H. Bartlett

GEOLOGISTS' ASSOCIATION

SOUTH WALES GROUP

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THE GEOLOGISTS' ASSOCIATION: SOUTH WALES GROUP. The Group was formed in 1959 as a direct result of the interest shown by the teachers of geology from Welsh schools attending refresher courses at the University Colleges at Aberystwyth, Cardiff and Swansea. It is designed to further the study of geology, with particular reference to Wales, and to provide a link between the amateur, the student, the teacher and the professional geologist. At present all four groups are strongly represented in the membership of 160 or so. The members are drawn from a catchment area extending from Pembrokeshire to Gloucester.

The Group's session coincides with the academic year. Ordinary Meetings are held monthly from September to March, the Annual General Meeting in March or April, and up to six Field Meetings — including one week-end excursion — between April and September. The Ordinary Meetings take place alternately at Cardiff and Swansea in the Geology Departments of the University Colleges. They are held at 11.00 a.m. on Saturday — usually the third of the month.

The annual subscription is £1 (which includes the cost of *The Welsh Geological Quarterly*). Student membership is 2 shillings. Further details available from: The Secretary, c/o Department of Geology, National Museum of Wales, Cardiff.

Please insert, opposite page 16 of vol.3, no.2 (Winter 1967),

to replace the original illustration.

MAP

H.B

Geologists' Association - South Wales Group

WELSH GEOLOGICAL QUARTERLY

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Cardiff : May, 1970.

NATURE-TIMES NEWS SERVICE

[July to September 1969]

Iron core for Mars predicted. The Times, 1st July.

A detailed prediction of the internal properties of the planet Mars has been made by Dr. A.B. Binder, of the I.I.T. Research Institute in Chicago, on the basis of the accurate measurements of the mass and radius of the planet which have become available in the past few years.

One of the chief conclusions of the study is that Mars should have a core of molten iron similar to that on the earth but considerably smaller.

Journal of Geophysical Research, v.74, p.3110, 15th June, 1969.

A tinge of blue on the moon. The Times, 2nd July.

The moon as seen by the astronauts of Apollo 8 and 10 is predominantly grey but earth-based instruments have picked up slight differences in colour between certain features of the moon's surface. The colour differences probably arise from the composition of the rocks, in which case they should assist in the geological mapping of the moon.

The differences have been brought out by scanning various spots on the moon through a series of colour filters. Light output from selected areas is recorded by a powerful telescope and compared with the output from a standard area in the Mare Serenitatis.

The technique, developed by Thomas McCord of the California Institute of Technology, has been used to scan more than 80 spots on the moon's surface.

Journal of Geophysical Research, v.74, p.3131, 15th June, 1969.

Strength of moon rocks measured. The Times, 4th July.

Almost on the eve of the first journey to the surface of the moon, due to begin next Wednesday, Dr. Leonard Jaffe, of the Jet Propulsion Laboratory in California, has published his conclusions about the nature of the surface of the moon based on measurements by Surveyor VII, one of the several unmanned rockets to have reached the surface in the past four years.

Dr. Jaffe's article, which appears in the current issue of Science, does, however, suggest that there will still be plenty for the first astronauts to look for when they reach the moon a week on Sunday.

Dr. Jaffe is chiefly concerned with the conflicting evidence about the density of the materials near the surface of the moon and with the attempts made to guess the load-carrying capacity of the lunar surface. Unmanned rockets to the moon such as Surveyor VII were designed to provide information like this, but the results have been inconclusive.

The metal scoop with which Surveyor VII was equipped fortunately picked up a small stone on the surface of the moon, and as a result it has been possible to infer that the density of the material of which it is made lies within about 15 per cent of 2.8 grams a cubic centimetre. This is entirely within the range of densities of rocks found on the earth.

One difficulty, however, is that the density of the single stone examined by Surveyor VII is much less than that calculated on the basis of chemical analysis carried out remotely at three separate sites on the lunar surface.

Science, v.164, p.1514, 27th June, 1969.

Temperature constant in Arctic. The Times, 9th July.

Measurements of the amount of oxygen isotopes in the microscopic shells of aquatic animals in the Arctic Ocean have now suggested that the temperature of the Arctic has been more or less constant in the past 25,000 years.

Because this period extends well back into the last stages of the last ice age, the results have an important bearing on theories of how the Arctic Ocean may have been involved in the genesis of the ice ages.

Measurement of oxygen isotopes is now widely used to determine the temperature at which aquatic creatures live. The two isotopes concerned are oxygen-18 and oxygen-16. The latter is the more abundant. The ratio of the two isotopes accumulated in the calcium carbonate shell of an animal growing in water will differ from the ratio of the isotopes in the water itself by an amount which depends on the temperature.

This means that the ratio of the isotopes in marine shells is an indicator of the temperature at which they were formed and, by extension, the ratio of the isotopes in the shells of marine creatures long since dead is an indicator of the temperature at which these creatures lived.

The new study of the Arctic has been carried out by J. van Donk and G. Mathieu, of the Lamont-Doherty Geological Observatory of Columbia University, New York. They have measured the ratio of oxygen isotopes in the microscopic shells of a species of foraminifera which has been plentiful in the Arctic for several thousand years. Fossil shells were obtained by drilling cores into the sea bed. The length of time for which the study is valid, 25,000 years, is determined by the date at which these microscopic creatures made their first appearance in the sediments.

Journal of Geophysical Research, v.74, p.3396, 20th June, 1969.

Is the moon a captured planet? The Times, 10th July.

The predominant age of the lunar rocks brought back by the Apollo astronauts may be about 700 million years. This prediction is made on the assumption that the moon was once a wandering planet that was captured during a close approach to the earth.

The origin of the moon is uncertain to the extent that there are still three radically different theories in the running. The moon may have accreted from the same cloud of dust and close by the earth, it may have been part of the matter spun off the earth at an early stage of its existence, or it may have been formed elsewhere in the solar system and captured by the earth some time later.

The capture theory holds what is probably a short lead over its rival by virtue of a remarkable calculation performed by Mr. H. Gerstenkorn in 1955. At present the tides raised on earth by the moon are slowing down the earth's rotation and pushing the orbit of the moon farther away at the rate of three centimetres a year.

Reversing this process into the past it is plain that the moon was once very much closer to earth or even, as some astronomers assume, a part of it. This calculation, first performed by George Darwin in 1878, seemed to rule out any theory of capture.

Gerstenkorn's feat was to show that the moon could have been captured if it had approached the earth in a direction contrary to its present motion and to the rotation of the earth. With the earth's spin and the moon's orbit in opposite directions, the gravitational attraction of the ocean tides would have pulled the moon in instead of pushing it away. But the tides would also have twisted the plane of its orbit in such a way as to flip the orbit over the poles of the earth and down the other side.

The effect of this manoeuvre is simply to reverse the direction of the moon's path round the earth. With its direction now the same as the earth's rotation the moon would begin to be pushed out by the tides towards its present position.

Gerstenkorn's theory has been criticized on several grounds, the chief of which is that he shows the moon making its closest approach to earth only a few hundred million years ago, which is well within the geological record. The effects of this approach, according to some geophysicists would have been catastrophic. Tides more than a mile high would have swept the earth from pole to pole, the oceans would have boiled away and all life would have been obliterated. The geological record shows that this did not happen.

On the eve of the moon landing a vigorous defence of Gerstenkorn's theory has been put forward by Professor H. Alfven of the Swedish Royal Institute of Technology. Together with Professor G. Arrhenius, of California University, he argues that the close approach of the moon would have been less catastrophic than expected and that traces of this event can be identified in the geological record as well as in falls of certain meteorites.

<u>Science</u>, v.165, p.11, 4th July, 1969.

<u>Creation epic in ice age jungles</u>. <u>The Times</u>, 17th July.

The immense variety of animals and birds that inhabit the tropical forests of central South America probably owe their existence to the climatic fluctuations of the last ice age. The abrupt swings of the climatic pendulum and the accompanying changes of vegetation were such as to encourage the rapid evolution of new species.

The theory is proposed by Jürgen Haffer, a geologist with the Mobil Research and Development Corporation in Dallas, Texas. He argues that the rise of the Andes mountains, which probably reached their full height only about two million years ago, caused a humid climate and the spread of dense forests across Brazil and the basin of the Amazon.

During the last great ice age, which began at almost this time, the forests expanded and retracted in response to the shifting moods of the climate. In dry periods the Amazonian jungle retreated into a number of smaller forests separated by tracts of open land.

Small groups of animals and birds found refuge in these pockets of forest where, in isolation from populations of their own species in other forests, they started to deviate genetically from one another.

Science, v.165, p.131, 11th July, 1969.

Moon, Mars may be parts of earth. The Times, 18th July.

Mars and the earth may once have been a single planet that deformed into two parts, with the moon being separated as a droplet of material between them. This would account for the overall composition of the three bodies, according to W.H. McCrea, Professor of Astronomy at Sussex University.

Professor McCrea is concerned to show that the large-scale features of the earth, moon and Mars, and of planetary formation in general, can be explained with a handful of simple physical facts. First among them is the recent observation that clouds of silicate dust, the chief component of ordinary rocks, are surprisingly plentiful in interstellar space.

Nature, v.223, p.259, 19th July, 1969.

Underground rocks surveyed by canal. The Times, 19th July.

An underwater device for studying the rock layers beneath the sea bed has been adapted for use on land. Towed along a stretch of the Grand Union Canal near Northampton, the device has revealed geological strata down to 350 ft. underground.

Used at sea, the seismic profiler, as the device is called, emits a stream of sound waves which are reflected back from the various rock layers under the seabed and recorded by a microphone towed behind the ship. From the recorded echoes a profile of the underlying strata is built up.

The profiler must be moved smoothly and steadily over the strata it is surveying, which is hard to do on dry land. But the device gives reasonably good profiles when towed along a canal, as has been shown by a team of geologists from Reading University, the Institute of Geological Sciences, and the Marine Science Laboratories at Menai Bridge.

Nature, v.223, p.295, 19th July 1969.

Quakes may have shaped moon's face. The Times, 21st July.

