimens were recovered from elsewhere in the rock and also from the overlying and underlying sand. Several bones and teeth were recovered from rock fragments and sand around the periphery of the Gathering Centre site. Some Reepham rock dumped at Langworth yielded a few fish fragments.

Following the 1985 Reepham discoveries a close watch was kept along the approximate outcrop of the Kellaways Sand in the area. Pieces of the consolidated sandstone and adjacent piles of loose sand, seen after the filling-in of minor temporary exposures such as the laying of a drainage pipe, have yielded further fragmentary vertebrate remains at Cherry Willingham, Sudbrooke, beside the Dunholme by-pass and at Spridlington (see Fig. 1).

The plesiosaur bones were prepared from the matrix, in the Universities of London and Newcastle upon Tyne, using the standard acetic acid technique. This allowed the principal specimen (SCUNM.P2889) to be identified as *Cryptoclidus eurymerus* (Phillips), type-genus and species of the family Cryptoclididae. Somewhat to our surprise, it was discovered that the mandible does not belong with P.2889 and is identified as the elasmosaurid plesiosaur *Muraensaurus leedsii* Seeley (SCUNM. P2916).

Vertebrate material and preservation

1. *Cryptoclidus*

The *Cryptoclidus eurymerus* specimen P.2889 comprises one disarticulated skull bone tentatively identified as the left postorbital; several detached teeth; most of the neck including at least 26 of the 32 centra which should be present (Brown, 1981); less than half of the dorsal and sacral vertebrae; 8 out of a total of about 25 caudal vertebrae; an incomplete pectoral girdle; the left femur; and numerous ribs, gastralia and phalanges.

The bones are clearly the associated remains of a single individual, and some of the vertebrae were preserved in articulated rows of 3 or 4. Mostly, however, the skeleton was disarticulated: a block containing the semi-articulated anterior half of the neck also included the postorbital; some teeth; some dorsal vertebrae; and 4 anterior caudal vertebrae which were again semi-articulated. This would indicate that the carcass had undergone extensive post-mortem decay and mutilation by scavengers before burial. Some ribs were solid and easily prepared from the matrix for most of their length, but were crumbling and incomplete at one end, suggesting that this end had undergone weathering on the sea floor following decomposition of the soft tissue.

The vertebral neural arches are free from the centra indicating that the specimen is a 'juvenile' (Brown, 1981: p. 255).

Characters diagnostic of *Cryptoclidus* are found in the vertebrae, the clavicle and especially the teeth. *Cryptoclidus* has a unique tooth ornament, with long mesial and distal axial ridges extending the full length of the tooth; only 3 to 5 lingual ridges and no buccal ridges (Fig. 2).

2. *Muraenosaurus*

The mandible of *Muraenosaurus leedsii* (P. 2916: Plate 1) consists of the dentary: small fragments of a splenial may be fused to its medial aspects, but the remaining elements have separated post-mortem and were not found. There are sockets for 19 teeth on each ramus, and some contain the crowns of immature (replacement) teeth. Brown (1981) gave 19 to 22 dentary teeth as the normal range in this species.

Preserved in the same block with the mandible was a large mature tooth (Fig. 2), with a ridge ornament typical of elasmosaurs and thereby differing considerably from that of *Cryptoclidus*.

Finally the block contained 4 metacarpals which were of the correct size order to have been from the same specimen; phalanges, however, are not diagnostic even at family level, and this occurrence with the mandible is open to alternative interpretation.

Isolated vertebrae referable to *M. leedsii* were collected from the same tip site; they may once have belonged with this specimen.

3. **Other reptiles**

Two crocodiles and a pliosaur are represented by detached teeth recovered from the Welton Gathering Centre and Dunholme sites. A few additional crocodile and plesiosaur vertebrae of indeterminate affinity are present in the collection.

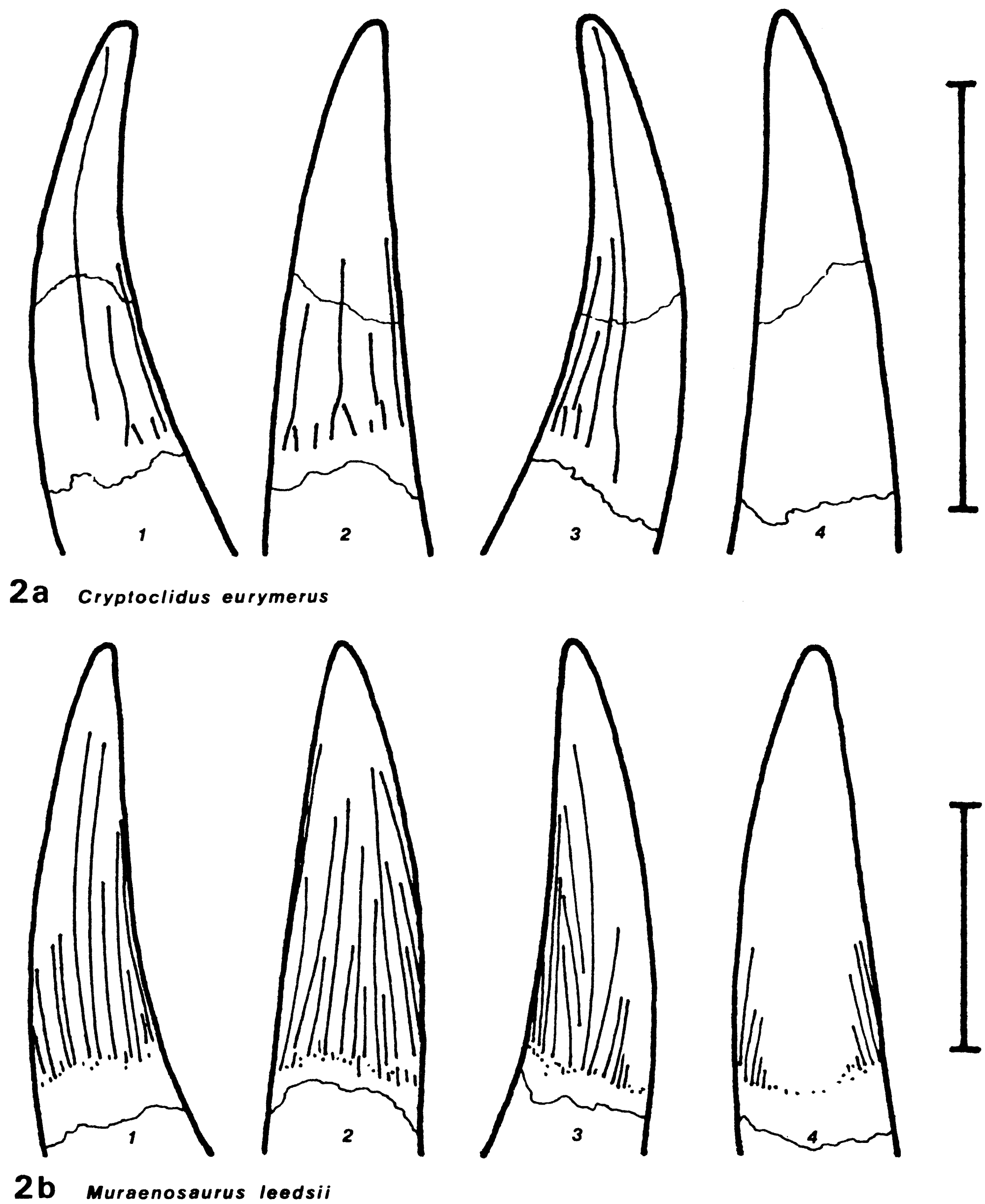

Fig. 2. Detached teeth [a] of *Cryptoclidus eurymerus* [SCUNM.P2889] and [b] of *Muraenosaurus leedsii* [SCUNM.P2916], showing pattern of ornamental ridges: 1 and 3: axial [mesial/distal]; 2: lingual, and 4: buccal aspects. Scale-line = 1 cm.

4. **Fishes**

Some of the fish remains are preserved as associated disarticulated specimens. A block of sandstone from Welton Gathering Centre, Reepham (found on the tip in Lincoln), contains associated skull bones, vertebrae and fin elements of the halecomorph fish *Osteorachis*. The *Heterolepidotus* material [a jaw and scales] is associated; and similarly a teleost genus, *Aspidorhynchus*, is represented by associated teeth, a jaw, scales and bones from both Reepham and the Dunholme site.

Typically, however, the fish fauna is represented by dissociated teeth and fin spines (Chondrichthyes) or by teeth, bones or isolated scales (Osteichthyes). Amongst the shark material the hybodontid species *Lissodus leiodus* and an unidentified hemiscyllid genus are rare taxa, each represented by a tooth; and an orectolobid taxon, again represented by a tooth, may be a new species (Miss A.L. Longbottom, pers. comm.). Two bones have been identified provisionally as gillrakers of the world's largest-ever fish *Leedsichthys*, although the resemblance is not exact (Dr. C. Patterson, pers. comm.).

Vertebrate faunal list

CHONDRICHTHYES	
Elasmobranchii	
Hybodontiformes	
Hybodontidae	
Acrodus sp.	Teeth
Hybodus sp.	Tooth, finspine
? *Asteracanthus* [=*Strophodus*] sp.	Tooth, finspine
Lissodus leiodus	Tooth, finspine
Neoselachii	
Incertae sedis	
Palaeospinax sp.	Tooth
Sphenodus sp.	Tooth, jaw
Squalomorphii	
Hexanchidae	
Gen. indet.	Tooth
Galeomorphii	
Orectolobidae	
Gen. indet. [= ? Gen. nov.]	Tooth
Hemiscylliidae	
Gen. indet.	Tooth
Holocephali	
Chimaeroidei	
Incertae familiae	
Ganodus [=*Leptacanthus*] *semistriatus*	Finspine
Edaphodontidae	
Ischyodus egertoni	Tooth

OSTEICHTHYES	
Actinopterygii	
Halecostomi	
Incertae sedis	
Semionotidae	
Lepidotes sp.	Scales, tooth
Dapediidae	
Heterostrophus sp.	Skull bones
Halecomorphi	
Caturidae	
Caturus [=*Strobilodus*]	Jaw
Osteorachis sp.	Associated bones
Heterolepidotus sp.	Associated scales, jaw
Teleostei	
Pachycormidae	
Gen. indet.	Tooth
Leedsichthys sp.	? Gillrakers
Aspidorhynchidae	
Aspidorhynchus sp.	Associated scales, bones, jaw
Leptolepidae	
Gen. indet.	Dentary
REPTILIA	
Archosauria	
Crocodylia	
Teleosauridae	
Steneosaurus sp.	Tooth
Metriorhynchidae	
Metriorhynchus sp.	Tooth
Sauropterygia	
Plesiosauria	
Elasmosauridae	
Muraenosaurus leedsii	Jaw, teeth, bones
Cryptoclidae	
Cryptoclidus eurymerus	Associated skeleton
Pliosauridae	
Liopleurodon ferox	Tooth

Classification of Elasmobranchii after Thies and Reif, 1985; holocephalans after Ward and Duffin, 1989; osteichthyans based upon Schaeffer and Patterson 1984; crocodiles after Steel 1973; plesiosaurs after Brown 1981.

Discussion

The vertebrate fossil material described above has been recovered from a few relatively small temporary exposures. Nevertheless, the faunal list, especially for the fishes, is extensive and diverse.

Comparable assemblage

The closest comparable vertebrate assemblage, with regard to horizon and geography, is that of the Lower Oxford Clay of the Peterborough area, 80 km to the south of Lincoln and immediately overlying the Kellaways Sand. Here the clay has been quarried extensively for brick manufacture since at least the mid-nineteenth century; and its vertebrate fauna is one of the best-known Mesozoic marine assemblages in Europe as a result of extensive research on specimens in the Leeds Collection.

By the beginning of the twentieth century Alfred N. Leeds had amassed from the brick pits the largest private collection of vertebrate fossils in Britain. Most of this collection is now in The Natural History Museum, London, where the reptiles were catalogued by Charles Andrews (1910–1913).

Current faunal list

In 1910 (p. viii), Andrews published a faunal list for the Leeds Collection, which was reproduced without change by Woodward in Arkell (1933: p. 358). This list was updated and incorporated into a compilation of data on the world distribution of Jurassic fishes by Schaeffer and Patterson (1984: Table 3, marine fishes; Table 4, non-marine fishes); their Tables permit the extraction of lists of recorded fish genera from the Callovian of Britain and the rest of the world. An up-to-date faunal list for the British Oxford Clay (Upper Callovian—Upper Oxfordian) has been given very recently by Martill and Hudson (1991). There are no previously published vertebrate faunal lists for the Kellaways Formation.

Elasmobranchii

Our list of elasmobranch sharks, with 9 genera (including indeterminate genera), compares with only 2 (*Asteracanthus, Hybodus*) on Andrew's list from the Leeds Collection. Martill and Hudson show 10 genera from the Oxford Clay, and their list does not include *Acrodus, Palaeospinax, Lissodus* or any hemiscylliid genera.

The genus *Acrodus* is shown by Schaeffer and Patterson from the British Sinemurian, Bajocian and Bathonian, with worldwide no previous Callovian records. Our record thus extends the British Jurassic range. *Acrodus* is known, however, from as high as the Lower Campanian, Upper Cretaceous [Capetta, 1987].

Similarly, the British Jurassic range of the genus *Palaeospinax* is extended upwards from the Sinemurian. Teeth of *P. riefgrafi* were described from the Oxfordian of Germany by Thies (1983): this constitutes the only reliable previous record of the genus outside the Lias, a report from the Upper Cretaceous of Canada having been rejected by Cappetta [1987] as impossible to establish.

The genus *Lissodus* was reviewed by Duffin (1985), who determined that the range of attributable species extends from the Lower Carboniferous to the Upper Cretaceous. *L. leiodus* is known only from 21 teeth from the English Bathonian and a further 5 from the ?Bajocian of Brora, N. Scotland. Our record thus constitutes the first Callovian record of this rare species and extends its range.