The major features of the lunar surface may have been shaped by vibrations that shook the whole body of the moon. The vibrations, set off by internal eruptions or the impact of large meteorites, were powerful enough to affect the general direction of mountain chains and valleys.

This is the theory proposed by scientists working at the North American Rockwell Corporation and Nebraska University. They point out that many of the major features of the moon, such as valleys and mountain ranges, tend to be oriented in particular directions of the compass, much as if they had been shaped by global forces. The shaping influence could be the characteristic oscillations of the moon, similar to the vibrations set off in the Earth by large earthquakes.

Nature, v.223, pp.259 and 250, 19th July, 1969.

Theory of gravity fluctuations. The Times, 22nd July.

A link between the variations in strength of gravity from one place on the surface of the earth to another and the movement of the continents has been suggested by two scientists from Hawaii University, Ralph Moberly and Mohammad Khan. Their argument is important because it may suggest ways of interpreting some of the features of the pattern of continental drift that have not yet been explained.

Variations in the strength of the earth's gravitational force have been known, of course, for more than a century. In some parts of the world the strength of the downward gravitational pull may differ from the average by two or three parts in a thousand.

In some places, as in Hudson Bay, or over Scandinavia, the strength of the downward force is less than elsewhere because of the way in which the rocks were pressed downwards by the ice which melted 8000 years ago, at the end of the last ice age. Elsewhere, as in the Himalayas, an excess downward pull is present because of the comparative youth of the mountains; there has not been time for the underlying rocks to find their own equilibrium again after the mountains were pulled on top of them.

Most of the regions of abnormal gravity, however, have not been explained in ways like this. For example, the eastern Atlantic, both north and south of the equator, is characterized by a downward gravitational pull some two parts in 1000 greater than elsewhere. In the western Atlantic, particularly towards the Carribean, the downward gravitational pull is less than the average by an almost similar amount. Why should this be?

The explanation now offered is that the difference between the east and west Atlantic is the difference between the regions on either side of what is called the Mid-Atlantic Ridge - the chain of submarine mountains running southwards from Iceland. This is now known to be the place at which fresh volcanic rocks appear from the deep interior of the earth and spread out sideways, pushing the continents of Africa and South America before them.

Nature, v.223, p.263, 19th July, 1969.

Moonquake pack first of chain. The Times, 23rd July.

The seismic recorder which Neil Armstrong and Edwin Aldrin left behind on Monday is likely to be the first of a chain of automatic stations stretching across the visible face of the moon. The instrument is a simplified version of the seismographs used to record earthquakes and offers the best available means of investigating the secrets of the lunar interior.

In theory the instrument standing on the lunar surface will determine whether the moon possesses a double structure, core and outer mantle of rocks as on earth.

Science, v.165, p.241, 19th July, 1969.

Magnetic reversals have long-term regularity. The Times, 24th July.

The possibility of a link between the rotation of the galaxy, which goes once round in 300 million years or thereabouts, and the reversals of the direction of the earth's magnetism, which take place every quarter of a million years or so, is suggested on the basis of an analysis of the geomagnetic record by I.K. and P.L. Crain, of the Australian National University of Canberra, and M.G. Plaut, of the University of Western Ontario. Their analysis is published in the current issue of Nature, and must be counted a piece of speculation, although a helpful speculation, given the inevitable uncertainty about the pattern of the earth's magnetic reversal.

Nature, v.223, p.283, 19th July, 1969.

Australia once joined to India. The Times, 25th July.

Australia and India were probably joined to each other some hundreds of millions of years ago, the west coast of Australia lying opposite the east coast of India and Ceylon. This is inferred by A.R. Crawford of the Australian National University, Canberra, on the basis of some 400 ancient rocks he has dated in various parts of India and Ceylon.

Nature, v.223, p.380, 26th July, 1969.

Anatomy of a Hawaiian volcano. The Times, 31st July.

The Kilauea volcano in Hawaii regularly changes shape during each cycle of eruptions. Every year or so the volcano expands like a balloon as chambers in its heart are pumped full of molten rock. When bursting point is reached the lava pours out and the volcano rapidly subsides until the next cycle.

American geologists have established an observatory on the rim of the crater, and by detailed study of the most recent eruption have inferred something of what must be happening inside the volcano to produce the cycle of expansion and deflation.

The events leading up to last year's eruption began in 1966 with a slow uplift of the summit. The total movement was about two feet, but the recording instruments were sensitive enough to show that the centre of uplift shifted from one place to another during the period of expansion, each movement being followed by a surge in the expansion of the volcano.

The migration of the centre of uplift suggests that a system of interconnected chambers lies within the heart of the volcano. Molten rock is pumped into the chambers from beneath and as each chamber is filled the summit of the volcano begins to expand in a different place.

From the shape of the expansion it seems that the system of chambers lies about a mile and a half below the summit and within the upper half of the body of the volcano. The molten rock that fills the chambers is probably generated some 30 miles below the ground, but since this would be a steady process and the expansion of the volcano is erratic it seems that there may be an intervening chamber some 20 miles below ground where the molten rock accumulates and is released at intervals.

Science, v.165, p.341, 25th July, 1969.

Make-up of the dust in space. The Times, 4th August.

The clouds of dust which obscure vast tracts of the Milky Way are a mixture of graphite and silicate grains, according to Professor Fred Hoyle and Dr. N.C. Wickramasinghe, of the Institute of Theoretical Astronomy at Cambridge University.

The composition of the clouds is important because the dust seems to be the material out of which stars and planets are formed; and for this and other reasons it may play a major role in the evolution of the universe.

What Professor Hoyle and Dr. Wickramasinghe have to say follows from a series of measurements reported earlier this year by a team of astronomers at California and Minnesota universities. These indicate that much of the interstellar dust consists of silicates, the major component of ordinary terrestrial rocks and sand.

Nature, v.223, p.459, 2nd August, 1969.

Fossil site found in old African lake. The Times, 9th August.

Recent excavations on Mount Elgon, straddling the Kenya-Uganda border, have provided a fresh glimpse into the assortment of animal species that inhabited East Africa some 20 million years ago. Geologists working on the same site have been able to reconstruct a picture of the countryside that surrounded the ancient lake in which the fossils were deposited.

The Mount Elgon site, discovered in 1965, is important because it fills in a gap between contemporary fossil finds in neighbouring parts of Uganda and Kenya. Several recent expeditions to the site have uncovered a rich hoard of fossil mammals and other species, which are described by Dr. Alan Walker, of Makerere University College, Kampala.

Several of the mammalian species were previously unknown in East Africa.

Nature, v.223, p.591, 9th August, 1969.

Evidence for life outside earth. The Times, 15th August.

Life has existed outside earth, if a new chemical analysis of meteorites is correct. Two chemists at Bradford University believe they have identified in meteorites chemicals that can only be formed in living cells.

The implication is that there was life in the universe before the earth was formed, because meteorites are at least as old as earth.

Previous claims to have detected signs of extraterrestrial life in meteorites have prepared what will doubtless be a sceptical reception for the new results. Most if not all of the biological chemicals found in meteorites are now thought to be terrestrial contaminants that seeped in after a meteorite had entered the earth's atmosphere.

The chemists, J. Brooks and G. Shaw, have detected a chemical in meteorites that is almost certainly not a contaminant since it forms some 4 per cent of the meteorite's weight. They believe that the chemical is sporopollenin, the biological material that forms the outer coat of pollen grains.

By a variety of chemical tests they have shown that the chemical in the meteorites resembles the sporopollenin both in present-day plants and in fossil plants. The fragments tested were from large meteorites that fell at Orgueil, France, in 1864 and at Muiiy, Kentucky, in 1950.

Nature, v.223, p.756, 16th August, 1969.

Oldest sea floor found in Pacific. The Times, 21st August.

An area of sea bed which is probably the oldest surviving patch of oceanic floor in the world has been discovered in the north-west Pacific. Thick layers of sediment, deposited over at least the last 140 million years, have been recovered from the area by the American research vessel Glomar Challenger, it was announced in New York yesterday.

The interest of the finding is that it will extend still further back in time the record of the earth's geophysical history, in particular of the way in which the continents have drifted over the face of the globe.

The area of sea bed lies to the east of the Marianas Islands, which are about half-way between New Guinea and Japan. It was surveyed by the Glomar Challenger during the sixth leg of an oceanographic voyage which started in the Gulf of Mexico last year and has already produced results of outstanding scientific interest. These have confirmed much of what was previously only conjecture about the history and formation of the ocean floors.

The research programme is supported by Joides, a consortium of five oceanographic institutions in the United States. Involving a comparatively modest series of drillings the project has in scientific terms yielded far greater dividends than more ambitious schemes in the earth sciences such as the Mohole project, the ill-fated attempt to drill a hole through the earth's outer layers down to the Mohorovicic discontinuity.

The latest success of the Joides programme will throw light on the history of sea floor spreading ....

Nature-Times News Service.

Study may help earthquake prediction. The Times, 23rd August.

A succession of large earthquakes which shook widely spaced sites in the Middle East early this year occurred in a particular pattern, according to an analysis by P.A. Mohr of the Smithsonian Institute of Massachusetts. If the pattern is real and not just a statistical coincidence there is the chance that it may afford a means of predicting earthquakes.

Earthquakes occur when the stresses built up between two adjacent blocks of the Earth's crust are suddenly released. Dr. Mohr's suggestion is that the shock waves travelling out from a primary earthquake may trigger off a cascade of secondary earthquakes elsewhere. Applying this domino theory to the Middle East, he notes that the first earthquake, which occurred in Turkey on March 28, was followed within a few days by shocks in Sinai and in the Afar region of Ethiopia.

The time and distance between these events can be explained on the assumption that a stress front travelling south from the Turkish earthquake at about 10 m.p.h. triggered off the secondary quakes in Sinai and Afar.

Another stress front, travelling somewhat faster, could have set off the second series of earthquakes which occurred in Sinai and Tanzania during April.

Nature, v.223, p.816, 23rd August, 1969.

How life on earth may have begun. The Times, 25th August.

A crucial problem in the origin of life on earth may have been solved, at least in outline, by a chemical model constructed in the laboratory. The model suggests how proteins and nucleic acids, the two kinds of chemical which constitute the essential machinery of life, could have come to interact with each other in the way that characterizes their relationship in the living cell.

Proteins and the components of nucleic acids would have been formed under the natural physical conditions prevailing on the primitive earth. It is the chemical problem of how they came to associate with each other in a self-replicating system that is the chief obstacle to understanding how life first evolved.

The obstacle is particularly formidable because a direct chemical association between nucleic acids and proteins no longer occurs in the living cell, having been replaced in the course of evolution by intermediary machinery of particular subtlety. The interest of the chemical model, constructed by James C. Lacey and Kenneth M. Pruitt of Alabama University, lies in its demonstration that some of the intermediary machinery are embodied in the direct interaction between protein and nucleic acid.

Nature, v.223, p.799, 23rd August, 1969.

How the earth strains after the moon. The Times, 26th August.

Strain meters set up in a disused railway tunnel in Yorkshire are recording the minute tides raised in the solid earth by the attraction of the moon. The earth tides occur twice a day, like the sea tides, but are microscopic in extent.

The strain meters are new devices developed by geophysicists at Cambridge and Warwick universities, who hope to use them for recording distant earthquakes and the free vibrations of the earth as a whole.

Nature, v.223, p.818, 23rd August, 1969.

White House on ice-age marsh. The Times, 27th August.

The White House in Washington stands on 500,000 years of geological history, composed of the detritus deposited during the tail end of the last great ice age. The deposits fill a wide channel excavated by the Potomac river, then much broader under the burden of the melting ice sheets.

The deposits came to light when a shallow layer of peat was unearthed by workmen during the rebuilding in Lafayette Park, on the north side of the White House. A test pit excavated by Arthur S. Knox, of the United States Geological Survey, has uncovered 100 ft. of silt and organic remains between the peat and the bedrock.

The remains record two retreats and advances of the mile-thick ice sheet that covered Canada and the Great Lakes area until a few thousand years ago.

Science, v.165, p.795, 22nd August, 1969.

Rockall islet may be sunken continent. The Times, 28th August.

A survey of the sea floor round Rockall suggests that the island may lie over an extinct volcano that erupted some 50 million years ago. There are signs that the geological history of the island, which may be a sunken fragment of continent, is connected with the opening up of the North Atlantic ocean that began at about this period.

The survey of the Rockall bank has disclosed a belt of magnetic anomalies in the rocks on the sea floor. The anomalies, which curve round the island in a broad sweep, are of the type that is formed by cooling lava flows.

On solidification the lava is permanently magnetized in the prevailing direction of the earth's magnetic field. The pattern of the magnetized belts, according to Dr. D.G. Roberts of the National Institute of Oceanography at Godalming, suggests that an extinct volcanic centre underlies the Rockall bank and Rockall islet.

Nature, v.223, p.819, 23rd August, 1969.

Astrobleme in Libyan desert. The Times, 29th August.

A triple ring of hills in the Cyrenaican desert of Libya may be an astrobleme, the scar left by a huge meteorite that collided with the earth. There are signs that the collision occurred some 35 million years ago.

The hills, a set of three nearly circular rings nested one inside the other, were discovered by A.J. Martin and D.J.R. Sheridan of the British Petroleum Company in Australia . The innermost ring, a third of a mile in diameter, consists of a jumbled mass of craggy outcrops rising some 50 ft. above the ground. The outermost ring is nearly two miles across.

Circular structures such as this are sometimes left by collapsed volcanoes and other geological processes. But the flat terrain around the ring bears no evidence of volcanic activity or earth movements. Dr. Martin believes the rings are the impact structure left by a meteorite.

Tektites, glassy, button-shaped objects which are probably of extra-terrestrial origin, have been found in the Libyan desert and dated by radio-active methods to 35 million years ago. The meteorite, which may in some way be connected with the tektites could have fallen at the same time.

Another ring of hills, the Carswell structure in northern Saskatchewan, has been examined by K.L. Currie of the Geological Survey of Canada. The structure consists of a double ring of hills some 20 miles across with cliffs up to 200 ft. high. In this case Dr. Currie has rejected the possibility that the rings are an astrobleme. Rather it seems they are the edges of a gigantic blister formed by a bubble of gas that gathered deep below the ground and burst to the surface some 475 million years ago.

<u>Nature</u>, v.223, p.940, 30th August, 1969.
and <u>Geol. Survey of Canada</u>, <u>Paper</u> 67-32.

<u>Israel moving up and down.</u> <u>The Times</u>, 3rd September.

A striking analysis of how various parts of northern Israel have moved vertically in the past 20,000 years or so has been provided by U. Kafri of the Geological Survey of Israel in Jerusalem.

Although it is known that many parts of the surface of the earth are still recovering from the disappearance of the ice after the last ice age and from the changes of sea level which also marked that time, the measurements now made in Israel have the interest of showing the oscillatory character of some of the changes still taking place.

The amount of detail revealed by the Israel survey is attributable to the way in which repeated geodetic levellings have been made of a network of bench marks in the past three decades. One set of the bench marks runs north from the Sea of Galilee to the border with Lebanon. The other runs from Nazareth to Haifa and south along the coast.

The first network of bench marks is of great interest because of the way it borders on the northern extension of the Rift Valley beyond the Sea of Galilee. The Dead Sea further south is known to have subsided at the rate of nine millimetres a year for the past 24,000 years, chiefly from measurements of the margins of the ancient Lisan Lake of which the Dead Sea is a relic.

It is also known that most of the change of level of the Dead Sea occurred between 24,000 and 23,000 years ago, when the level of the lake changed by 190 metres in a mere 1,000 years.

Further north the rates of change are on the average less rapid, although still considerable.

Journal of Geophysical Research, v.74. p.4246, 15th August, 1969.

Cause of deep quakes. The Times, 13th September.

The doctrine of sea-floor spreading, well on the way to becoming the philosopher's stone of geophysics, has now suggested a theory of the deep earthquakes which occur in some parts of the world, especially around the margins of the Pacific Ocean. In the current issue of Nature, B. Isacks and P. Molnar of the Lamont-Doherty Geological Observatory in New York, argue that detailed studies of typical deep earthquakes have shown that many of them occur at places in the outer layers of the earth where the crustal rocks are being carried into the deep interior of the earth.

The notion that movements within the earth's crust may be the driving force for earthquakes is not, of course, new. In the past few years, geophysicists have recognized several different ways in which processes related to continental drift can cause earthquakes and even volcanoes. In Africa, for example, the patch of seismic activity south-west of the southern end of the Rift Valley is thought to be a consequence of the progressive opening of the valley under the influence of external stresses on the continent of Africa.

The Californian earthquakes, and even the existence of the San Andreas Fault along which they occur, are by contrast thought to be a sign that the coastal strip in the south-west United States is at the eastern edge of a huge section of the earth's crust which is being moved bodily northwards relative to the rest of the continent.

Earthquakes caused by these processes, however, occur at comparatively small depths in the earth's crust, 10 to 20 miles down or thereabouts. The theory which has now been put forward by Dr. Isacks and Dr. Molnar is meant to account for the earthquakes which occur at depths of 100 to 500 miles, well into the mantle of the earth and far beneath the plates of solid material which are believed to drift intact across the surface of the earth.

Nature, v.223, p.1121, 13th September, 1969.

Atlantic Ridge has acidic rocks. The Times, 18th September.

Accepted notions about the geochemical processes in the outer layers of the earth's crust may be modified as the result of the discovery of acidic rocks associated with the outer slopes of the mid-Atlantic Ridge, the submarine mountain range running north to south from Iceland into the South Atlantic.

The discovery, which is reported in the current issue of Science by Dr. F. Aumento of the Geological Survey of Canada, may also help to explain away the previously puzzling appearance of small acidic rock samples at the bottom of the deep oceans and far away from the nearest land.

The rocks of which the ocean floors are made, usually described as basalt in general character, are chemically non-acidic or basic. According to the now fashionable doctrine of sea-floor spreading, material of this kind is continually being pushed outwards from the mid-oceanic ridges, of which the mid-Atlantic Ridge is now one of the most closely studied examples. Because the material found on the tops of the ridges or on the upper slopes of the mountain ridges is thought to be characteristic of the material of which the mantle of the earth is made, it has been assumed that the outermost layers of the earth's solid mantle are largely basic in character.

The rocks now recovered from the ocean floor at a place known as the High Fractured Plateau, 60 miles west of the mid-Atlantic Ridge in latitude 42°N. are a surprise because they are chemically acid. The mineral of which this material is made is similar to that known as diorite. The pieces of rock recovered in this way seem to be angular lumps of material showing few signs of rounding by ocean waves and other forces of erosion. The question is why they should occur in such unlikely circumstances.

Science, v.165, p.1112, 12th September, 1969.

Valley as prehistoric centre. The Times, 19th September.

It has now begun to seem as if the Omo Valley, running north into Ethiopia from the edge of Lake Rudolph, will emerge as one of the principal sources of pre-human fossils. In the current issue of Nature, Professor Clark Howell of the University of Chicago explains how he has been able to recover from the valley fossils representing creatures on the line of descent to human beings which were living between three and four million years ago. By this step, Professor Howell has been able almost to double the recorded history of the direct ancestors of man.

The Omo Valley has been close to the hearts of paleontologists for several years, and especially since geological studies in the area demonstrated that a vast tract of land running from close on 200 miles north of Lake Rudolph may have been filled with comparatively recent deposits of gravel and other loose material of the kind in which fossils are preserved comparatively well.

An environment of this kind is known to have been responsible for the way in which the Olduvai Gorge, south and not north of Kenya, has been a happy hunting ground for Dr. Louis Leakey and his fellow anthropologists. The rapid accumulation of material in the Omo Valley is probably accounted for by the change in the course of the Nile, now lying far to the north, which would have taken place during the period of the ice ages.

Although the chance to make expeditions to this area has been sought eagerly in recent years, the hazards of the search have been recognized for a long time. The area is one in which groups of bandits still operate, and the first expedition in 1967 was accompanied by an armed guard under the aegis of the governments of Kenya and Ethiopia.