Lissodus is listed by Schaeffer and Patterson only as a non-marine genus; Duffin, however, concluded that it was primarily marine, but with some Triassic and Cretaceous species secondarily invading freshwater. *L. leiodus* he regards as a marine species, pointing out that most of the British Great Oolite (though lacking ammonites) is demonstrably marine and comprises carbonate bank deposits containing abundant echinoid and other marine invertebrates. Thus the finding of this species for the first time in an ammonite-bearing deposit does not appear to pose any palaeoecological questions. The possibility that the teeth have been reworked cannot be discounted.

The range of the galeomorph family Hemiscylliidae is given by Cappetta (1987) as Cenomanian [Upper Cretaceous] to Recent, and so our record of an unidentified hemiscylliid genus from the Callovian would appear to extend the family range. However, we are informed by Dr. C. J. Duffin [personal communication] that teeth from the Toarcian of Germany described and figured by Thies (1983: p. 28; Pl. 6 fig. 4; Pl. 7 figs 1–8) as *Heterodontus duffini* n.sp. are also hemiscylliid. Ours is thus the first Callovian and first British Jurassic record of the family.

Holocephali

Andrews listed 3 genera of chimaeroid holocephalans from the Leeds Collection [*Ischyodus, Pachymylus* and *Brachymylus*], of which we have found only *Ischyodus*. The genus *Leptacanthus* was reported from Bajocian, Bathonian, Kimmeridgian and Portlandian Stages by Schaeffer and Patterson [1984] and is listed from the Oxford Clay [without qualification of horizon] by Martill and Hudson [1991].

Osteichthyes

Of interest amongst the osteichthyan fishes on our list is the halecomorph *Heterolepidotus*. This record fills a gap in the known range of the genus, being the first material to be reported from the World Callovian. Schaeffer and Patterson (1984) gave the British range as Hettangian to Sinemurian, with additional records only from the Toarcian and Kimmeridgian of Northern Europe.

Comparison with Leeds Collection fauna

Comparing the fish faunas of the Leeds Collection [Lower Oxford Clay] and our study of Kellaways Sand in Lincolnshire, the diversity is broadly similar: Andrews listed a total of 14 genera and 19 species; we list 20 genera with 5 being indeterminate. There are, however, apparent differences in the balance of major groups: our fauna is dominated by elasmobranch sharks, whereas the Leeds Collection is dominated by the 'ganoid' halecostome fishes. These differences may in part be taphonomic, and they also reflect fossil size and collector enthusiasm: Leeds largely overlooked the very small neoselachian teeth; they are nevertheless present in the Oxford Clay, as shown by Thies [1983] in his micropalaeontological study.

The reptilian material is less easy to compare and assess, since most isolated bones such as vertebral components, phalanges, and ribs, are non-diagnostic or determinable only at ordinal or even subclass level. In general, a substantially associated skeleton or skull is required to distinguish genera and species. One also needs a large net to catch large animals; and so their diversity within the fossil assemblage is likely to be understated, in comparison with the smaller and more readily distinguishable fishes, when relying on erratic small-scale sampling.

The positive identification of 5 genera, representative of 5 families [all of which occur in the Leeds Collection: Andrews, 1910], is based on teeth; a single *Muraenosaurus* mandible; and the associated *Cryptoclidus* skeleton which, significantly, was the only specimen recovered *in situ*. The Leeds Collection contains a large number of such skeletons, and Andrews' list of 19 genera reflects the large-scale sampling which was available to the collector. The clay quarries were worked by hand, and the quarrymen summoned Leeds and worked elsewhere so as to enable him to collect skeletons when they were found [Leeds, 1956].

The Lower Oxford Clay is about 12 m thick in the Peterborough area, vertebrate fossils being more abundant in the basal 1 m thick section comprising the zone of *Kosmoceras jason* (Martill, 1986). Even this zone cannot be described as vertebrate fossil-rich, and has only yielded so much material because of large-scale quarrying extended over a long period of time. In contrast, it would appear from the comparable fauna list and small scale of sampling that the fossiliferous upper part of the Kellaways Sand [2 m seen at Reepham to be vertebrate-bearing] is very much richer in vertebrate fossils.

Comments

This is not a chance finding of an isolated rich lens, since the distribution of sites of recovery of specimens covers a distance of 12 km along the outcrop (Fig. 1), indicating that the Kellaways Sand is rich in vertebrates over this area.

The importance of the discovery which we describe lies not so much in the scientific value of any individual fragmentary specimen but more in the implication that the bed in question is exceptionally rich, laterally extensive, palaeontologically very promising and, in theory, would be easily accessible for future systematic exploration as it lies only a few metres below farmland.

Acknowledgements

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British Petroleum generously provided financial assistance towards materials to prepare the *Cryptoclidus* skeleton; most of the work was undertaken in the Geology Department of Queen Mary College, University of London, by Phillip Jones, Christopher Mole and Archie McLaughlan. Dennis Parsons and David Elford assisted with the collection of the specimen.

Reptilian material was seen by Dr. Angela Milner, and fish remains were identified by Dr. Colin Patterson and Miss Alison Longbottom of The Natural History Museum, London.

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Plate 1. Dentary [dorsal aspect] and detached tooth of *Muraenosaurus leedsii*, from the Kellaways Sand of Welton Gathering Centre, Reepham, Lincolnshire.

A CONTINTENTAL HOT-SPOT

by

Dr I. D. Sutton

Presidential Address delivered 1988

Summary

The Snake River Plains and Yellowstone Park provide us with one of the classical sites of recent volcanic activity. The history of the volcanic activity in both areas is describe together with the relationship of the activity with Plate Tectonics and mantle plume theories. Details of the caldera formation in Yellowstone Park are described, as are the world famous geothermal features. Much discussion revolves around the topics of possible further volcanic eruptions in Yellowstone Park. Geophysical evidence helps us to make some evaluation of the prospects of future activity in the area.

Introduction and Location

Fifty million years ago, a mantle plume with its surface expression, a hot-spot, was present in the Pacific Ocean off the Oregon coast of North America. During the period from then to the present, the American Continent has moved steadily west-south-westwards at an estimated speed of about 4 cm per annum and, in the process, has overridden marginal parts of the Pacific Ocean including the hot-spot. During the Pliocene, Pleistocene, and Holocene, this movement has resulted in the hot-spot being centred at progressively more easterly positions on the continent of North America, initially through southern Idaho and then to its present position in Yellowstone Park in Wyoming. The result of the movement has been a trail of volcanic activity left across this area of the U.S.A. indicating the progression of the lithosphere over the hot-spot. This resulted in the vast outpourings of lavas which produced the Snake River Plateau in southern Idaho and the quite remarkable volcanic events which have occurred in Yellowstone and its environs during the last two million years or so.

The Snake River Plateau and Yellowstone are located geologically in the young fold mountain belt of the Cordillera which extends along the western sea board of both North and South America. In the immediate neighbourhood of the Snake River Plateau and Yellowstone are the Basin and Range fault blocks and grabens occurring to the south, the Green River sedimentary basin to the southeast, the Middle Rockies to the east and the Columbia Plateau to the northwest.

The presentation of this address is possible as a result of 5 visits to this area during the last 10 years together with the extensive use of the vast amount of published literature. Many of the thoughts about the area have been developed by colleagues and students who have visited the area with me.

The Snake River Plateau

Introduction

Together with the Columbia Plateau, the Snake River Plateau forms one of the largest areas of continental basaltic lava outpourings anywhere in the world. Only the Deccan Plateau of India is larger.

The Columbia Plateau is considerably larger than the Snake River Plateau and has a history dating back to the Miocene period about 25 million years ago. In both the Snake River and Columbia Plateaus, the original

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relief was considerable and the initial volcanic activity, largely acidic and intermediate, produced accumulations of volcanic material which filled depressions, levelling the topography and eventually forming a fairly monotonous flat plateau area.

History of the Development of the Snake River Plateau

The Snake River Plateau itself is really a smaller version of the Columbia River Plateau. It is a high plateau built up of lava flow upon lava flow, all having been erupted fairly recently during Pliocene and Pleistocene periods with some flows, such as those in the neighbourhood of the Craters of the Moon National Monument, being no more than 2,000 years in age (Fig. 1) (Parsons 1978).

In the early stages of the volcanic history of the Snake River Plateau, much silicic volcanism took place, but quickly basic basaltic activity became dominant and a huge proportion of the plateau is composed of basaltic flows. The volcanic activity in many places appears to be related to rifts or fissures, but, nevertheless, much of the basaltic outpourings have been from central type conduits rather than fissures, and the flat plateau nature of the area is a result of many very low-angled shield volcanoes overlapping with their neighbours. The monotonous terrain is interrupted in places by small volcanic cones. In the Craters of the Moon National Monument (Crawford, 1978) a series of small but distinctive spatter and cinder cones occur along the great rift zone. To the northeast of Idaho Falls, on the southern margin of the Snake River Plateau, the Menan Buttes consists of a series of cones formed when basaltic lava rose to the surface through water-saturated gravels of the Snake River flood plain. The basic magma reacted violently with the water in the gravels to produce an explosive series of eruptions and small cones were formed of a mixture of solidified fragmented lava and river gravels, many of the gravels having been shattered by the explosiveness of the eruption (Alt and Hyndman 1972).

General Features of the Snake River Plateau

The Snake River Plateau (Fig. 1) stretches for about 300 miles from west to east and up to 60 miles from north to south. To the north, the plateau lavas reach thicknesses of 10,000 feet, burying completely the old pre-volcanic landscape (Parsons, 1978). The plateau, which to the eye appears virtually flat, does in fact slope gently from north to south. This slope has had a marked effect on the hydrology. The Snake River which is, of course, the main river, flows across the southern edge of the plateau receiving many tributaries from the highlands to the south of the plateau. The plateau itself has very little surface drainage, the basalts being highly porous with a multitude of vesicles, good vertical columnar joints and abundant lava tubes. Rivers flowing from the higher ground to the north on to the plateau have soon found their way beneath the surface on reaching the basalt.

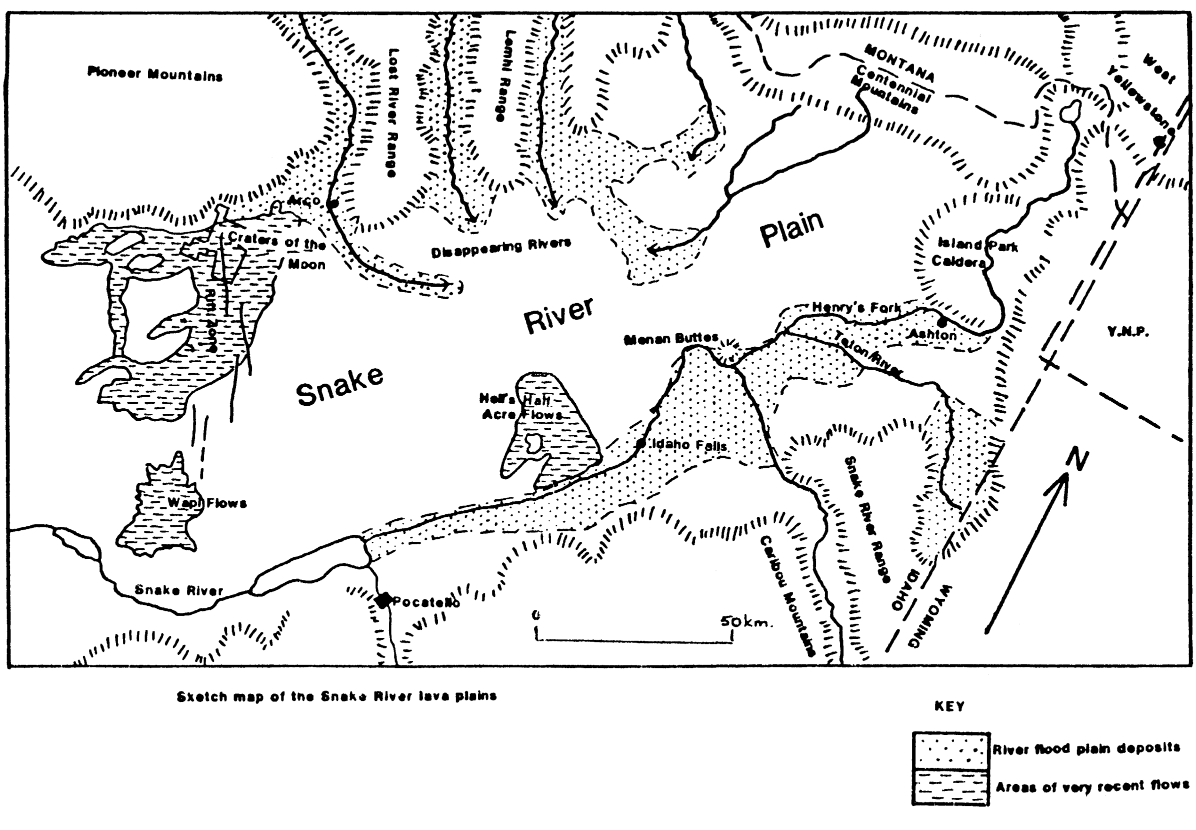

Fig. 1. The physical setting of the Snake River Plain with areas of very recent volcanic activity indicated (after Parsons, 1978).

The lavas of the plateau show typical features of low viscosity basalts. Despite their age, of around 2,000 years, the basalts of the Craters of the Moon are remarkably well preserved, having suffered little weathering in the rather dry climatic conditions. Pahoehoe and aa flows are beautifully displayed as are such features as lava tubes and pressure ridges.

Yellowstone and Island Park

Introduction

In many ways, Yellowstone should be considered as an eastward extension of the Snake River Plateau, but it has so many unique characteristics that it has to be considered separately.