Nature, v.223, p.1234, 20th September, 1969.

Allende meteorite age decided. The Times, 22nd September.

The age of the Allende Meteorite, which fell near Pueblito de Allende, in Chihuahua, Mexico, on February 8 last, has now been estimated by two physicists at Birmingham University. Their report, which appears in the current issue of Nature, is important, not only because it is the first published account of this meteorite, one of the largest ever to have been seen to fall on the earth, but also because the method of age determination should be a useful check on other ways of doing this.

...... the Birmingham physicists conclude that the age is probably something between one million and seven million years.

Nature, v.223, p.1219, 20th September, 1969.

Oldest fossils on earth? The Times, 23rd September.

A suggestion that some microscopic rocks from South Africa may be the oldest fossils on the earth has been undermined by Dr. B. Nagy and Dr. L.A. Nagy, working at Arizona University.

The issue is important because of the continuing controversy, in the past decade, about the interpretation of what are described as organized elements in some forms of meteorites and in ancient rocks from the Precambrian. On several occasions in the past few years recognizable structures in these materials have been likened to the fossilized forms of extinct plant cells, possible algae or even pollen grains.

The rocks which the researchers have studied are from the Onverwacht series of sedimentary structures in South Africa, and are known to be more than 3,000 million years old. The rocks are an exceedingly thick layer which seems to be six miles thick in places. A part of its interest is that it lies immediately beneath younger rocks, called the Fig Tree series, in which it seems most probable that some so-called organized elements are fossilized forms of extinct plant creatures.

...... What the researchers have done is to subject the small structure which can be teased out of the rock to the kind of chemical analysis which has been used with other materials to demonstrate the existence of organic materials. Their results are inconclusive but probably negative.

Nature, v.223, p.1225, 20th September, 1969.

Data galore on lunar surface. The Times, 26th September.

The first scientific report of the studies of moon rocks carried out in Houston has appeared in the current issue of Science under the names of 30 geophysicists from government establishments and universities.

The report is extremely detailed but strictly factual. Although it is clear that in the long run the studies now being carried out will have an important influence on the development of theories of the origin of the moon, for the time being the people with access to the samples from Apollo 11 are suppressing the temptation to speculate.*

Nature-Times News Service.

Sea urchin fossil with false teeth. The Times, 27th September.

A fossil sea urchin that has lain at the centre of palaeontological debate for more than 50 years has been revealed as a forgery. The fossil has turned out to have false teeth.

The forgery, part of the collection at the British Museum (Natural History) has been detected by Dr. Porter M. Kier, of the United States National Museum in Washington. The particular specimen, known scientifically as Conulus subrotundus, is well known to palaeontologists because it is the only example of its species to possess teeth. Fossils of the Conulus sea urchins, which flourished some hundred million years ago, are commonly found in the chalk deposits of the British Isles.

Some but not all modern sea urchins possess teeth, which are part of the bony central structure that often survives the death of the sea urchin and are known after their first discoverer as Aristotle's lanterns. Battle has rolled for nearly a century as to whether the Conulus group of sea urchins possessed teeth.

The question seemed to be resolved when in 1911 Professor H.L. Hawkins discovered a specimen with teeth in an old collection at the British Museum. It has been assumed ever since that sea urchins of the Conulus type possessed teeth and Aristotle's lanterns.

As part of a study of the Aristotle's lantern in sea urchins Dr. Kier was particularly anxious to examine a Conulus lantern but dissecting hundreds of fossils found none. Studying Professor Hawkins's specimen he discovered that the teeth protruding from the mouth of the fossil were fixed in with dental cement.

Palaeontology, v.12, p.488, September 1969.

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* Fuller details of the Report will be given elsewhere in the Quarterly.

A FIELD GUIDE TO THE MYNYDD BODAFON-LLIGWY BAY AREA

Denis Bates.

Introduction

The region described was visited in April 1969 by a party of teachers taking part in the annual course organized by the Schools Service of the National Museum of Wales for teachers of geology in the schools of North Wales. It was chosen because it comprised within a small area a wide variety of rock types and structures. Exposures on the coast are excellent, and a traverse from Traeth yr Ora to Moelfre or Traeth Bychan makes a good half day or day excursion.

Mona Complex

The bare and rugged ridge of Mynydd Bodafon is formed of green schists and quartzites of the Gwna Group of the Mona Complex. The quartzites (Locality 1 on the accompanying map) are extremely hard and recrystallized quartz sandstones; they are very resistant to weathering and form the highest and best exposed ground on the hill. A "Z"-shaped outcrop starts at the north-eastern end of the ridge, curves round to the summit, and to the south-west forms almost a ring of hills surrounding the hamlet of Bodafon. The hamlet itself is situated on the softer schists. These schists, called by Greenly the Bodafon Moor Flags, are micaceous and may be partly pyroclastic. They appear to underlie the quartzites.

The gneisses and Coedana Granite north-west of City Dulas are not well exposed, though there is a small quarry half-a-mile west of City Dulas, on the minor road.

Ordovician

Shales and mudstones of lower Ordovician age lie north-west of Mynydd Bodafon, but are poorly exposed. At the north-eastern end of the ridge, half-a-mile south-west of Bodafon Isaf farm, exposures of shale occur beneath the Mona Complex quartzite. This contact (Locality 2) is faulted (the Bodafon Thrust of Greenly), the quartzite being thrust over the shales at a high angle. A slickensided surface of quartzite dipping south at 70°, marks the plane of shearing. Cleaved and sheared grey shales form the footwall.

Further exposures of shale are present in the stream bed of the Afon Goch, upstream from City Dulas. In contrast to those on Mynydd Bodafon the rock here is poorly cleaved, and bedding, defined by silty layers, dips at low angles.

Old Red Sandstone

Rocks of Old Red Sandstone facies form a transgressive series, outcropping as a belt from the coast north of Traeth Dulas to the south, resting on the Ordovician and the Mona Complex. They overstep the Ordovician shales onto the quartzite at the northern end of the ridge, thus proving that the Bodafon Thrust was formed before the deposition of the sediments of the Old Red Sandstone. The succession and conditions of deposition have recently been redescribed by J.R.L. Allen (1966).

The basal Bodafon Beds can be traced from Bodafon Isaf, over the shoulder of Mynydd Bodafon in a southerly direction. The pebble sandstones and conglomerates (Locality 2) contain material derived predominantly from the quartzites, gneisses and schists of the Mona Complex, with subordinate fragments of sandstones and shales from the Ordovician(?). A breccia of quartzite blocks is present on the slopes of Mynydd Bodafon 400 yds. west-north-west of Plas Bodafon (Locality 1) and represents a small outlier of

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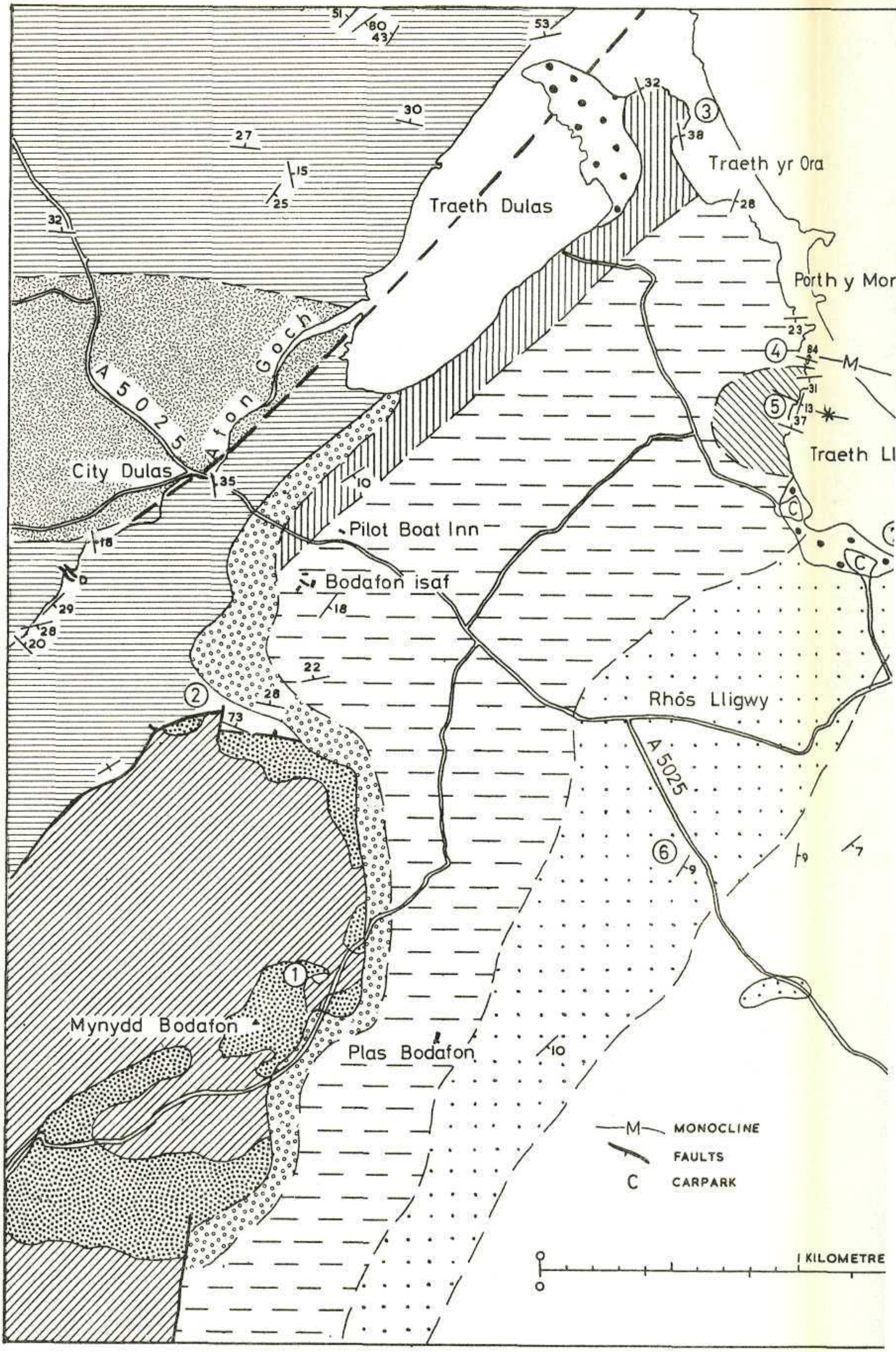
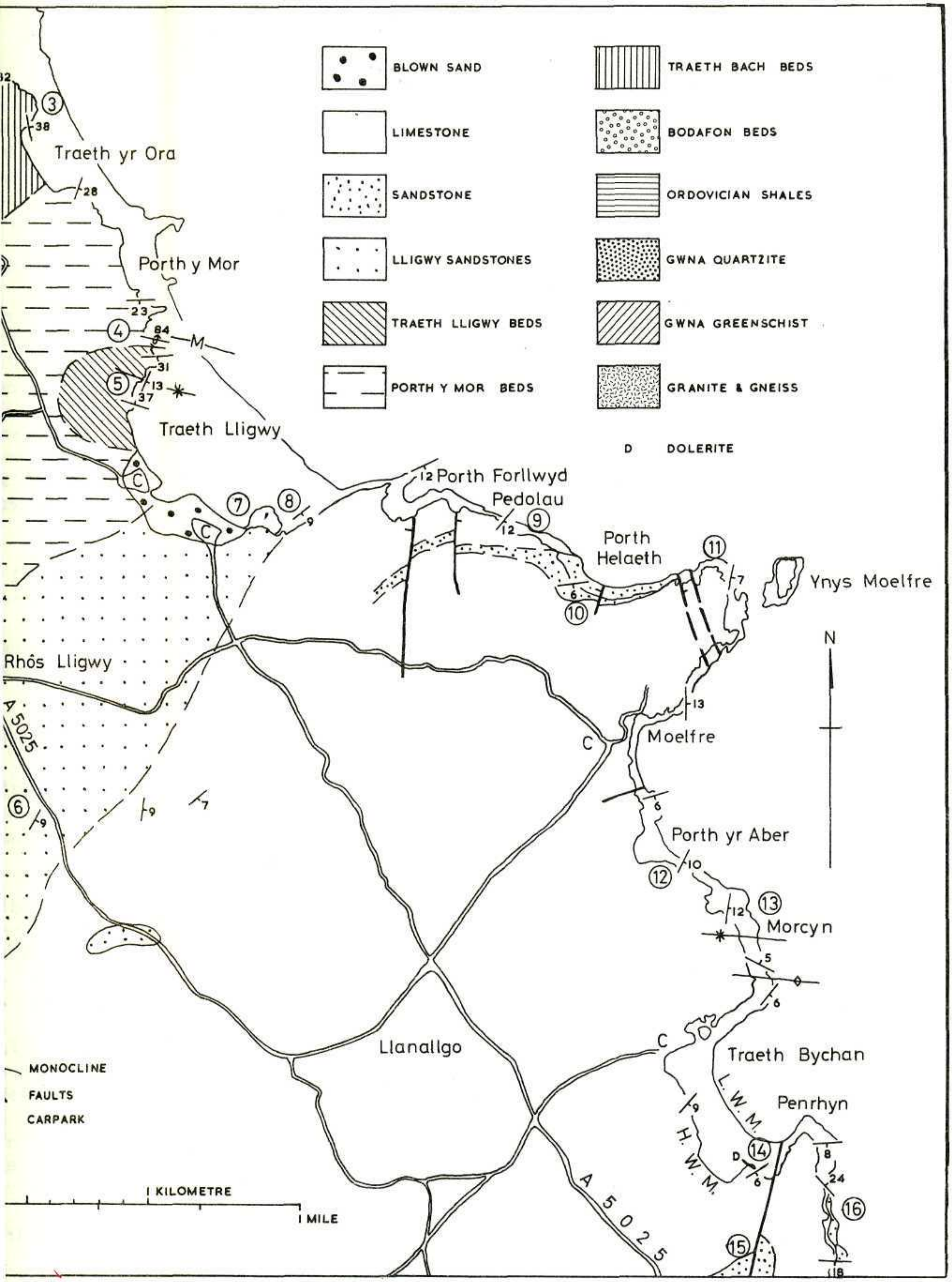
TABLE 1 : Succession

	Thickness in feet	
Limestones, shales, sandstones and limestone-conglomerates	> 750	Carboniferous
Lligwy Bay Conglomerate	> 20	Carboniferous
	unconformity	Carboniferous
Limestone	?	Carboniferous
Sandstones	> 200	Carboniferous
	unconformity	
Traeth Lligwy Beds	80	Devonian
Porth y Mor Beds	1140	Devonian
Traeth Bach Beds	425	Devonian
Bodafon Beds	10-150	Devonian
	unconformity	
Shales and mudstones	?	Ordovician
	unconformity	
Quartzites and greenschists	?	Pre-Cambrian


Traeth Dulas
Traeth yr Ora
Porth y Mor
Traeth Ll
A 5025
Afon Goch
City Dulas
Pilot Boat Inn
Bodafon isaf
Rhôs Lligwy
A 5025
Mynydd Bodafon
Plas Bodafon
M MONOCLINE
FAULTS
C CARPARK
1 KILOMETRE


BLOWN SAND
LIMESTONE
SANDSTONE
LLIGWY SANDSTONES
TRAETH LLIGWY BEDS
PORTH Y MOR BEDS
TRAETH BACH BEDS
BODAFON BEDS
ORDOVICIAN SHALES
GWNA QUARTZITE
GWNA GREENSCHIST
GRANITE & GNEISS
D DOLERITE
Traeth yr Ora
Porth y Mor
Traeth Lligwy
Porth Forllwyd
Pedolau
Porth Helaeth
Ynys Moelfre
Rhôs Lligwy
A 5025
Moelfre
Porth yr Aber
Morcyn
Traeth Bychan
Penrhyn
Llanallgo
L.W.M.
H.W.M.
N
MONOCLINE
FAULTS
CARPARK
1 KILOMETRE
1 MILE

the base. Further south, outside the area of the map, inliers of quartzite are present. The surface of unconformity was quite irregular, and seems to have risen to the south, as the Traeth Bach Beds are cut out in that direction, and the Porth y Mor Beds rest on, or abut against, the basal conglomerates. It appears that the quartzites of Mynydd Bodafon stood out as a resistant mass then, as now.

The higher beds of the Old Red Sandstone form a well exposed section between Traeth Dulas and Traeth Lligwy, with a general southerly dip. Allen describes a generally cyclical succession (Fig.6 of Allen) of sandstones and siltstones with cornstones, considered to have developed in a freshwater fluviatile or lacustrine environment, the cycles being due to changes in river meanders or to flood conditions. Finer siltstones may have been deposited in more permanent lakes, as settlement from suspension. The cornstones (i.e. limestone concretions) form in siltstone layers, and increase in amount upwards to form, when the cycle is well developed, a limestone or dolomite. Their formation is believed to follow the drying up of the lake, by a chemical replacement of the siltstone by carbonate, proceeding gradually downwards.

At the north end of the section the Traeth Bach Beds (Locality 3) are formed of red concretionary siltstones which grade up into concretionary limestones or dolomites. Conglomerates with pre-Cambrian or Ordovician pebbles occur at several horizons. Apart from the conglomerates coarse detritus was not being carried into the area, and the carbonates suggest that the playa lake was dry for long periods.

The bulk of the succession is formed of the cyclical deposits of the Porth y Mor Beds (Locality 4). Each cycle (Fig.6 of Allen) starts with a scoured surface, followed by coarse cross-bedded material, which may include conglomerate. Fine siltstones eventually replace the sandstones; they are typically without any lamination, but contain limestone or dolomite concretions, increasing in amount towards the top.

The highest beds (the Traeth Lligwy Beds, Locality 5) are exposed on the north side of Traeth Lligwy, in a syncline. Although cycles are present, they are composed only of alternations of fine grained red sandstone and sandy siltstones, without either conglomerates or concretionary rocks. Allen considers them to have been deposited in a more persistent lake.

The structure of the Old Red Sandstone rocks, as demonstrated by Greenly, is beautifully exposed on the coast. A steady southward dip characterises the northern part of the succession, but south of Porth y Mor the dip increases to vertical in a monoclinal structure (Locality 4). At the north end of Traeth Lligwy the highest beds are disposed in an easterly plunging syncline (Locality 5). A cleavage is developed in the finer sediments. It is parallel to the axial plane of the syncline, but it is rotated in the vertical limb of the monocline, which thus appears to be a later structure. Faulting is not conspicuous in the succession, except for a thrust in the Traeth Lligwy Beds south of the synclinal axis (Locality 5).

Carboniferous

Lower Carboniferous strata rest unconformably on the Old Red Sandstone, and are almost continuously exposed on the coast from Traeth Lligwy south-eastward to Red Wharf Bay. They dip at low angles to the south-east, but are cut by a series of vertical normal faults. The lowest beds are sandstones, which form low, scrub-covered country running south-westward from Traeth Lligwy; the bulk of the succession is of limestones, which are more resistant, and forms a series of scarps facing north-westward.

The Lligwy Sandstones of Greenly are exposed on either side of the A5025 near Rhos Lligwy (Locality 6). A quarry on the south-eastern side of the road offers good exposures of a coarse white sandstone, rather like the Millstone Grit, with conspicuous black carbonized plant fragments at certain horizons. It is not known whether the sandstone is, like the Millstone Grit, non-marine. From the inland exposures the sandstones appear to be followed by the limestones of the south-eastern side of Lligwy Bay, but the coastal succession, which starts at Carreg Ddafad, shows the relationships to be more complicated.

The lowest exposed horizon is the Lligwy Bay Conglomerate (Locality 7), a fossil beach deposit not unlike the present day beach shingle derived from its erosion. Blocks of pre-Cambrian and Ordovician origin are dominant, but a grey Carboniferous limestone is also common. The largest block is of this limestone, and forms a stack on the foreshore measuring at least 30ft. x 15ft. x 4ft. high. The bedding both within this limestone, and in the surrounding conglomerate, is sub-horizontal, and conglomerate adheres to the sides of this mass and to its top. The block can perhaps be interpreted as a Carboniferous sea stack which was surrounded in Carboniferous times by a beach conglomerate, much as it is now surrounded by the modern beach shingle. Its presence suggests that a limestone horizon must be present not far below the exposed Lligwy Bay Conglomerate. This limestone probably overlies the Lligwy Sandstone.