As has already been explained, the Snake River Plateau is considered to have been formed as the American Plate moved southwestwards over a mantle plume and, as it did so, the volcanic activity associated with it moved relatively to the east (Smith and Braile, 1982). Yellowstone is at the northeast end of the Snake River Plain and it is likely that the Yellowstone area is over the hot-spot which produced the basaltic plain to the west at an earlier date.

History of the Exploration of Yellowstone

Although there appears to have been a long history of Indians living in Yellowstone, the first white man to visit the area was possibly a John Colter, originally a guide, who on leaving an expedition, in 1806, crossed into and explored the Yellowstone area. He returned home with stories of "fire and brimstone" which were dismissed by his acquaintances as being too far-fetched to be credible (Tuttle, 1982). Much later in 1857, another explorer renowned for his way-out tales came back with what were at their best considered good but preposterous stories about the fantastic sights he had witnessed in Yellowstone. It did, however, stimulate the geologist, Hayden, to attempt an expedition to the area in 1859. This was thwarted by heavy snowfall, but in 1870 and 1871, he was able to lead successful visits into the area and was also able to convince the Congress of the day that the area should be set aside as a national park. President Grant signed the bill authorising the establishment of this, the first and nearly the largest of America's national parks in 1872 (Kirk, 1972).

Geographical Setting of Yellowstone National Park

The National Park (Fig. 2) is mainly in the state of Wyoming but it extends to just over the borders into the neighbouring states of Idaho and Montana to the west and north respectively. The Park is about 60 miles in length from north to south, and almost as wide from east to west.

Yellowstone in many ways is surprisingly flat. It forms a plateau area of about 8,000 feet with its highest points being a little over 10,000 feet. Near the south centre of the Park is Yellowstone Lake at an elevation of 7733 feet; it is the largest fresh water lake in the United States outside the Great Lakes area (Tuttle, 1982).

The Yellowstone River rises in the south of the Park and flows northwards right across it, draining into and out of Yellowstone Lake in the process, and forming the unforgettable Grand Canyon of Yellowstone further north. The river flows on northwards to join the Missouri in Montana and, eventually, via the Gulf of Mexico, into the Atlantic Ocean. To the northwest side of the Park, the Madison River also takes a northerly path to reach the Missouri, but the southwestern part of the Park is drained by the Snake River and its tributaries to flow out of the Park to the southwest and eventually westwards to the Pacific Ocean. Yellowstone is thus situated on the 'Great Divide' between drainage to the Atlantic and to the Pacific. Surrounding Yellowstone are the mountain ranges of the Middle Rockies with heights of 10,000 to 14,000 feet. To the northwest are the Madison and Gallatin Ranges separated from each other by the Valley of the Gallatin River. Further round to the north are the Beartooth Mountains. All of these ranges have cores of Pre-Cambrian granites and gneisses, in places flanked by younger Palaeozoic and even Mesozoic rocks. On the eastern side of Yellowstone, the Absaroka Range is formed almost entirely from andesitic pyroclastic volcanic rocks which formed the extensive Absaroka volcanic field in the early Cenozoic. To the south, the famous Teton Range, again typical of the Middle Rockies, is largely constructed of granites and gneisses of Pre-Cambrian age to form a splendid background to Yellowstone when looking southwards.

Within Yellowstone Park, nearly all the rocks are associated with volcanic outbursts during the last 2.5 million years. In this period, there appear to have been three main volcanic episodes with a gradual migration of activity in a northeastwards direction across the Park (Tuttle, 1982).

Recent Volcanic Activity in Yellowstone

A great part of the central area of Yellowstone National Park is a large caldera. Just over 2 million years ago, the recent volcanic history of the area started with a tremendously explosive acidic eruption of over 600 cubic miles of rhyolitic material. To put this eruption into perspective, it was more than 5,000 times greater in the volume of volcanic material erupted than the 1980 Mount St Helens eruption (Smith and Braile, 1982). After the eruption, collapse produced a large caldera, the Island Park caldera, the remains of which can be seen today on the edge of and outside the western boundary of the Park. This early eruption and the caldera which it produced, represents the first of three volcanic cycles of the Yellowstone Plateau area.

The second eruptive cycle about 1,600,000 years ago, produced a caldera between the Island Park caldera and the present Yellowstone caldera, but most of the features of this eruption have been buried by later volcanic activity. This second cycle erupted an estimated 67 cubic miles of acid volcanics, much smaller than the Island Park eruption but, nevertheless enormous when compared with any eruption during historical times.

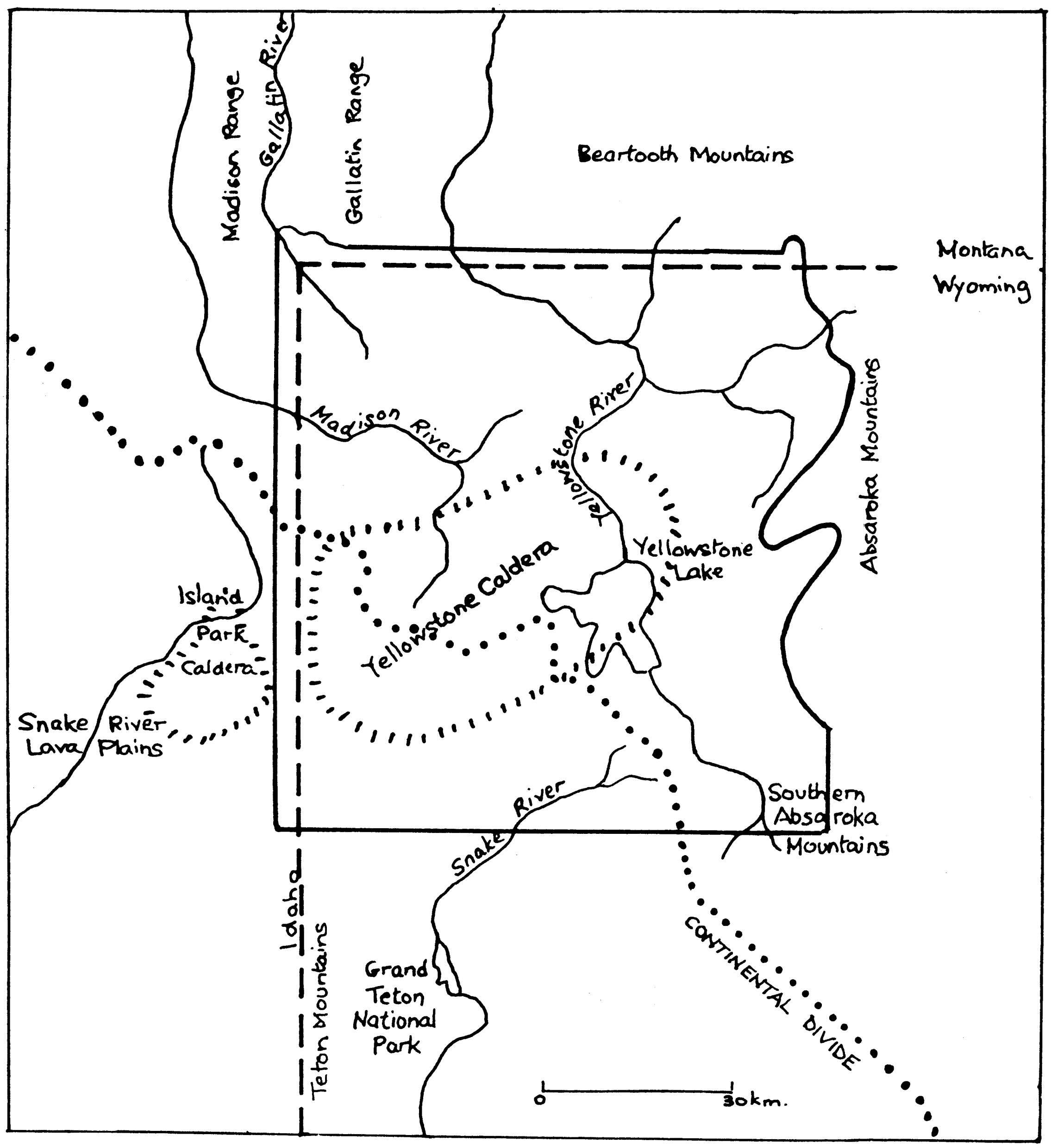

Fig. 2. Map to show the physical features of the Yellowstone area and the approximate positions of the Island Park and Yellowstone calderas (after Tuttle, 1982).

The third eruptive cycle forms most of the present Yellowstone Plateau and created the huge caldera centrally placed in Yellowstone Park (Crandall, 1977). The main eruptive phase of this cycle started about 600,000 years ago and this eruption ejected about 240 cubic miles of material. The story started with the rise of a magma chamber to a high level in the crust underneath Yellowstone (Fig. 3). This would have resulted in the arching, stretching and eventual cracking in great ring fractures of the overlying crust. The fractures produced would have provided avenues for the upward movement of the magma to the surface, and its subsequent eruption. The eruptions were undoubtedly highly acidic and explosive, with pumice, ash and rock fragments being violently ejected, accompanied by vast quantities of hot expanding gases, which swept the erupted dense debris across the countryside in the form of ash flows. The ash flows would have first filled depressions in the landscape such as river valleys but, eventually, the whole area must have completely been buried beneath the thick pile of compacted and welded ash flow deposits. This particular ash flow has become known as the Yellowstone Tuff. During the eruption, much fine ash was also carried high into the atmosphere and dispersed over a large area of north America, very much like the 1980 Mount St Helens eruption but on a far larger scale.

The Caldera Formation

When the eruption was complete, the vast quantity of material removed from the magma chamber left a huge void beneath the surface. The overlying rocks were exceedingly unstable. A large number of fractures, mostly normal faults, developed as large blocks of the chamber roof began to collapse into the magma chamber (Fig. 3). The collapse must have been considerable, but it is not certain to exactly what depth it took place, although it is considered that it must have been certainly on the scale of several thousand feet.

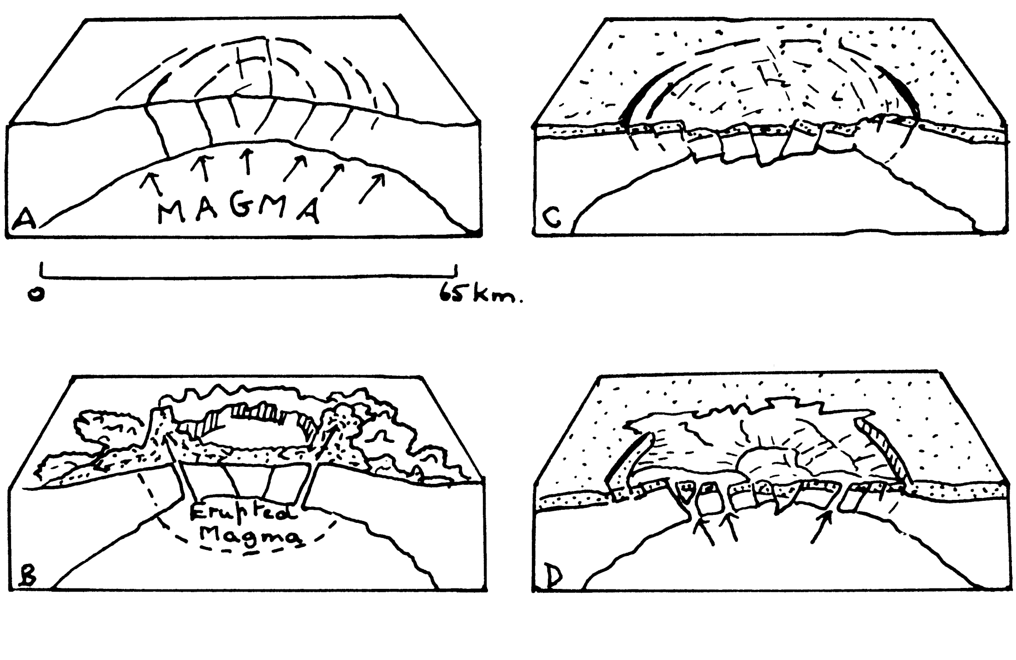

Fig. 3. Block diagrams to show the evolution of the Yellowstone caldera commencing about 600,000 years ago (after Keefer, 1971).

(*a*) Magma rising below Yellowstone arching the country rocks and producing a series of concentric fractures which extend downwards towards the magma chamber.

(*b*) Ring fractures tap the magma chamber. Gases dissolved and the magma escape. Violent explosive eruptions eject vast volumes of pumice and ash flows from the fractures. Air suspended ash distributed over huge geographical area.

(*c*) Void produced by the immense eruptions in (*b*) allow the roofing rocks to collapse along the ring fractures to produce a huge caldera.

(*d*) The caldera is gradually filled up by rhyolitic lava flows erupted from the ring fractures. These eruptions are relatively placid, the magma having been depleted in gases.

Renewed Volcanic Activity

Following the caldera formation, volcanic activity did not stop. Magma rose again in the form of twin magma chambers which arched and cracked the overlying crust. From these two magma chambers, which are situated over the present Upper Geyser Basin near Old Faithful and to the east of the Hayden Valley, lava in the form of acidic rhyolite erupted along the fractures produced by the arching. The eruptions started soon after the formation of the Yellowstone Caldera, and continued intermittently until the last eruptions about 65,000 years ago. The rhyolite lavas flowed out over the caldera floor and gradually filled the depression so that the caldera today has very little relief, and certainly it is not the spectacle it must have been immediately after formation. The rhyolite lavas were very viscous and a flow brecciated texture, produced by the breaking up of the tops of the lava flows due to the continual movement of the still liquid but highly viscous lava beneath, is a common feature. The viscosity of the lavas also played a part in producing the glassy form of the lava known as obsidian which is beautifully displayed today at Obsidian Cliff in the Park.