The Lligwy Bay Conglomerate is succeeded by a sequence of sandstones, shales and limestones, themselves partially broken up by pene-contemporaneous disturbance. Limestone conglomerates, which are a feature of the Carboniferous succession of Anglesey, were described by Greenly from several localities along the coast, and one can be seen in the beach platform mid-way between Localities 7 and 8. The conglomerate is formed of sub-angular blocks of limestone, cemented by a matrix of the same limestone; no foreign material is present, and the conglomerate may pass abruptly into solid limestone. The relationships suggest that the limestone must have been brecciated and re-cemented in situ, perhaps by dessication and/or earthquake shocks.

A spectacular collapse (?) structure (Locality 8) is present in limestones just above the shore platform, and was described by Greenly at some length. It also involves the breaking up of the limestone, but with features which suggest that the structure was much later than the deposition of the beds. The blocks of limestone are rounded, and set in an uncemented matrix of red clay, which was probably weathered either from the limestone or a now vanished deposit above. The rubble has filled what must have been a cave or swallow hole within the solid limestone.

The dominant rock type of the Carboniferous succession is massive limestone, but it is interbedded with shales, limestone-conglomerates and sandstones, all of which tend to be impersistent laterally. The thickest of these intercalations is the 20ft. Porth Helaeth Sandstone (Locality 10) which can be traced inland for half-a-mile. The limestones are richly fossiliferous, but it is usually difficult to extract specimens. Specimens are more readily obtained from the mudstones, or from weathered surfaces beneath overhanging ledges (Locality 9). Small faults in the sequence are picked out by differential erosion and by calcite veining. The throws in the less important ones do not exceed a few feet, and can be measured by comparing the successions on either side of the fault gash, but in other cases the strata cannot be matched and the throws are therefore unknown.

On the point east of Porth Helaeth sandstone pipes (Locality 11) described by Greenly, indicate the changing conditions of deposition. These pipe-like or bowl-like masses of sandstone occur in massive limestone immediately beneath a prominent bedding plane. The sand within the bowls must have been infilled from above, during a pause in the deposition of the limestone and after erosion of the bowls; any continuous bed of sandstone above the pipes must have been eroded before the deposition of the overlying limestone. Another horizon of pipes is present on the south side of Porth yr Aber (Locality 12), and here the sandstone of the pipes passes up into a continuous bed of sandstone.

South of Porth yr Aber, at Morcyn (Locality 13) the corals Dibunophyllum and Lithostrotion are plentiful, and are preserved in position of growth. Gentle folding of the limestones also occurs here.

A dolerite dyke (Locality 14) is present in Traeth Bychan. Only a few inches wide, it has caused little thermal alteration to the limestone on either side; it is probable that little magma passed up it. The important Dinas Valley Fault cuts the succession in the south-eastern corner of Traeth Bychan, but it is not exposed there. It can, however, be examined in the caravan site 400 yds. to the south (Locality 15), where slickensided surfaces of sandstone are exposed in a lane leading through the site.

The shore section south of Penrhyn (Locality 16) is of limestones resting on a series of coarse sandstones. The sandstones form a series of ridges striking east-west, and the limestones are draped over them, suggesting that the sandstones were partially eroded before deposition of the limestones.

Post Carboniferous earth movements have caused gentle tilting and folding of the Carboniferous strata, together with normal faulting. None of the exposed faults in the area has a displacement of more than 100 ft., but there is probably a fault along the Afon Goch and Traeth Dulas which is a major line of fracture, responsible for shearing and the production of near vertical dips in the Carboniferous Limestone on Ynys Dulas; at City Dulas it throws the Mona Complex gneisses against the Ordovician, while at the entrance to Traeth Dulas it must throw the Old Red Sandstone against both the Ordovician and a basal Carboniferous conglomerate. The latter is exposed on the north side of Traeth Dulas, and rests on Ordovician shales: on this side of the fault the Old Red Sandstone is cut out completely.

Geomorphology

The relationships between rock type and structure and landscape are unusually clear in this area, partly because the drift cover is thin, and glacial features mainly erosional. Ice moved across the region to the south-west, presumably stripping the existing soil cover, and met resistance chiefly from the Mona Complex quartzites and the Carboniferous limestones.

The quartzites of the Mona Complex stand out as extremely resistant masses, with exposure of over 80%. Their present form has been moulded by the ice, which gave smooth north-east-facing surfaces and plucked faces to the south-west (Localities 1 and 2). The rock is so resistant to weathering that even on the summits of the ridges the polish is extremely fresh and striations are easily visible. The schists, being much less resistant, form the lower portions of Mynydd Bodafon, and are much more poorly exposed. The inlier of Coedana Granite and gneiss north-west of City Dulas is not well exposed, but like the Ordovician shales is drift mantled. The latter were gouged out by the ice - probably following existing valleys - and the hollows filled with boulder clay, which is not, however, moulded into drumlins.

The Old Red Sandstone is well exposed only in the basal Bodafon Beds and the calcareous Traeth Bach Beds. The latter beds form the scarp of Coed y Gell, overlooking Traeth Dulas. By contrast the higher and more silty beds form the gently sloping and more poorly exposed ground along the south-east side of Mynydd Bodafon.

The basal sandstones of the Carboniferous are unusual in that, in spite of their massive appearance, they are relatively friable, and easily weathered, and thus give the low heath and gorse covered ground inland from Traeth Lligwy. It is surprising that this ground is relatively thinly covered with boulder clay (further south-west the sandstones are extensively covered with alluvium).

The Carboniferous Limestone country starts with a prominent scarp, marked by a steep hill on the A5025. A succession of scarps succeeds this to the south-east, though individual scarps tend to fade laterally, suggesting that the limestones themselves are in fact lenses. The dip slopes are mantled with boulder clay.

On the coast the boulder clay caps the cliffs. It rests on an ice-smoothed platform, which can be seen in section, and sometimes in plan where the boulder clay has recently been eroded back. Where fresh (usually close to the boulder clay cover), glacial striations are preserved, exceptionally with chatter marks and crag and tail structures (Locality 9). The blocks within the boulder clay are of varied composition, and from them Greenly deduced that the floor of the Irish Sea north-east of Anglesey contained Carboniferous strata, with Mesozoic rocks, including Trias and Chalk, farther away in a basinal structure.

Access

The coast sections are easily reached from Moelfre, Traeth Lligwy or Traeth Bychan, where car-parks are available. If a bus is used, it is wise not to leave the A5025 or the road to Moelfre. A coastal path and right of way extends from Traeth yr Ora to Benllech, and is marked on the current 1-inch O.S. map. The summit of Mynydd Bodafon is reached over open moorland, but other inland localities are on private land, and permission to visit them should be sought from the owners.

Bibliography

Allen, J.R.L. 1965. The sedimentation and palaeogeography of the Old Red Sandstone of Anglesey, North Wales. Proc.Yorks.geol.Soc., 35, 139-185.

Greenly, E. 1919. The geology of Anglesey. Mem.geol.Surv.U.K. 2 vols.

The map is based on the published maps of Edward Greenly and J.R.L. Allen, with additional information from R. Harbinson, B. Johnson, P. Wood and the author.

The geological map which accompanied Greenly's Memoir has recently been reprinted, in separate drift and solid editions.

Welsh Geological Quarterly, vol.5, no.1, pp. 17-23.

NEWS AND NOTES

PROJECT KING SOLOMON

On Thursday 30th January at 3 p.m., five young British 6th-form volunteers will leave London Airport for Addis Ababa to assist the Ethiopian Ministry of Mines with their geo-chemical survey of the Country.

These 18 year old volunteers will spend eight months in a virtually unexplored area, reputed to be the site of the legendary King Solomon's Mines.

The venture is sponsored by PROJECT, a new British voluntary organisation set up to assist developing countries throughout the world with skills and techniques at present chiefly available in highly industrialised societies.

Project King Solomon will give the boys invaluable experience on the ground by allowing them to work with their opposite numbers in Ethiopia before going on to read geology at University.

[The leader of the team was Peter Heath of Bridgend Boys' Grammar Technical School.]

Press Release, 29th January, 1969.

TRACE TREK

On Saturday 56 students and four postgraduate supervisors set out on the largest geochemical survey ever undertaken in this country. About 60,000 samples, covering the whole of England and Wales at an average density of one sample to the square mile, are to be gathered in ten weeks. The project, instigated by the Geology Department of Imperial College and financed by the Wolfson Foundation, aims at the production of a territorial trace element atlas that will be the first of its kind.

The Guardian, 24th June, 1969.

SOVIET 'MOHOLE' BURROWS ON

The project to drill five super-deep boreholes in different areas of the U.S.S.R. is now well under way - according to recent Soviet press statements the final drilling stage of the boreholes in Axerbaijan and the Caspian will start in 1972, and the rest a year later. Each well should take from five to six years to drill to the required depth of 15 to 18 km.

New Scientist, vol.41, no.636, 20th February, 1969, p.383.

SECOND SURVEY OF THE DISTRIBUTION OF FIELD INSTRUCTION IN GEOLOGY

As reported in Information Circular 2, the Geological Section [of the Nature Conservancy] has commenced a second survey into the distribution of field instruction in geology in Britain. Whereas the first survey of 1963/65 was concerned only with university extended field trips, the second survey is designed to be more comprehensive in its scope and to include not only localities used on day excursions but also sites visited by schools. The part of the survey concerned with schools is well advanced, although the results have not yet been collated; it is hoped to carry out the university and technical college part of the survey in the near future.