During the time rhyolite lavas were being erupted, a small caldera-making event took place between 100,000 and 200,000 years ago. As a result of an explosive ash flow eruption, followed by caldera collapse, a depression of 6 miles by 4 miles, now filled by the waters of the West Thumb of Yellowstone Lake, was formed.

No volcanic eruptions have occurred in Yellowstone for about 65,000 years. It is suggested (Keefer, 1971) that possibly the last eruptions have taken place in this area and that the magma chamber beneath Yellowstone is cooling. There is still, however, a high geothermal gradient, quite sufficient to provide the present day highlights of the varied geothermal features.

Geothermal Activity in Yellowstone

One of the undoubted main reasons for Yellowstone being designated a national park is the incredible range of geothermal features in the form of geysers, hot springs, mud pools and fumaroles (Marler, 1978). Within Yellowstone, there are a few thousand geothermal features, the greatest concentrations anywhere in the world. They occur in many different regions of the Park area, but most are concentrated in a few areas known as geyser basins. The geyser basins are closely associated with the areas where fracturing occurred during caldera formation, the fractures providing passageways for the rise of heat towards the surface.

Hot Springs and Geysers

Hot Springs are recognised as any spring where the water is above human body temperature. There are a few thousand of these in Yellowstone. Geysers are described as intermittent hot springs which periodically erupt fountains of hot water and steam (Plate 2). In some cases, such as Old Faithful (Plate 6) the eruptions are very regularly spaced whereas other geysers are much more unreliable time-wise (Fischer, 1960).

Research work has shown that although no two geysers are alike although the reasons for their behaviours are similar (Fig. 4). Beneath a geyser is a plumbing system which consists of a main conduit which is normally nearly vertical and a number of side channels which often tap very porous rock. This network of channels lies fairly close to the surface, usually to depths of only a few hundred feet, but the main conduit connects downward to sources of hot water at depth (Keefer, 1971).

With this information, we can now appreciate the likely sequence of events which take place in the eruptive cycle of a geyser:

(*a*) After an eruption, the main conduit and side channels are practically emptied of water (Plate 3). Water is then replenished by flow from the side channels in the highly porous water-bearing rocks, and hotter water, often superheated, rises from the heat source at depth. The superheated water begins to turn to steam as pressure reduces during the water ascent, but at this stage, the gas bubbles often condense due to lowering of temperature by the inflow of cooler water from the side channels. Gradually, the water temperature increases and a stage is reached when no longer will the gas bubbles continue to condense.

(*b*) Almost certainly the geyser conduit will vary in width, in places being quite wide and in other places being rather constricted. The gas bubbles will grow in size and often become trapped in one of the constricted parts of the conduit. The expanding gas in these trapped areas will soon force its way up to the surface and cause a number of preliminary spurts of water (Plate 4).

(*c*) One of the preliminary spurts will eventually discharge enough water for the pressure in the whole system to be reduced sufficiently for all the water to flash to steam. This is the main eruptive phase, often with spectacular spurts of steam and water.

(*d*) In different geysers, the actual main eruption phase is quite variable although in most cases, it lasts for no longer than a few minutes. When the eruption ceases, the conduit and side channels will be nearly empty and the whole process of recharging the system has to recommence before the next eruption takes place. In the case of Old Faithful, the eruption interval is about one hour, many geysers have shorter periods of quiescence and some much longer, ranging from a number of hours to a day, weeks or even months.

The Upper Geyser Basin, which includes Old Faithful amongst its number as the most famous, has the greatest concentration of geysers anywhere in the world. Nearly all the water which supplies the geysers and hot springs originates as rain or snow at the surface, and then percolates downwards (Chronic, 1984). The cold surface waters descend to depths of several thousand feet using the fractures produced during caldera formation. The water is heated rapidly as it descends due to the high geothermal gradient which in drill holes has been shown to produce temperatures of about 250 °C at 1,000 feet depth. Some of this water goes directly into the plumbing systems of the geysers but much of it finds its way to great depths where it is heated to temperatures in excess of 400 °C. At depths of several thousand feet, it is unable to boil because of the hydrostatic pressure but it begins to expand and rise. At these elevated temperatures, the hot water will dissolve some silica from the surrounding country rocks. This water enriched in silica rises towards the surface and eventually, through geysers or hot-springs, it reaches the surface. As the temperature of the water drops, the silica is precipitated out both above and below the ground, lining the passageways of the hot-springs and geysers, or forming mounds which are often very irregular in shape at the surface. This material which is deposited is known as siliceous sinter (Plate 1). Throughout Yellowstone the deposits around hot-springs and geysers are invariably of siliceous sinter, except in the north of the Park at Mammoth Terraces. Here the water has passed downwards through limestone, and when the water has reached the surface again as hot-springs, they are charged with calcium carbonate and this is deposited on the flanks of the hill side at Mammoth Terraces as exquisite calcite formations (Plate 5).

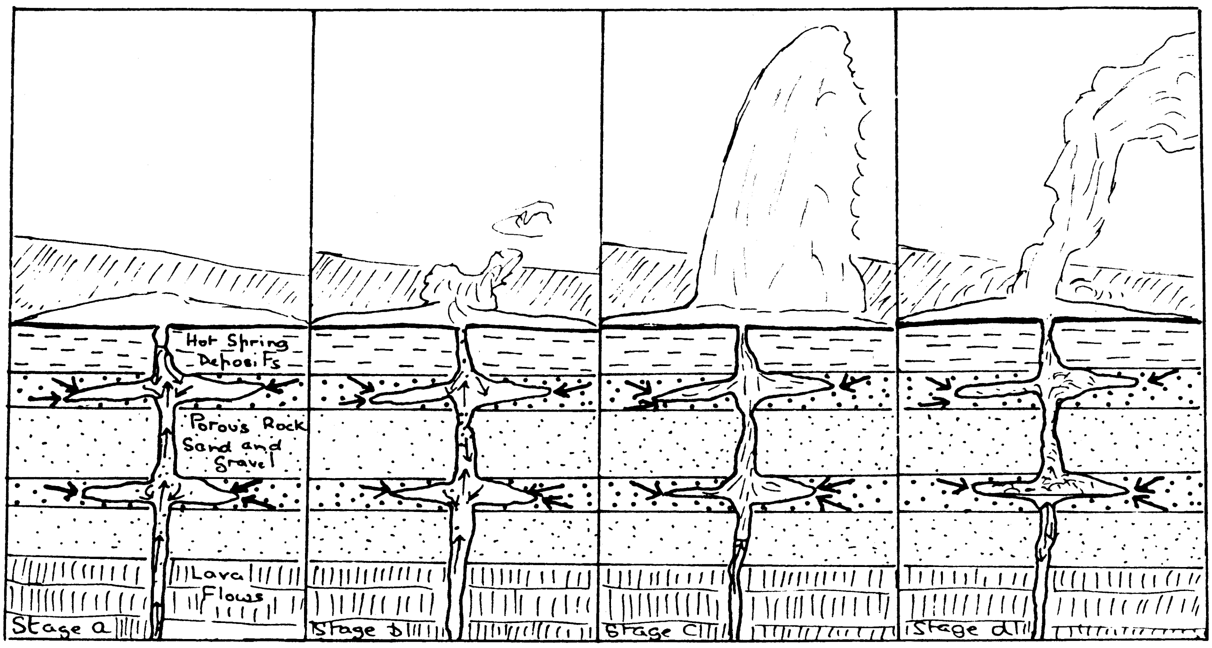

Fig. 4. Section through Old Faithful to illustrate what probably happens during a geyser eruption (after Keefer, 1971).

Stage A

This is the recovery or recharge stage when, after an eruption, the emptied conduits of the geyser fill up again with water. Hot water rises from depth and cold water infiltrates from the porous sands and gravels at higher levels. At depth, some of the water is converted to steam bubbles which on rising towards the surface, condense. As the temperature in the system increases, the steam bubbles no longer condense.

Stage B

As the temperature in the system increases and more bubbles form, they are likely to clog in parts of the system particularly where constrictions of the conduits occur. When this happens, the expanding steam suddenly forces its way to the surface causing some preliminary spurts at the surface.

Stage C

At this stage, one of the preliminary spurts removes sufficient rocks from the top of the system to cause a reduction in pressure sufficient to trigger the whole system, causing the water in the system to flash into steam and cause the geyser to surge into full eruption.

Stage D

Small pockets of water in the system are converted to steam but generally when the eruption is over, the system once more begins to fill with water and the whole cycle starts again.

Mud Pools

Mud Pools are really types of hot springs, but ones with a limited supply of water. Hot water rising from below chemically weathers the surface rocks which are decomposed to a clay. The clays produced vary in colour from black, white or cream, and sometimes are tinted by reds and browns of iron oxides; the most common colour, however, is a light grey. The consistency of the mud varies from what could be described as dirty water through to a very thick paste, depending on the amount of water available. The availability of water varies with the seasons, and in July and August some of the mud pools have a tendency to dry out completely.

Fumaroles

These are thermal features which only discharge steam and other gases and are often referred to as steam vents. They are extremely numerous through the Yellowstone area.

Yellowstone in the Future

'Is Yellowstone going to be the site of further eruption in the near future?', is, of course, the one million dollar question. Geophysical studies in the area have helped to give us some insight into possibilities (Smith and Braile, 1982).

The upper crust beneath the Yellowstone Caldera has p-wave velocities of between 4.0 km/sec and 5.7 km/sec (Fig. 5). These are very low values compared with surrounding areas where p-waves are in the order of 6.0 km/sec in the upper crust. The boundary of the 5.7 km/sec p-wave body closely corresponds to the outline of the Yellowstone caldera, with the 6.0 km/sec velocities representing the surrounding thermally undisturbed basement.

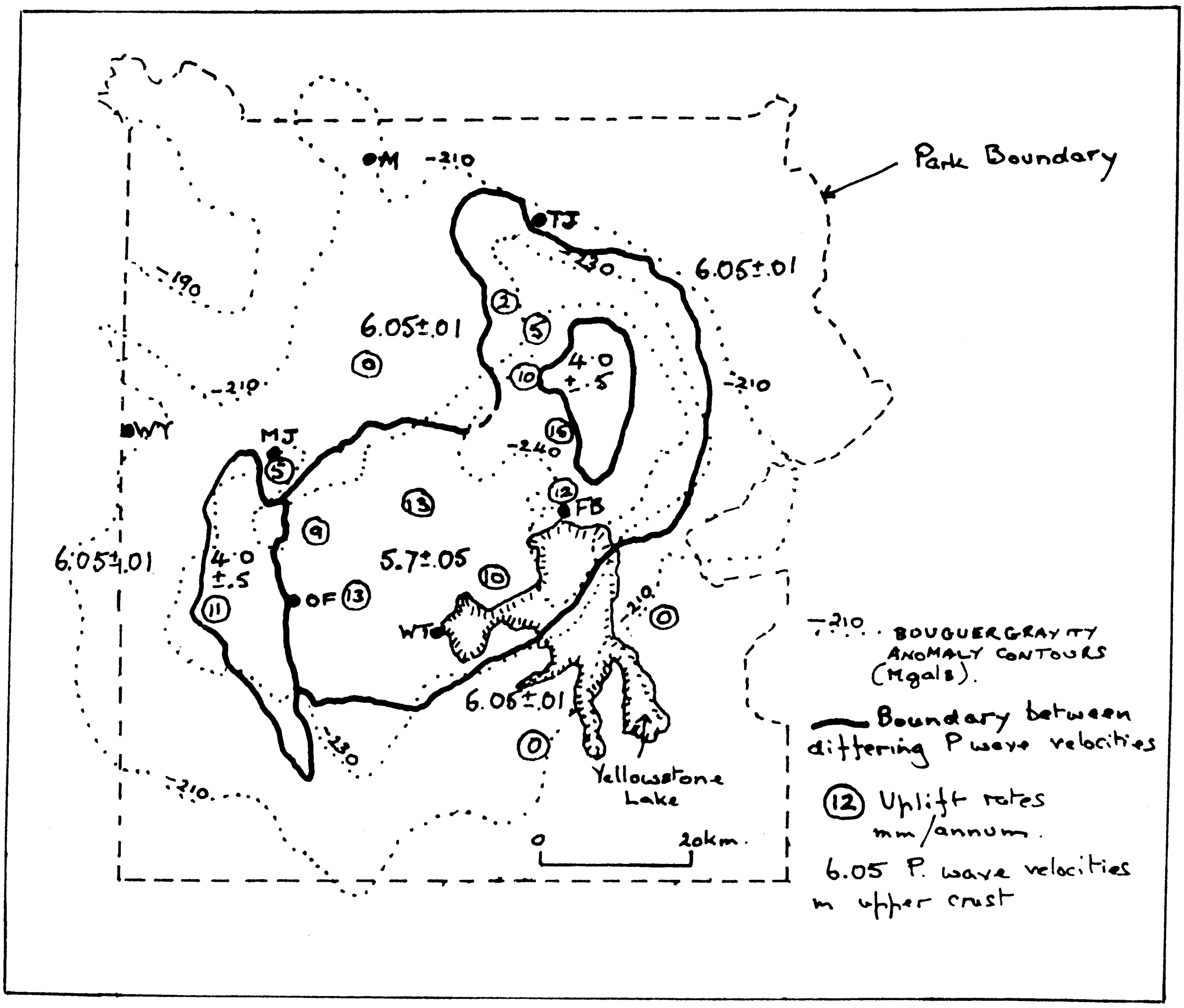

Fig. 5. Map of the Yellowstone area (after Smith and Braile, 1982) to show the area of low P. wave velocity zone in the upper coastal rocks (2 km–10 km), the negative Bouguer depth gravity anomaly contours (Mgal) and the zone of relatively rapid uplift particularly in the north east and south west parts of the Yellowstone caldera (figures in mm per annum).
FB: Fishing Bridge, M: Mammoth, MJ: Maddison Junction, OF: Old Faithful, TJ: Tower Function, WT: West Thumb, WY: West Yellowstone.