Through the courtesy of the Examination Boards it proved possible to compile a list of schools and colleges presenting candidates for examination in 'O' and 'A' level geology. The list contains 899 schools - 797 in England, 97 in Wales but only 5 in Scotland where geology still lacks recognition as a school subject. Apart from Scotland the distribution of schools is remarkably even, though it is noticeable that in proportion to population, the Welsh counties tend to have twice as many schools teaching geology as do the English. In England geology is most popular in Somerset schools and, somewhat surprisingly, least popular in Derbyshire.

Not unexpectedly the areas used for field instruction by schools in general tend to be more local than those used by the universities, though some such as the Dorset coast, the Lake District, the Craven Pennines and the Peak District attract school parties from distant parts of England.

When the final results of the survey are complete it is hoped to publish them in some appropriate journal. A full abstract will be given in a succeeding circular.

Geological Section of the Nature Conservancy, Information Circular 3, May 1969, pp.6-7.

SEARCH FOR CARDIGAN BAY GAS STEPPED UP

Offshore exploration wells are likely to be sunk in Cardigan Bay shortly to test for the presence of natural gas or oil. Mr. Elystan Morgan, M.P., has been told this by Mr. Reginald Freeson, Parliamentary Secretary to the Ministry of Power, in a letter giving the up-to-date position on the search.

Mr. Freeson said: "As you appreciate, exploration of the Irish Sea has not yet reached a stage where predictions can be made about the finding of natural gas or oil. But the initial surveys show basins of sufficient interest to encourage drilling offshore."

Mr. Freeson continued: "The Institute of Geological Sciences has carried out a seismic survey of the Cardigan Bay area and is now drilling a well on the coast at Mochras (Harlech) to supplement the geophysical studies. In addition, several exploration licence holders have undertaken studies since the area was designated last summer. Some production licences are expected to be awarded in Cardigan Bay about the end of this year. These should result in wells being sunk in the area during the next year or two. Any basin containing fairly thick sedimentary deposits (which the seismic evidence suggests to be the case in Cardigan Bay) can be regarded as potential hydrocarbon-bearing territory. But only deep exploration wells can determine the stratigraphy and hence the prospects for accumulations of gas or oil."

Mr. Freeson added: "Only time and exploration will tell, but we all hope this to be the case in Cardigan Bay."

Cambrian News, 5th September, 1969.

ANTARCTIC FOSSIL CLUE TO DRIFTING CONTINENTS

The discovery of the 200 million-year —old skull of a reptile in Antarctica has been hailed in the United States as one of "the great fossil finds of all time", which has "established without further question" that the earth once consisted of only one or two continents and that these split and drifted apart.

The find was made by an American team of scientists in the Queen Alexandra range, 400 miles from the South Pole, and was reported at the weekend to the National Science Foundation. It gives considerable weight to the theory of continental drift.

Dr. Edwin Colbert, of the American Museum of Natural History in New York, identified the skull as lystrosaurus, a reptile 2ft. to 4ft. long, other remains of which have been found in Asia and South Africa. The reptile is called a "key index fossil" of the Lower Triassic period.

Dr. Laurence Gould, the geologist who was chief scientist on the 1928 Byrd expedition, said the discovery "established beyond further question" the existence of the southern continent of Godwanaland, called after the Godwana region of India. According to this theory, the land masses were originally divided into only two continents. These then broke up and over millions of years drifted slowly across the globe to their present positions.

PRESENCE OF COAL SEAMS

The fossil was uncovered by a team organized by Ohio State University in the first bed of reptilian and amphibian fossils ever found in Antarctica. In the same bed are remains of the codonts (ancestors of dinosaurs and the present-day alligators and crocodiles) and labrynthodonts.

The concept of continental drift also explains the presence of coal seams in Antarctica, which indicate that the continent once had a far warmer climate.

According to the theory, Antarctica was originally much closer to the Equator and gradually drifted to its present position.

Striking similarities have also been found between fossil Antarctic vegetation and plants from India, South Africa, Australia and South America. This has led some scientists to claim that these lands were linked during the Permian period, about 250 million years ago.

Others have disputed this idea, saying that seeds could have been blown across the oceans or carried over by other means. This could not have been the case with the lystrosaurus fossil.

Added endorsement of the theory comes from a look at the map, which indicates that the bulge of South America could have fitted into the Gulf of Guinea, off the west coast of Africa, that India could have rested along the east coast of Africa, that Antarctica could have been linked to South Africa and Australia joined to Antarctica.

Lystrosaurus is called an index fossil because it is found in large numbers in Southern Africa and has frequently been used to date a particular deposit there and in India.

RESEMBLANCE TO HIPPOPOTAMUS

The creature somewhat resembled the modern hippopotamus in that its nostrils and eyes were high on the head, presumably so that it could both see and breathe while wallowing in shallow waters. Because of this characteristic it is unlikely that it could have swum across the vast expanses of the open ocean.

The site of the fossil was discovered on November 23 by Dr. David Elliot, of the Institute of Polar Studies at Ohio State University. It was the first day of fieldwork by his team of nine. The spot is known as Coalsack bluff, a name given to it by New Zealanders because of the coal seams that had previously been found there.

<u>The Times</u>, 8th December, 1969.

HIGH PRICES FOR MINERAL SPECIMENS

A recent sale of exotic shells and minerals at Sotheby's auction rooms in London fetched an amazing total of £12,304. Two Triton's trumpet shells, each about 16 inches long, went for £50, and a giant clam weighing 200 lbs for £58. Among the minerals sold were malachite, pyromorphite, milky and smoky quartz, garnet, tourmaline, amethyst, topaz, agate, beryl, emerald, opal, aquamarine, and zircon. A geode, 11½ inches long and broken to reveal amethyst crystals on agate fetched £40, and a rock crystal ball 4½ inches in diameter, mounted on a rock crystal column and base went for £500. Prices for decorative shells and good quality minerals seem to be increasing at a very rapid rate, so a closer watch on mineral collections may well be needed.

Commonwealth Geological Liaison Office Newsletter for April and May, 1969, p.11.

'GEOLOGY': A NEW JOURNAL

The first volume of Geology, the Journal of The Association of Teachers of Geology, was published in September, 1969.

The contents include articles on: "The formation of The Association of Teachers of Geology" by D. Emlyn Evans; "Geology in Secondary Schools" by V.R. Paling; "Techniques for the extraction of selected microfossils" by A.C. Higgins and E.G. Spinner; "Primary School geology" by Stephen Hannath; "The search for gas in the North Sea" by Rex L. Birch; and "William Smith, the Father of English Geology and of Stratigraphy: an Anthology" by D.A. Bassett; and a report of the Annual Conference, 1968.

The following paragraphs from the Preface, by the President, Professor L.R. Moore, reflect the significance of some of the contents:-

"The timing of a venture of this magnitude is often a delicate matter, but it is doubtful if any other geological journal has been launched in quite such an exciting and one hopes auspicious time. At the Conference at Keele in September 1968, Professor Sutton emphasized the importance of the revolution which Geology is at present experiencing - a revolution which is probably comparable in importance with the major qualitative changes brought about as a result of the work of Abraham Gottlob Werner, by James Hutton and William Smith in the Heroic Age of Geology. The contribution by Mr. R.L. Birch was a reminder that Geology is being applied within the United Kingdom and particularly around its shores on a much greater scale and with a greater intensity than ever before. At this Conference many speakers emphasized the spectacular growth in the number of schools offering Geology as a formal examination subject. Others spoke of the excitement generated in primary schools over an acquaintance with, and knowledge of, rocks and fossils - which in some centres were voted as the most popular of all the topics considered. Several speakers referred to the increased interest as shown by the number of pupils studying the subject, a factor which is increasingly evident in the numbers of applications for entry at University level.

Now, at a time when the Journal goes to press, a further extra terrestrial dimension has been added to the subject for the World and "Everyman" awaits the reports in the daily press or by means of the ubiquitous television coverage on the two boxes of rock samples from the Moon's surface brought back by Apollo 11. The precautions taken to safeguard the Earth from possible contamination have highlighted the possibility of extra terrestrial life - and throw into perspective the evolutionary plethora and Man's very existence as an Earth being. Geology has been introduced to the attention of a vast "audience". The superlative and spectacular photographs of the Moon's surface, its temporary habitation by Man coupled with the remarkable photographic evidence sent back by Mariner 7 from Mars have resulted in a "personal involvement". This is the ultimate essence of Geological study; the interest is real and the time is opportune."

ATLANTIC GAS, OIL POTENTIAL

The Atlantic Ocean may be a future potential source of oil and natural gas supplies.

A new sedimentary basin has been discovered in the North Atlantic, 300 miles north-west of Ireland, which "might contain oil or natural gas", the Natural Environment Research Council announced in London yesterday.

Located on an area known as Rockall Plateau, named from Rockall Island, a British possession, the structure is claimed to be similar to sedimentary basins known to exist in the Irish Sea and the North Sea. While large discoveries of natural gas have been made in the North Sea, offshore drilling has only just started in the Irish Sea and so far no positive results have been announced.

Although the oil industry has made massive technical strides in the past few years in taking the offshore search for oil and gas into deeper waters the problems of operating 300 miles out in the Atlantic would obviously be enormous.

The Times, 9th October, 1969.

HOPE BOWDLER ROAD CUTTING, SHROPSHIRE

Thanks to prompt action taken by Professor Wood and his colleagues (Aberystwyth) in informing the Conservancy of temporary exposures of great geological interest in new road excavations at Hope Bowdler negotiations for the retention of permanent exposures were speedily and successfully completed. A Conservation Corps party, based at Wren's Nest NNR, later spent a "day off" over Easter 1969 in cleaning 42 yards of face showing Caradocian unconformably overlying an irregular surface of Uriconian. The Caradocian shows a great variety of sedimentary rock types.

This section is immediately west of Hope Bowdler on the Church Stretton Road, G.R. 32/473925, and provides a much better educational section than the well-known farmyard exposure in the village. Many Shropshire sites have been wrecked by educational parties and collectors and this outstanding section could be ruined by selfish activity. It has therefore been requested that no hammers be used on this face; special arrangements required by research workers can be made. Besides the destruction of the geological interest caused by excessive hammering, it must be pointed out that the road engineers will not tolerate loose rocks being prized off and left on a classified highway and if this occurs they may feel obliged to grass the section over. A party could be subject to legal action if the verge or highway is left in a dangerous state.