There are two bodies which are represented by p-wave velocities of about 4.0 km/sec, one to the northeast side and the other to the southwest side of the Yellowstone caldera. The low velocity body to the northeast also has an additional gravity low (minues 240 m.gal.) in addition to the large regional anomally of minus 60 m.gal. Smith and Braile (1982) considered that this low velocity, low density zone may well correspond to an upper crustal fluid-filled silicic body.

The southwestern low velocity body is not accompanied by a gravity low and Lehman *et al* (1982) suggested that this body is possibly the result of a fractured fluid saturated zone representing the northward extension of the Teton fault system which further south provides the impressive fault scarp on the east side of the Tetons.

In summary, the 5.7 km/sec zone beneath the Yellowstone caldera appears to represent a hot plastically deforming body of granitic composition, possibly rhyolitic lavas and associated ash flow tuffs which filled the deep Yellowstone caldera during the Quaternary. The features of the 4.0 km/sec body to the northeast of the caldera boundary have been suggested as representative of an acid body which could range from a highly porous water/steam saturated system to a 10-50% partial melt of the upper crustal rocks. The southwestern 4.0 km/sec body is thought to represent quite possibly a highly fractured northward extension of the Teton fault belt (Smith and Braile, 1982) as previously mentioned.

Recent Surface Uplift in the Yellowstone Area

Changes of surface level in the Yellowstone caldera during the last 55 years have been carefully monitored by Pelton and Smith (1982). Data obtained have indicated anomalously high uplift rates over the area of the Yellowstone caldera as a whole with variations from 5 mm per annum towards the outer edge of the caldera to local uplifts of as much as 15 mm per annum in the area of the northeast low velocity body (Fig. 5). Over the 55 year period, this has produced high uplift rates resulting in a total of 700 mm elevation. This uplift corresponds closely to other observed uplift rates in volcanically active regions such as Hawaii and Iceland.

Speculation on Possible Future Eruptions in Yellowstone

Smith and Braile (1982) suggest that the 5.7 km/sec body under Yellowstone may well represent a relatively solid but plastically deforming body. What is of considerable interest, however, is the northeast 4.0 km/sec low velocity body, interpreted, as already stated, as possibly a fluid filled steam/water body or a partial melt. Whether this situation represents a pre-eruption feature is debatable but the coincidence of a low density, low velocity body with associated surface uplift suggests that in the northeast of the Yellowstone caldera, we may have a site for a future eruption. If an eruption occurred, the inference from the fairly small volume of the 4.0 km/sec body is that an eruption would not be on the catastrophic scale of the major eruptions which have devastated Yellowstone in the last 2 million years. It may well be a future potential hazard, but on the other hand, the crustal deformation which is taking place may only represent the successive introduction and solidification of melts in the upper crust with associated inflation and deflation of the surface, but with no eruption.

Under the rest of Yellowstone the geophysical date do not give rise to any suspicion of a possible volcanic episode in the near future.

Conclusions

The volcanic history of the Snake River Plateau and Yellowstone Park provides abundant evidence of the movement of the North American Plate in a south westerly direction over a mantle plume which has produced a line of volcanic activity indicating this movement. In the Snake River Plateau, the initial silicic eruptions followed by a long history of basic eruptions have produced the thick sequence of basaltic lavas now present. Beneath Yellowstone Park, the present position of the mantle plume coincides with the Middle Rockies and, consequently, a much greater thickness of continental crust which undoubtedly has had its influence on the dominance of acidic eruptions from this area.

Today, and during the last 60,000 years, the Yellowstone area has had no true volcanic eruptions and activity is represented by the famous and varied geothermal features.

The possibility of a future eruption in the Yellowstone area has been discussed, and the geophysical evidence suggests that the northeast part of the Yellowstone caldera is the most likely candidate. It is probably underlain by a melt which has the possible potential of producing a future eruption, albeit on a scale likely to be much smaller than the three caldera-forming eruptions of the last 2 million years or so (Smith and Christiansen, 1980).

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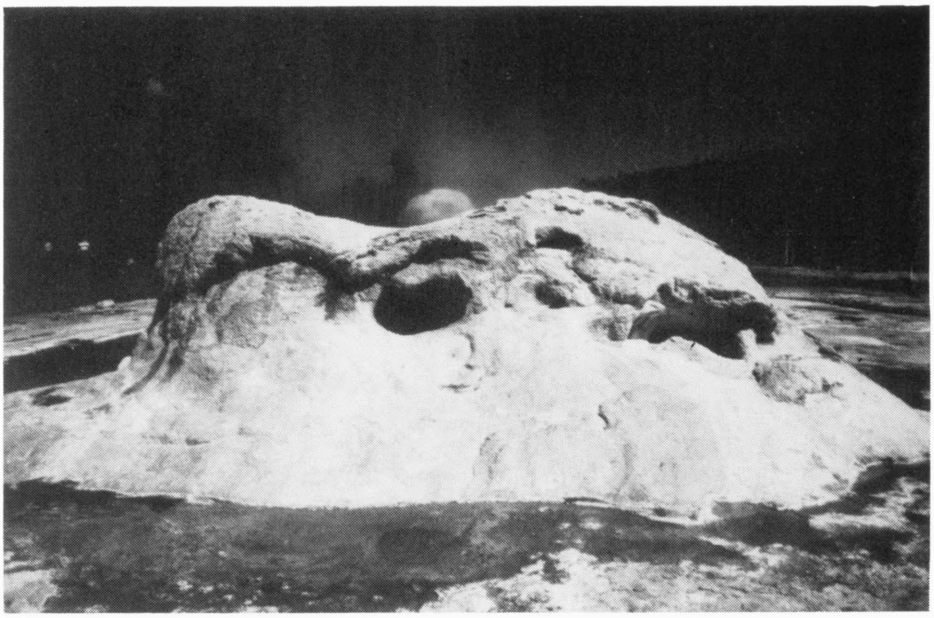

Plate 1. Grotto Geyser, Upper Geyser Basin, with appreciable deposits of siliceous sinter.

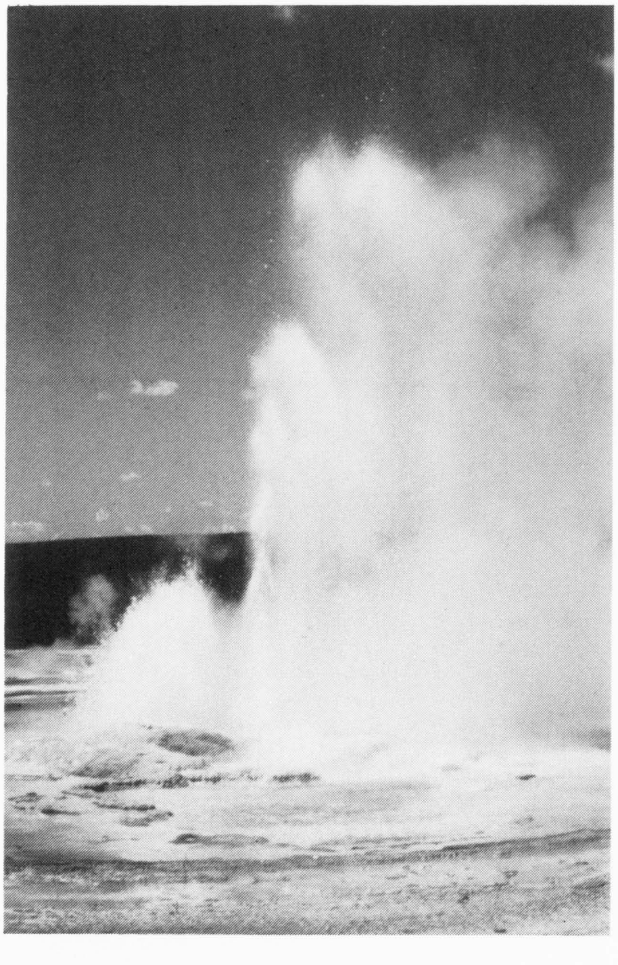

Plate 2. Clepsydra Geyser, Lower Geyser Basin. A geyser which is in almost continuous eruption.

Plate 3. Echinus Geyser. Norris Geyser Basin. The geyser after eruption and before recharge has commenced.

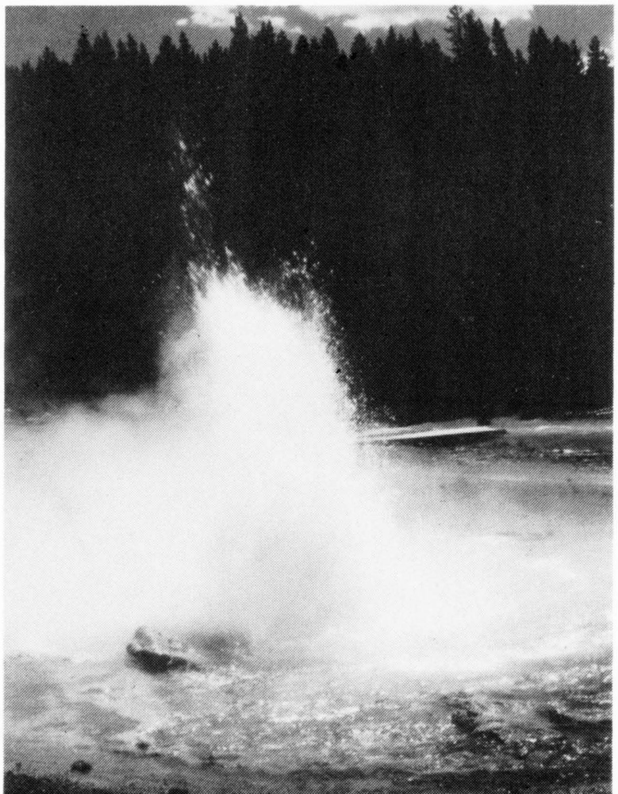

Plate 4. Echinus Geyser, Norris Geyser Basin. The geyser erupting at about half normal strength.

Plate 5. Minerva Terrace, Mammoth Hot Springs. This is a view of the active part of the terrace formed of calcium carbonate from hot spring water which has risen through limestones.

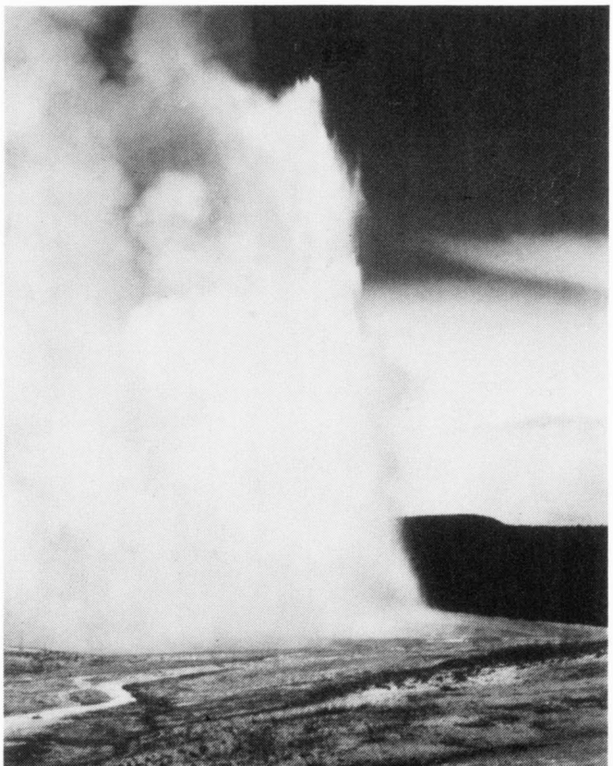

Plate 6. Old Faithful in full eruption.

EAST MIDLANDS GEOLOGICAL SOCIETY
SECRETARY'S REPORT FOR 1989/90

The Society has enjoyed yet another successful year with a steady influx of new members both professional and amateur, the membership currently standing at 502 comprising 402 ordinary joint and student members and 100 institutions. Some members are sadly no longer with us having retired due to illness and it is with much regret that we heard recently of the death of Peter Brayne whom many of us will have known and our deepest sympathy is extended to his wife Jean and family.

The Society events during the year have covered the usual wide and interesting range of topics and upon looking through the list it seems to have been a year very much of economic and engineering geology. We have learnt of the problems of engineering in Hong Kong and of those of the Channel Tunnel nearer home and we have been instructed in not only the geology but also the archaeological history of our local gypsum mining industry and seen at close hand the steel industry in Scunthorpe, motorway construction in Oxfordshire and the building stones of Nottingham together with the limestone quarrying at the National Stone Centre. All of our meetings both in and outdoors have been very well attended reaching what may be a Society attendance record of 142 at the January meeting when we had to change lecture halls to avoid members expiring from the body heat generated in our usual meeting place!

For the A.G.M. we celebrated the culmination of our first twenty-five years with an affectionate reminiscence introduced by one of our founder members Frank Taylor, who I am delighted to say has agreed to be nominated for Council again this year, followed by an excellently put-together presentation of slides by our Treasurer, Jack Fryer, from items loaned by members for the occasion.

In April we had a most interesting talk by Russel Arthurton of the B.G.S. explaining the problems and role of the geologist in the design and construction of major engineering works in that unique part of the world, Hong Kong. Then in May for our first venture outdoors we had a fascinating visit to the old Gypsum workings in and around Tutbury combined with visits to two of the local churches to view the beautifully carved end products of those workings. The leaders were our Editor Ron Firman who knows so much about the industry and John Young of the Chellaston Local History Group who put the industry into a historical and archaeological context for us.

Into June and we had a splendid evening visit to the National Stone Centre at Wirksworth led by one of our members, Robin Jeffcoat. We were welcomed to the Centre by the Director Ian Thomas and then Robin led us on a fascinating trail through the limestone environments of the old quarries upon which the Centre is sited. We ended in the gloaming after 10.00 p.m. having been accompanied throughout the latter half of the tour by a small black cat—a lucky omen for the Society we hope!

July was a busy month starting with our one-day Symposium on the Geology of the East Midlands at the B.G.S. in Keyworth coordinated by Mark Dean one of our Council members. It was a most interesting day born out of the recent work carried out by a B.G.S. team on "The Nottingham Project"—a re-mapping and surveying of our own local region—but broadened to include recent work on a variety of geological topics in the wider context of the East Midlands. We had the benefit of several speakers from the B.G.S. and others from B.P., British Coal and Nottingham Polytechnic. We are most grateful to the B.G.S. for allowing us to use their excellent facilities for the Symposium and to all of the speakers who gave us the benefit of their investigations and expertise.

In mid-July, on what was one of the hottest evenings of a year of hot evenings, we had a leisurely and instructive stroll around Nottingham City Centre led by Neil Turner of Wollaton Hall Museum when we all looked upwards instead of down, as is the wont of geologists, and saw how much we usually missed of some of our quite beautiful city buildings and the decorative carving and beautiful stone used in their construction.

Then at the end of the month there was a week-end excursion to investigate the geology of Anglesey attended by 20 or so members, all of whom thoroughly enjoyed the trip. The leader was Dr. Tony Evans of Leicester University, an old friend of the Society.

We then allowed our members six weeks or so rest and recommenced activities in mid-September with an excursion to the South Ferriby area of North Lincolnshire and the old Scunthorpe Steelworks quarries; a day which started out in torrential rain (we only narrowly avoided losing a few members in the glutinous quicksand of the Oxford clay in the bottom of the South Ferriby quarry) and ended in glorious warm sunshine. Those members who decided to stay in bed when they saw the early morning weather missed a super day jointly led by Alan Dawn and David Elford and even the bus driver had an excellent day, thoroughly enjoying his drive along the quarry roads which were later last year to be used as one of the stages in the R.A.C. rally.

Our last full meeting of the season was to view the Jurassic strata of Oxfordshire as seen in the exposures produced by the major new motorway roadworks for the M40. Albert Horton, our leader on the day, is part of the B.G.S. team who have been remapping the Thame sheet. Both for the mappers and for us these works are a real bonus despite their undoubted despoilation of the countryside and probably for many a lasting memory of the day will be of seeing the phalanx of huge earth moving machines cutting a swathe of new road. The power (and the noise!) was phenomenal.

To the winter programme, and only five days after our last field trip we started the indoor season with a fascinating lecture by Robin Gill of Royal Holloway and Bedford New College based on his work on the east Greenland coast with its evidence of the continental separation which occurred there during the Tertiary period. We saw multitudes of magnificent dykes and banded gabbros.

In November we held another of our successful joint meetings with the Yorkshire Geological Society on the Quaternary Geology of Northern England. The speakers had all carried out recent work within this general topic area and we were privileged to hear their latest findings in their specialised fields.

To December and we decided to enliven the dull days of winter with a visit to the South Pacific Island of Tonga with Dave Tappin of the B.G.S. Unfortunately this was not a field trip but we did follow the proceedings with our usual Christmas party. This was as ever successful and we are very grateful to all those members who so kindly helped in providing festive fayre.

We started the new year with what proved to be our best attended meeting of the session, a most interesting talk by Dr. Tony Brown of Leicester University on the Post Eruption History of Mount St. Helens concentrating on the environmental impact of the 1980 eruption with its associated devastating blast, mass movements and flooding and the response and recovery rate of the eco-systems, hydrology and geomorphology of the area.

The Society year ended with the Foundation Lecture at the beginning of February. The President had chosen the Channel Tunnel as the topic and we were most fortunate to have Dr. Lionel Lake of Mott Macdonald Geotechnical who gave us a fascinating insight into the history as well as the modern techniques of tunnelling and the geological constraints of the tunnel site on both sides of the channel. The lecture was followed by a most enjoyable buffet meal at the University Staff Club attended by some 55 members which was generally agreed to be a splendid finish to the year's proceedings.

Five Council meetings have been held during the year to discuss the Society's affairs and eight circulars have been produced to inform the members of Society events and other matters of interest.

One member of Council, Tim Charsley of the B.G.S., had unfortunately to resign from Council during the course of the year as he was posted to Jordan which is why he is being replaced after only one year on Council.

I reported last year that the Society's exhibit was being redesigned. This has now been carried out by Mick Stanley and our thanks are given to him for producing the new one which was first on display at the joint meeting with Y.G.S. in November.

I personally would like to thank Jack Fryer and Ian Sutton who have respectively been responsible for organising the programme of indoor meetings and field excursions, and also of course Judy and Philip Small who have again this year produced, with the aid of a small sub-committee, the Society circulars. All these jobs were formerly part of the secretary's task and my job would be a lot more onerous if not impossible without their help.

We are all extremely grateful to the speakers and excursion leaders who have so willingly given of their time to instruct and entertain us during the year and of course to the University for the use of the lecture hall facilities in the Geology, Geography and Biology Departments all of which we have utilised during the year.

Lastly but certainly not least, thanks to all the members of the Society who have helped in any way during the year with a particular mention to the small band who regularly help in hand delivering the circular and journal and who help check the journal prior to distribution. And to you the members for your excellent support of Society activities. Thank you.

Susan M. Miles
10th March 1990

THE WEEK'S EXCURSION TO WEST CENTRAL WALES, August 1987

The headquarters for the week was the Dolmelynllyn Hotel at Ganllwyd, 5 miles north of Dolgellau, where 8 of the party of 12 stayed. It proved to be in a scenic position with pre-breakfast walks for those so inclined; the building was old and the ascent to our various bedrooms and bathrooms was tortuous, to say the least, but we nevertheless enjoyed a comfortable and well-fed week.

The journey to Wales had been fine and warm, but after heavy rain during the evening and night the two campers woke up to find a lake surrounding their tent as described below; fortunately, their sleeping compartment remained dry. This was the last rain we saw until after the last excursion on the following Friday.

Sunday 2nd August—The Ordovician rocks at Rhyd and Tan y Grisiau, south-central Snowdonia, North Wales

After a night of heavy rain we woke up in a lake! Cindy and I had decided to camp, but that morning, surrounded by soggy chaos, we wished we had stayed in the hotel with the rest of the party. The morning was however splendidly sunny so we made our way to Ganllwyd anticipating a fine day in south central Snowdonia where Martin Smith of the British Geological Survey (Aberystwyth) was to introduce us to sedimentation and tectonics in the Ordovician rocks at Tan y Grisiau and Rhyd.

We proceeded to Tan y Grisiau and parked near the Tourist Information Centre. At this first locality (SH6814 4529) we traversed a section up through the local Tremadoc-Arenig junction. Classical interpretation of this feature, on the regional scale, involved an important angular unconformity as evidenced by Arenig strata resting on older Precambrian to Cambrian beds (see George 1961 and Anderton *et al* 1979 for summaries). Here however the junction appeared gradational and was marked by the sudden replacement of relatively deep water Tremadoc shales and mudstones by the shallow water conglomeratic Garth Grit of the basal Arenig. Martin demonstrated the junction here was marked by a 'disconformity', with the Garth Grit interdigitating with the finer background sediments. He also showed us a wide range of sedimentary structures, such as cross-bedding, scours, wave ripple channels and crude grading cycles, in the overlying flaggy Arenig strata which indicated deposition within shallow, wave dominated to intertidal environments.

At the second locality, starting in a disused quarry (SH6404 4188) a similar scenario was described. As we climbed to the summit of Moel y Llys we again witnessed an apparently gradational Tremadoc-Arenig junction and saw again similar sedimentary structures in the clean, well sorted Arenig deposits which Martin again interpreted as a basal transgressive sequence.

At the summit we ate lunch and enjoyed a variety of scene. To the north and south we looked respectively towards the Snowdonia foothills and the Harlech Dome, whilst to the west Tremadoc Bay and the Lleyn Peninsular were clearly visible. The view most relevant to the excursion however was to the north-east where in the foreground was part of a complexly structured tract of land, classically interpreted as part of a huge thrust-fault breccia (see George 1961 pp. 52–5). This area was to be the afternoon's subject and Martin introduced it to us as the "Rhyd Olistostrome".

The term olistostrome is applied to chaotic deposits emplaced by debris flows and related mass gravity processes, which are composed of extra-formational material or which contain exotic clasts (olistoliths) which are older than the enclosing sedimentary sequence (Rupke 1981 p. 379). At our next locality (SH6340 4191) Martin showed us a large raft of basal Arenig grit, in bedded and cleaved pelites, which represented a large block within the olistostrome. At its basal contact, the prominant vertical quartz veins seen crossing the block made virtually no inroad into the adjacent meta-sediments, and the cleavage in those meta-sediments was clearly seen to deform around the block. At the final locality on our itinerary (SH 6288 4119) further evidence for the olistostrome was shown to us where several small rafts of Arenig sandstone could be seen in a matrix of slump folded and sheared pelite. The day ended at the spoil heaps of a local pisolitic iron ore mine.

Everyone enjoyed their day with Martin Smith and thanked him for his patient and lucid leadership of this excursion to part of his PhD mapping area. We recognised his bravery to question the conventional explanation of the geology of the Ordovician rocks in south central Snowdonia, and were stimulated by his ideas which were based on an impressive sound and thorough knowledge of the rocks in question. Where appropriate, his

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1991, pp. 109–113.

interpretations also benefited from modern knowledge of sedimentary and tectonic processes. The party wished Martin every success in the future.

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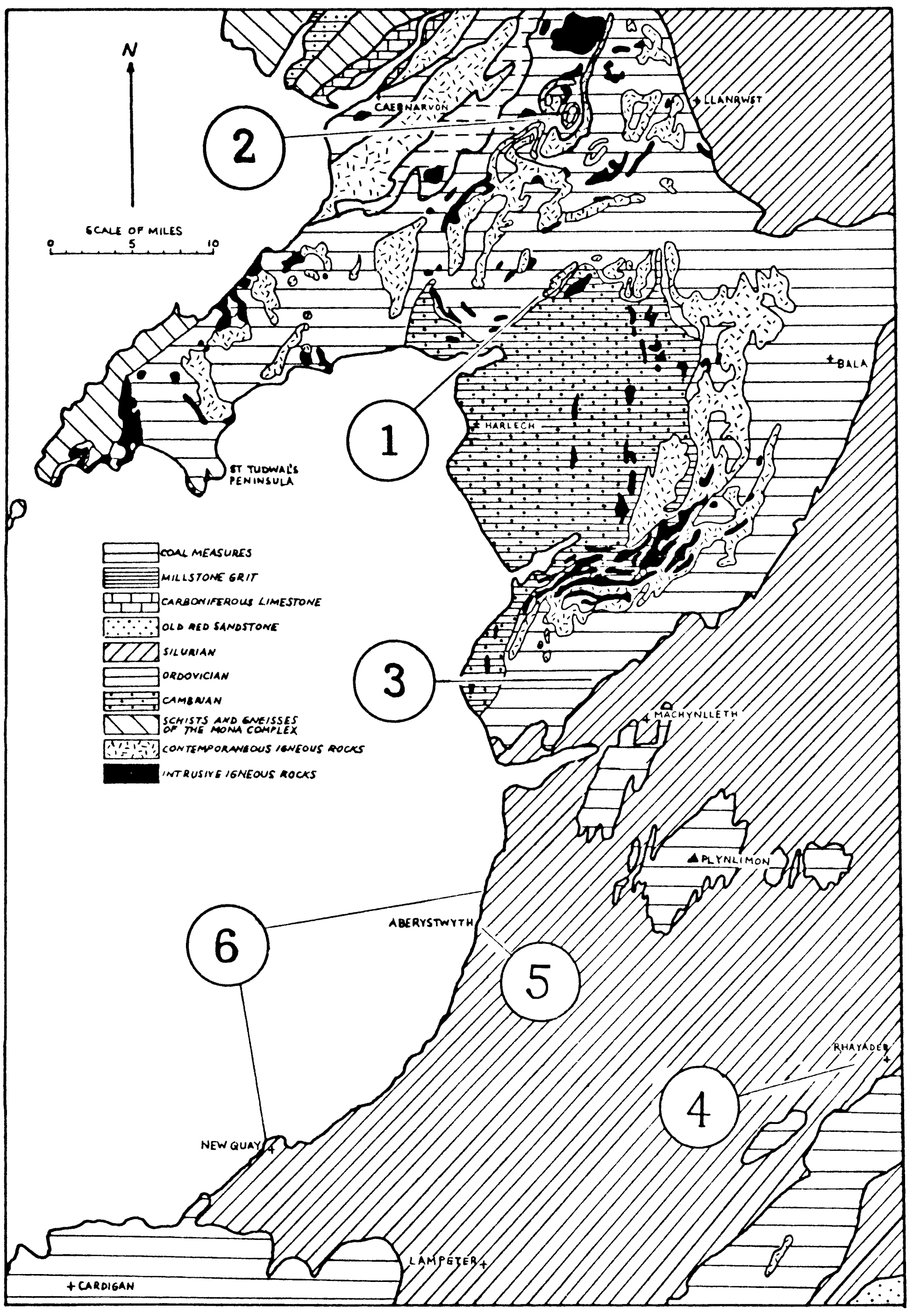

Fig. 1. *Simplified outline map of the solid geology of west-central Wales.* (Based on Smith & George, 1961; George, 1970). *Excursion Locality numbers:* 1. South-central Snowdonia; 2. Northern Snowdonia; 3. Cader Idris; 4. Central Wales; 5. Aberystwyth; 6. New Quay to Clarach.

Monday 3rd August—Volcanism in Northern Snowdonia at Cym Idwal.

We met the leader, Dr. A. J. Reedman, at Bettws y Coed and followed in convoy to Idwal Cottage car park, (SH 648 603), the starting point for our excursion to the rocks of the Snowdon Volcanic Group, (Upper Ordovician), exposed in the Idwal Syncline. The first location was a worked out quarry, south of the car park, where it could be seen that excavation had taken place along the strike of even and cross-bedded tuffs, alternating with thin beds of tuffite and mudstone; this sequence, as the leader explained, resulted from deposits of fine-grained ash, carried by the prevailing wind from a distant erupting vent, settling into water in which muddy sediments were being deposited. The tuffs had been quarried for use as honestones, on account of their fine grain and hard silicous character.

West of the quarry, some distinctive ice-scoured crags expose the ash-flow tuffs of the Pitts Head Tuff, overlain and underlain by sandstones. On weathered surfaces the welding foliation in the Tuff is picked out by siliceous segregations along the closely space foliation planes; a zone of siliceous nodules, 2 to 3cm diam., occurs near the centre of the section, within a fold marked by the foliation planes. The leader explained that similar nodules are common in the Snowdonia volcanic rocks; they may have formed from the infilling of gas bubbles in the tuffs, or by the growth of quartz around a nucleus.

A short distance southwestwards along the ridge brought us to a classic example of a roche moutonnée and much other evidence of ice erosion. This prominent outcrop overlooks spectacular views northwestwards down the ice-carved Nant Ffancon valley, to Bethesda and beyond to Anglesey, and southwestwards into Cym Idwal, and provided a vantage point from which Dr. Reedman pointed out the principal glacial features of the area.

After crossing the morainic drift at the mouth of the cym, and climbing the stile in the nature reserve, we returned to the main purpose of the day and discussed the solid geology of the cym while eating our lunch at the lakeside. Looking southwestwards towards Twll du the structure of the Idwal Syncline, with the basalts high in the back wall forming the core, was readily apparent. Following the track along the east shore of the lake, the steep slope above has been eroded in the lower units of the Lower Rhyolitic Tuff Formation, with prominent dip and scarp features. The basal unit, seen just to the north of Idwal Slabs, comprises breccias formed of blocks of acid tuff, vesicular basalt and sandstone in a matrix of finer volcanic debris. At the edge of the Slabs the breccias grade upwards into massive ash-flow tuffs. Idwal Slabs is a popular venue for climbers; one member of the party confessed to having scaled them in her younger days but was reluctant to give a demonstration on this occasion.

As we continued southwestwards along the track, higher units in the Lower Rhyolitic Tuff Formation were seen to comprise massive-bedded ash-flow tuffs with interbedded tuffs and sediments; a prominent feature, which had been remarked on from the lunch stop, proved to be a weathered out, fine grained tuffaceous mudstone, 1.5m thick. Above this, sedimentary structures were more apparent, cross-lamination and graded bedding being noted in several of the tuffs. Higher beds within this formation, consisting of siltstones and sandstones with thin tuffs and tuffite bands, were crossed as we approached the back wall of the cym, where a dark blue-grey rhyolite forms steep crags. Columnar jointing is developed in places in the rhyolite, and the leader pointed out the flow-banding and flow-brecciation features which can be seen on weathered surfaces.

The uppermost unit of the Lower Rhyolite Tuff Formation, consisting of massive acidic tuffs, were seen, above the rhyolite, just below the cleft of Twll du. The junction of this unit with the base of the overlying Bedded Pyroclastic Formation is well exposed. These green basic tuffs and tuffites show ripples and laminations in places, including both fine and coarse grained beds, representing changes in the nature of the pyroclastic materials erupted from nearby vents.

The more agile members of the group climbed higher up the steep slope to examine, in situ, the pillowed basalts forming the core of the syncline; those less energetic examined these rocks in the fallen blocks.

Turning downslope and following the track towards the western side of the lake, an exposure in the upper part of the Lower Rhyolitic Tuff Formation was seen to include contorted layers, attributed by the leader to slumping or dewatering of the unconsolidated sediments, probably due to earthquake shocks. From here, the track followed the line of the classic moraines on the western side of the lake before rejoining the path down to Idwal Cottage.

The traverse of the Idwal Syncline was completed by a short walk northwestwards along the road to an exposure of the Pitts Head Tuff on the western limb of the syncline. The grey-green tuff is highly silicified; the welding foliation can be picked out on fresh surfaces from the alignment of green fiamme. Contortion in the foliation was noted, and explained by Dr. Reedman as due to movements within the tuff after emplacement but before cooling.

Tuesday 4th August—Field Trip to Southern Part of BGS Sheet 149. (Cader Idris)

The 3 leaders for the day, Mary Shufflebotham, Melanie Leng and Warren Pratt, were met at Tonfanau railway station. (SH 563 038). The main purpose of the day was to examine the Upper Ordovician/Lower Silurian rocks of the area, but this first locality provided an interesting exposure of Quaternary deposits.

Walking through the station and an old army camp to the coast, we were able to examine the boulder clays forming the low cliffs; a distinctive feature is the large rafts of Jurassic sediments seen in the deposits, probably of fairly local origin as Jurassic rocks are present in Cardigan Bay. With a strong breeze blowing along the shore, we were also able to witness the mechanics of wind ripple formation.

The next location, the Tonfanau Dolerite Quarry, is visible from the railway station, and was reached by a short drive southeastwards. A large doleritic body is intruded into the Beacon Hill Volcanic Formation and the Bifidus Slate Formation, but the contacts between the dolerite and the tuffs and sediments of the country rock reveal complex intrusive relationships resulting from two separate phases of intrusion. Quartz vein networks are developed at the contacts, although these could only be seen from a distance. Mineralised zones, with pyrite and chalcopyrite, were seen.

The third location, Bird Rock (Craig yr Aderyn), was reached by driving inland along the valley of Afon Dysynni. Bird Rock provides a spectacular view over the valley, and from this vantage point the leaders pointed out the overall structure of the Bird Rock Anticline. From here, the route took us past the Tal-y-Llyn lake, where a brief stop was made for photographs; the lake is sited in a classic U-shaped glacial valley, and is impounded by a large natural dam, possibly a terminal moraine.

Lunch was taken at the Corris Craft Centre, an unusually civilised location for a geological field trip, but much appreciated as a change from the hotel's packed lunches. It was also to prove a useful preparation for the scramble up the steep scree slopes to the Aberllefenni Slate Quarries, in the Dulas valley. The scree results from the waste thrown out from the quarries. The well-cleaved silty mudstone forming the Narrow Vein Formation, of Ashgill age, is some 20 m thick and is extracted in slabs, from quarries and from underground workings, for use as paving stones, gravestones and in snooker tables.

The Devil's Bridge Formation, of Llandovery age, exposed in the sidings of Machynllech railway station, was to be the last location of the day. The leaders had planned to visit one further locality, near Machynllech Golf Course, but the rival attraction of the steam locomotives in the railway station took up too much of the available time. Tearing ourselves away from the power of steam, we examined the magnificently exposed plunging anticline, comprising a sequence of turbiditic sand-, silt-, and mudstones and the cleavages and joints displayed; the bedding surfaces showed "slickencrysts", probably representative of slip-type movement during folding.

On several occasions during the week the leaders had to compete with the noise of low-flying aircraft, but on this occasion a particularly low one completely disrupted proceedings for a time; the pilot had probably spotted the Cardigan Bay Express in the station and was trying to read its number.

Wednesday, 5th August. Silurian Sediments in Central Wales.

The leaders, Jan Zalasiewicz and David Wilson, met the group in the car park in Rhayader, where we transferred to two Landrovers and a sturdy car; the day was to be spent examining Silurian sediments and structures exposed in outcrops around the reservoirs in the Elan Valley, west of Rhayader, mostly reached by unmetalled roads.

The first stop was at a small roadside shale dump, beyond Caben Coch Reservoir, where the leaders had found specimens of burrows in the shale. None of the party found the evidence totally convincing, but this was obviously because we were not yet sure of what we were looking for. Later, in a stream section below Claerwen Dam, we saw burrows which were much more obvious. Here, too, the rocks displayed good banding, differentiating the succession of shales and mudstones.

The structure of the Towy Anticline became apparent as we drove along, and features of it were pointed out from our lunch-time vantage point beside the Dam. The sheep here seemed particularly hungry and competed strongly for our lunches; those that were not trying to snatch food from our hands were foraging in our rucksacks whenever opportunity occurred.

The unmade roads around the reservoirs were at least as rough as the leaders had promised, and we were grateful for the frequent stops at the various exposures along the traverse, as the Silurian sedimentary history of the area was demonstrated to us. The graptolites required a little imagination, but after our earlier experience with the burrows we were prepared to concede that we were seeing graptolites. The banding in the rocks, formed by the alternation of shale and mud sequences, became less clear than at the earlier exposures.

The final exposure of the day was in the impressive Cabon Quarry, (SN 924 6460), immediately north of Cabon Coch Dam. A conglomerate sequence, some 20 m thick overall, is made up of a wide range of conglomerates, grits and interbedded mudstones, interpreted as part of the proximal portion of a large submarine fan, deposited at the foot of the continental slope. This magnificent and unusual exposure made a fitting climax to the excursion.

Thursday 6th August—Visit to British Geological Survey at Aberystwyth.

Dr. Reedman had invited the group to visit them at Bryn Eithyn Hall, their headquarters in Wales. We were welcomed by him and Dr. Bazely and over coffee they talked of the work of the office and the mapping of areas only superficially covered previously. Various maps and books recently produced were available for purchase. The Hall is situated south of Aberystwyth and overlooks a splendid view. It is thought that the site has been used possibly from the 7th century, although the present building was established in the early 1800's and various alterations later. We left them about midday and the afternoon being free went our various ways.

Friday. 7th August. The Aberystwyth Grits, New Quay to Clarach.

We met the leader, Denis Bates, at University College of Wales, Aberystwyth, and drove to the first locality for the day, at New Quay, where we parked on the cliff top. (SN 387 604). Here, the leader outlined the objects of the day's excursion.

The Aberystwyth Grits, of Silurian age, form a magnificent example of a turbidite sequence, exposed in cliff sections over some 40 km of coast extending from south of New Quay northwards to Borth. The coastal exposures display a wide range of sedimentary and tectonic structures, and indicate a transition from proximal turbidite deposition, in the south, to distal characteristics in the north. Flute and groove casts tend to confirm the S-N current direction. The localities to be visited had been chosen to demonstrate this transition, and to show some of the wealth of structures exposed.

Following this introduction, we scrambled down to the beach near a seafood factory; the factory's products were made very obvious by the smell, and by the waste that we walked through. The cliff section beyond the factory is cut in thin beds, strongly folded and faulted, in contrast to the thicker beds on which the factory is sited.

A short distance further, around the next promontory, a number of rarely seen turbidite features were pointed out; these included a sedimentary sill, with several vertical dykes injected upwards through mudstone into the overlying turbidite unit. Underlying this sequence, thin, laminated sandstone beds occur within 3 m of mudstone and show prominent current ripples. Other turbidites show slump features and large intraclasts; one intraclast, about 30 cm in diameter, contains a cone-in-cone concretion truncated by the clast surface. Other sedimentary dykes were pointed out, injected upwards into mudstone, possibly as a result of earthquake shocks. A thick mudstone occupying a curved hollow in a thick greywacke was interpreted as representing a mud-filled slide scar.

At Aberarth, the first cliff section is composed of boulder clay, with layers of sand and gravel; solifluction features are apparent in the upper part of the cliff. Further north, the cliffs are cut along the strike of the solid rocks, with beds of 30–50 cm thickness. Some of the thicker units include intraclasts ranging in size from 1 cm to rafts of more than 1 m in length. Slurrying was noted in many of the turbidite units and the leader pointed out the "prolapsed bedding" structures which occur. Well-developed bottom structures were seen at several horizons.

This first sequence is faulted against a sequence of thinner units, with turbidites less than 10 cm thick, succeeded in turn by much thicker beds; one multiple bed is 5 m thick, and is clearly recognisable from a distance, when the bedding appears vertical and parallel to the cliff face. Horse-shoe shaped flute casts are a notable feature of this bed.

At Clarach, parking at the north beach, (SN 587 841), we first viewed the beach exposures from the cliffs, noting the clearly visible complex folding. Descending to the beach, we then studied the wide range of sedimentary structures and other features exposed in the wave-cut platform and in the cliffs. The wave-cut platform exposes a sequence of haphazard folding, with slaty cleavage developed in places but with no consistent relationships to the folds. This feature has been interpreted as soft-sediment deformation, the result of down-slope sliding shortly after deposition. Graptolites were found in some beds, more generously proportioned than those seen on the Rhayader excursion.

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BOOK REVIEWS

BOWEN, R., 1988. *Geothermal resources*, 1989, 2nd. Ed. Elsevier Applied Science, Linton Road, Barking, Essex IG11 8JU, England £60.00, hardback, 485pp. ISBN 1 85266 287 1.

In his Preface, Robert Bowen has stated his aim as being "both to interest and to stimulate the reader in addition to offering a compact, but comprehensive, source of geothermal information for office and field use by earth scientists, engineers and isotope geologists, environmentalists, sociologists and land planners". To what extent has the author succeeded?

Indeed, for its size, the book is packed with information, tables and with references, although many of the latter are from the late seventies with some up to 1986. There are seven chapters that lead the reader logically through from the origins of geothermal resources to their use and environmental impact. Chapter 1 outlines the origins of earth heat right from the first condensation of dust and gases to the differentiation of core, mantle and crust and their associated thermal characteristics. Chapter 2 defines the different geothermal systems, conductive and convective, the nature of heat flow through factured media and fluid systems, and then both idealised models and selected case-study models of hydrothermal systems.

Chapters 3, 4, and 5 cover geothermal exploration, resource assessment and exploitation respectively. These deal with each topic with a very practical "how-to-do-it" methods approach, including both the types of pre-production modelling employed as well as specific items of equipment necessary for exploitation. They have clearly been compiled with care by someone who knows the practicals from firsthand experience. Specific projects are used to some extent, including the Los Alamos and Cornish Hot Dry Rock projects, although considering the number of geothermal operations in the world today, perhaps a greater number and variety of case studies could have been presented.

Chapter 6 discusses some of the environmental impacts of geothermal resource development. Chapter 7 outlines the different uses of geothermal energy including both electrical and non-electrical schemes (eg. process heating, space heating, horticulture and fish farming). Some information is presented here on the experiences in selected countries around the world, although space precludes a thorough treatment of each.

The Glossary, four Appendixes and comprehensive author and subject Indexes are a very helpful addition to the book. Appendix 1 is, in fact, mainly a bibliography of more recent work arranged by country, which to some extent addresses the relative lack of recent case studies and references in the main part of the book. The other appendixes give names of companies and organisations of geothermal interest and a world list of geothermal localities.

Certainly the author has succeeded in producing a useful and informative book that goes much beyond his 1979 edition. Clearly it is not the last nor the only word on a subject that must surely become increasingly important for all of us in the near future. For those involved in the field and who can afford the price, buy it; otherwise recommend it to your library. It is not, however, a book to stimulate those not already working in the area.

Dorrik A V Stow

BARKER, A. J., 1990. *Introduction to metamorphic textures and microstructures*. Blackie and Son Ltd. Glasgow and London. 153 pages, 88 figures, 8 pages of colour plates. £13.95 paperback, £30 hardback. ISBN 0 216 92684 X and 0 216 92685 8 pbk.

Most textbooks on metamorphic rocks deal largely with mineral assemblages and more recently with estimates of their conditions of formation. There are many good books of this type available. In isolation, the mineral assemblages tell only a part of the history of a rock; much more is locked up in its structures and textures. Few books covering metamorphic textures have appeared since the classic work by Spry in 1969. Andrew Barker attempts to improve the knowledge and awareness of this latterly neglected aspect of metamorphic petrology, with a text that fills the obvious gap that has arisen in the last twenty years.

The book is divided into three sections. The first short one (20 pages), called "An introduction to metamorphism and metamorphic rocks", deals briefly with a general outline of metamorphic petrology. This is essentially the ground covered in great detail by most other books on metamorphism.

The second section, "Introduction to metamorphic textures and microstructures" (45 pages) begins with a discussion of the two terms. Many geologists may believe that they are synonymous; in metamorphic petrology and indeed geology in general the term texture is commonly used for any microscopic arrangements of crystals or grains. However, the author points out that in the fields of metallurgy and materials science, from where much of the theory for this type of work is derived, the term texture is only used for a fabric with preferred orientation, whereas microstructure is a more general term for all microscopic arrangements. He makes a plea for geology to come in line with the other physical sciences and use microstructure. There is good sense in this but as "texture" is so entrenched in both the literature and minds of most geologists it is perhaps optimistic to believe it will be widely adopted. This section mainly deals with the development of fabrics, crystal shapes and sizes, inclusions, intergrowths and overgrowths. They are discussed in terms of fundamental processes and are clearly explained and well illustrated. In only one or two places, such as the use of the strain ellipsoid that is referred to in several places, did I think a little more explanation might have helped the reader with a limited background.

The third section, comprising nearly half the book, covers "Interrelationships between deformation and metamorphism". This is to a great extent the main theme of the book and the one that makes it stand out from most others. The vast bulk of metamorphic rocks are deformed but this aspect is skimmed over by most other texts. The section covers firstly deformation mechanisms, classifications of deformed rocks and the influence of deformation on metamorphic processes. The latter is particularly important as reaction rates are speeded up by several orders of magnitude. Further sections cover porphyroblasts and their relations to foliations and a shear sense deduced from pressure shadows. Vein formation, a phenomenon widespread in many lower grade terranes is described and related to various modes of formation. Such information is only usually found in texts on structural geology but is clearly an integral part of the metamorphic process. Fluid inclusions are also briefly discussed.

The final section deals with "deciphering polydeformed and polymetamorphosed rocks". A brief outline is given of some of the features these complex processes produce.

The book clearly fulfils the author's aim—to fill a gap left by most modern texts on metamorphism. It is something of a border zone between mineralogy, structural geology and materials science and all the better for that because surely that is what a study of metamorphic terranes entails. There is enough information to give most students an idea of what the subject entails and adequate references to point the more serious researcher in the appropriate direction in the more specialised disciplines. At a cost of £14 in paperback it represents good value for money and it can be highly recommended as an adjunct to the standard texts on metamorphic petrology.

M.T. Styles

MOSELEY, F. (Editor), *The Lake District*. Geologists' Association Guide, London, 1990. 213pp., no plates, 58 figs., £9.50, softback. ISBN 0 7073 0591 8.

The Lake District has provided geologists with a host of geological puzzles and complexities in great variety and has, as a consequence, received countless individuals and parties during the last hundred years or so who have come to enjoy the wonderful scenery and explore the fascinating geology.

The geological pilgrimages to the Lake District have added to the ever increasing pressures brought about by the droves of visitors each year and one of the first and very pleasing reactions to this excellent new guide is the care that Dr Frank Moseley has taken to educate we geologists in the conservation of the magnificent terrains we have inherited. Moreover, many of the well known classical excursions in the Lake District have been over-used and it is most refreshing to see many relatively unknown excursions described in this guide. It is to be hoped that this will 'spread the load' of many of those easily distinguishable visitors sporting their hand lenses draped round necks, and sketch maps and note books in hand!—dare we hope for less prominence of those destructive hammers?

The guide follows on rapidly from the publication of the excellent 'Geology of the Dorset Coast' which we hope has set the standard for future Geologist Association publications. The new format is so much more attractive than the old mustard or buff coloured, dated guides, which we hope will all receive the overhaul they so badly need.

The Lake District guide has an attractive, coloured, typical Lake District panorama for a cover and the layout of the book is clear. The quality of the sketch maps, however, is very variable, some may well be difficult to follow. Another small worry would be wondering how well a bulky text of this type will stand up to the rigours of living in an anorak pocket in typical Lake District conditions.

As Dr Frank Moseley so rightly states, we can now look at the complexities and puzzles of Lake District geology with reference to the evolution of the Iapetus Ocean and the geological history in this context is dealt with in a clear and concise way in Dr Moseley's introductory chapter.

It is pleasing to have a guide of this type which has used the expertise of a number of specialists who have recently worked in the areas of the itineraries they describe and the detail and preciseness of these itineraries reflects this excellent knowledge of those areas. The object of the guide was to cover equally all the main divisions of Lake District geology and while accepting there have been omissions because of difficulties of access or lack of authors for some areas, there has been a strong bias towards the Borrowdale Volcanic Group which form, in full, or in part, the contents of 16 of the 25 excursions. If the guide was designed to cover equally all aspects of the Lake District geology it is a pity that room could not be found for some of the well known but, nevertheless, classic excursions such as the Shap area, the Skiddaw Granite aureole and the Silurian sequences in the Skelgill area to the east of Windermere. Admittedly reference has been made to some of these areas in itinerary 1, but they deserve more. It could also be said that these excursions have been well covered in other guides; the same however could be said for the Carrock Fell excursion which has been included.

Despite my minor criticisms I warmly recommend what is an excellent guide. It has something for everyone, from the keen amateur to the professional geologist, and it also caters admirably for those who love to combine fell walking with geology. Itinerary 1, which is a road route itinerary, has many advantages. The locations on this itinerary can give a broad overview to the geology of the area for a visitor whose time is limited, the localities can be used when bad weather prevents using many of the other itineraries and it can also be very useful for those who find that the passing of time is beginning to take its toll on physical fitness. This itinerary is most commendable.

The guide provides excellent references to maps and the bibliography is extensive and up to date. This paper-back, at a price of £9.95, is well worth every penny and is thoroughly recommended.

Dr. I.D. Sutton

COOPER, M.P. & STANLEY, C.J., *Minerals of the Lake District: Caldbeck Fells*. 1990. Natural History Museum Publications, London. 160pp., 90 plates of which 72 are in colour, 21 figs., A4 format, £14.95, softback. ISBN 0565 01102 2.

At first sight this guide might appear to be something very much for the specialist and of possible limited appeal to the 'general' geologist. It is, however, very much an authoritative guide to the mining history and minerals of the Caldbeck Fells, possibly the most famous and interesting of all the Lake District mining areas. It is from this area of the Lake District that some of the most beautiful and finest specimens of minerals, such as hemimorphite, linarite, mimetite (campylite) and pyromorphite have been collected. Some of the minerals which have been found are extremely rare and although there are no minerals unique to this area, quite a number have been found only in a very few other locations in the world. An area which boasts some 175 mineral species, many of which have produced museum quality specimens and others noted for their rarity, deserves special treatment. This guide by Mick Cooper and Chris Stanley does just that.

The way the book has been prepared is excellent. It has a first class introduction and is followed by chapters which have a sensible, logical sequence and plenty to stimulate the interest. There is an excellent short chapter dealing with the geology of the Caldbeck Fells, very well illustrated by maps, including an 1824 map prepared by William Smith. The chapter on the Mineral Deposits sets out very clearly a classification of the mineralisation based largely on the main types of mineral veins and this is followed by discussion on the conditions of origin and formation of the mineral bodies.

An added virtue of the book is the way the authors have used historical documents in a very attractive, illustrative way. This is particularly so in the detailed, but interestingly stimulating chapter on the mines and mining. The details of mining history and the geology of mines have always produced a compatible combination and although the evidence of the early history of mining in the Caldbeck Fells is very much fragmentary the detail described in this chapter for the last two centuries or so gives us some insight into the social history of the area during that period, as well as precise information about the history and the development of the individual mines.

Both authors have an obvious affinity with fine mineral specimens and this has the effect of stimulating the reader to appreciate the aesthetic beauty as well as the scientific interest of the minerals. For each of the minerals the chemical composition, occurrence, form, relative abundance and locations are described and many are superbly illustrated with marvellous photographs. The details of the physical properties are not within the scope of this guide.

The guide is completed with two useful appendices and an excellent bibliography. All in all, a first class publication, one that I strongly recommend and, other than a little nit picking over the lack of scale for one or two of the mineral photographs I have nothing other than praise for a beautifully produced and magnificently illustrated guide.

Dr. I.D. Sutton

ODE TO A THRUST

During the long late spring evenings of May 1984 an adult education party from the University of Nottingham were inspired (possibly with the aid of a few drams) to write the following lines of verse. They were staying at the Inchnadamph Hotel in Assynt, where a few yards down the road on the shores of Loch Assynt on a rocky knoll of thrusted Cambrian dolomite is a memorial to Drs. Peach and Horne. The memorial erected in July 1930 is in recognition of the excellent work of these two officers of the Geological Survey while mapping the Assynt area. In a highland haze and with notable poetic licence the following words were written.

Came that auspicious summer morn,
  When Mr Peach and Mr Horne
Went out with Hammer, ink and pen,
  To map the Torridonian.

Said Mr Peach, "It seems to me,
  This is no unconformity,
They must take to me to be a fool,—
  This is the thrust of Loch Glencoul."

And so straightaway they went to see
  The old Director, Archie G,
Who said, "Return! Map all again!
  Put Cambrian o'er Lewis-i-ain."

Then two and twenty years of work,
  Through sun and mist and Scottish murk,
Until at last they reached their goal—
  The thrusts of Moine, Ben More and Sole.

And now to-day their monument,
  O'er the banks of Loch Assynt,
Commemorates their lifelong toil,
  Upon that stable foreland soil.

Now students come from far and near,
  And as they stand, they shed a tear
To pay their homage they insist,
  Though cannot tell their gneiss from schist.

Now Peach and Horne have both passed on,
  And you may ask, "Where have they gone?"
"To meet their Maker", I reply.
  "And map those thrust planes in the sky."

THE MERCIAN GEOLOGIST

Journal of the East Midlands Geological Society

The journal first appeared in December 1964 and since that time 45 parts, comprising 11 volumes have been issued; the last, Vol. 12 No. 1 in Feb., 1990. The Mercian Geologist publishes articles especially on the geology of the Midlands of England, but other articles have been published which are of current interest to geology generally. Contents include original papers, review articles, biographies, bibliographies, excursion reports, book reviews and the Secretary's report on Society activities.

For Contributors:

Authors intending to submit manuscripts of papers for publication in the Mercian Geologist are asked to follow the format of papers included in a recent number of the journal, and if possible to provide two copies. As the journal is read by Members with a wide spectrum of geological interest and ability, authors are asked to ensure adequate introductions for their papers, particularly, if the subject has not been reviewed in the journal over the last few years. The paper should be complete in itself without the need of the reader to refer to specialist journals not easily available to the average Member of this Society. It follows that the length of the paper may be greater than that published by some other journals but authors are asked to be as lucid and concise as possible and to avoid repetition.

Text-figs. normally occupy a full page of the journal, but part diagrams can be fitted into the typed page. Double page diagrams have been published with a single fold but each printed page has to be folded by hand. The standard reduction by our present printing process is approximately $\times 0.75$. Thus the optimum size for the original diagram, including space for caption, index and explanation if required on the diagram, should be 285×190 mm (285×380 mm with a single fold). Greater reduction is possible but care must be taken with the original to ensure that at the final reduced size (230×155 mm; or 230×310 mm) the smallest letters are no smaller than 1 mm and that there is a similar minimum spacing between letters and lines. Bar scales (metric) should be provided as the exact reduction cannot be guaranteed.

Half-tone plates are reproduced at the original size, and should not exceed 230×155 mm. The quality of the published photograph depends initially on the quality of the original and it follows that the photographs submitted should be exactly as the author would wish them to appear in the journal—good contrast, in focus, adequate magnification and without distortion.

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