The Shropshire Trust have accepted responsibility for the conservation and management of this site.

Geological Section of the Nature Conservancy, Information Circular 3, May 1969, p.8

WELSH CAVE IS LONGEST AND DEEPEST

The South Wales Caving Club says it has established Ogof Ffynnon Ddu, the Cave of the Black Spring, near Penwyllt, Breconshire, as the longest and deepest in the British Isles.

Recent research in the cave has shown that the total length of known passages in the system is more than 20 miles and that the vertical separation of the highest and lowest points is 850ft. Previously the longest known cave was Agen Allwedd, near Crickhowell, Breconshire (about 14 miles), and the deepest was the Oxlow Cavern-Giants Hole system in Derbyshire (about 620ft.)

The Penwyllt cave was discovered in 1946 but the vast extensions were entered only recently. The system consists of an impressive stream passage more than three miles long, with waterfalls, cascades, and potholes, and it is liable to serious flooding; there is also a maze of interconnecting galleries and chambers at different levels.

Because of the danger of being lost in the labyrinth of passages, access to the cave is strictly controlled; in an effort to conserve it, it has been designated a Site of special scientific interest.

The cave is the seventh longest in the world. The others are: Mammoth Ridge, United States (51 miles); Flint Ridge, United States (more than 60 miles); Eisreisenwelt, Austria (26 miles); Carlsbad Caverns, United States (33 miles); Hölloch, Switzerland (53 miles); and Tantalhöhle, Austria (23 miles).

The Times, 3rd November, 1969.

PRELIMINARY EXAMINATION OF LUNAR SAMPLES FROM APOLLO 11

A physical, chemical, mineralogical, and biological analysis of 22 kilograms of lunar rocks and fines.

The Lunar Sample Preliminary Examination Team*

An extract from the first scientific report on the examination of the samples returned from the Apollo 11 landing in Mare Tranquillitatis on 20 July 1969 - reprinted from Science, 19 September 1969 with the permission of the Editor.

Geologic Setting

Apollo 11 landed in the southwestern part of Mare Tranquillitatis at 0.67°N, 23.49°E, approximately 10 kilometers southwest of the crater Sabine D. The landing site is approximately 25 kilometers southeast of the landing site of Surveyor 5 and 68 kilometers southwest of the crater formed by the impact of Ranger 8. This part of Mare Tranquillitatis is crossed by relatively faint, but distinct, north-northwest trending rays associated with the crater Theophilus, which lies 320 kilometers to the southeast. A fairly prominent

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north-northeast trending ray lies 15 kilometers west of the landing site. This ray may be related to Alfraganus, 160 kilometers to the southwest, or to Tycho, about 1500 kilometers to the southwest. The landing site lies between major rays but may contain rare fragments derived from Theophilus, Alfraganus, Tycho, or other distant craters.

Approximately 400 meters east of the landing point is a sharp-rimmed ray crater, approximately 180 meters in diameter and 30 meters deep which has been informally named West crater. West crater is surrounded by a blocky ejecta apron that extends almost symmetrically outward about 250 meters from the rim crest. Blocks as much as 5 meters across occur on the rim and in the interior of the crater. Rays of blocky ejecta with many fragments 0.5 to 2 meters across extend beyond the ejecta apron west of the landing point. The LM landed in an area between these rays, which is relatively free of extremely coarse blocks.

At the landing site, the lunar surface consists of unsorted fragmental debris which ranges in size from particles too fine to be resolved by the naked eye to blocks 0.8 meter across. This debris forms a layer, the lunar regolith, that is porous and very weakly coherent at the surface. It grades downward into similar but more densely packed material. The bulk of the regolith consists of fine particles, but many rock fragments were encountered in the subsurface as well as on the surface.

In the vicinity of the LM, the mare surface is pockmarked with small craters ranging in diameter from a few centimeters to several tens of meters. Just southwest of the LM is a double crater 12 meters long, 6 meters wide, and 1 meter deep with a subdued raised rim. Approximately 60 meters east of the LM is a steep-walled (but shallow) crater 33 meters in diameter and 4 meters deep which was visited by astronaut Armstrong near the end of the extravehicular activities.

All of the craters in the immediate vicinity of the LM have rims, walls, and floors of relatively fine-grained material with scattered coarser fragments that occur in about the same abundance as on the intercrater areas. These craters are about 1 meter deep or less; evidently they have been excavated entirely in the regolith.

At the crater 33 meters in diameter east of the LM, the walls and rim have the same texture as the regolith elsewhere; however, a pile of blocks occurs on the floor of the crater. The crater floor probably lies close to the base of the regolith. Several craters of about the same size, with steep walls and shallow flat floors, or floors with central humps, occur in the area around the landing site. From the depths of these craters, the thickness of the regolith is estimated to range from 3 to 6 meters.

Coarse fragments are scattered in the vicinity of the LM in about the same abundance as at the Surveyor 1 landing site [1]. They are distinctly more abundant than at the other Surveyor landing sites on the maria, including the landing site of Surveyor 5 northwest of the LM. Surveyor 1 landed near a fresh blocky rim crater but beyond the apron of coarse block ejecta, as did Apollo 11. It may be inferred that many rock fragments in the immediate vicinity of the spacecraft, at both the Surveyor 1 and Apollo 11 landing sites, were derived from the nearby blocky rim crater. Fragments derived from West crater may have come from depths as great as 30 meters beneath the mare surface.

Rock fragments at the Apollo 11 landing site have a wide variety of shapes and most are embedded to varying degrees in the fine matrix of the regolith. A majority of the rocks are rounded to subrounded on their upper surfaces, but angular fragments of irregular shape are also abundant. A few rocks are rectangular slabs with a faint platy structure. Many of the rounded rocks, when picked up, were found to be flat or of irregular angular shape on the bottom. The exposed part of one unusual rock, which was not collected, was described by Armstrong as resembling a distributor cap. When this rock was dislodged with a kick, the sculptured cap was found to be the top of a much bigger rock, the buried part of which was larger in lateral dimensions and angular in form.

The evidence suggests that processes of erosion are taking place on the lunar surface which lead to the gradual rounding of the exposed surfaces of rocks. Several processes may be involved. On some rounded rock surfaces, individual clasts and grains (of which the rocks are composed) and glassy linings of pits on the surfaces of the rocks have been left in raised relief by general wearing away or ablation of the surface. Rocks which exhibit this differential erosion most prominently are microbreccia. The ablation may be caused primarily by small-particle bombardment of the surface.

Some crystalline rocks of medium grain size have rounded surfaces that have been produced by the peeling off of closely spaced exfoliation shells. The distributor-cap form observed by Armstrong may have developed by exfoliation. It also could have been produced by spalling of the free surfaces of the rock as a result of one or more energetic impacts on the top surface.

Minute deep pits, a fraction of a millimeter to about 2 millimeters in diameter, occur on the rounded surfaces of most rocks. They were observed by Armstrong, who recognized that they had been produced on the surface of the rocks and that they were distinguishable from vesicles. As described below, many of these pits are lined with glass. They are present on a specimen of microbreccia which has been identified in photographs taken on the lunar surface and for which the orientation of the rock at the time it was collected is known. The pits are found primarily on the upper side: they clearly have been produced by a process acting on the exposed surface. They do not resemble impact craters produced in the laboratory, and their origin remains to be explained.

Another discovery made by Armstrong was the presence of blebs of material with specular surfaces partially covering areas 2 to 10 centimeters wide in the bottom of six or eight raised-rim craters 1 meter in diameter. These apparently glassy blebs, which resembled drops of solder, were observed by Armstrong only in craters. The form of the blebs suggests they have been formed by the splashing of molten material that impacted at low velocity. Their distribution suggests the blebs are natural features on the lunar surface, but there is a remote possibility that they are artifacts produced by the landing of the LM.

Lunar Soil Mechanics

The upper few centimeters of the surface material in the vicinity of Tranquility Base are characterized by a brownish, medium-gray, slightly cohesive granular soil, largely composed of bulky grains that range in size from silt to fine sand. Angular to subrounded rock fragments ranging up to 1 meter in size are distributed throughout the area. Some of these fragments are lying on the surface, some are partly buried, and others are barely exposed.

The lunar surface is relatively soft to depths ranging from 5 to 20 centimeters. It can be easily scooped, offers low resistance to penetration, and offers low lateral support for staffs, poles, or core tubes. Beneath this relatively soft surface, the material's resistance to penetration increases considerably.

The mechanical behaviour of the lunar soil can be summarized as follows:

1) Confinement of the loose surface material leads to a significant increase in resistance to deformation, which is a characteristic of soils deriving a large portion of their strength from interparticle friction. The relatively small LM footpad penetrations of 2.5 to 7.5 centimeters and astronaut footprint depth of up to 5 centimeters .... correspond to average static-bearing pressures of 0.6 to 1.5 pounds per square inch.

2) The soil possesses a small amount of cohesion. This was evidenced by the following observations: (i) it possesses the ability to stand on vertical slopes and to retain the detail of a deformed shape; the sidewalls of tranches dug with the scoop were smooth with sharp edges; (ii) the fine grains stick together, and, in some cases, it was hard for the astronauts to distinguish soil clumps from rock fragments; (iii) the holes made by the core tubes were left intact upon the removal of the tubes; and (iv) the material collected at the bottom of the core tubes did not tend to pour out when the core bit was unscrewed.

3) Natural clods of fine-grained material crumbled under the astronauts' boots. This behaviour may be indicative of some cementation between the grains although in LRL tests the soil grains were found to cohere again to some extent after being separated.

4) Most of the footprints at the low loads imposed by the astronauts caused compression of the lunar surface soil, although in a few instances bulging and cracking of the soil adjacent to the footprint occurred. The latter observation indicates shearing rather than compressional deformation of the soil.

5) At the LRL, the specific gravity of lunar soil was measured as 3.1, considerably higher than the average value (about 2.7) for terrestrial soils. Based on the value obtained for the lunar soil and the measured bulk densities, the void ratio of the material in core 1 is 0.87 and in core 2 is 1.01. The respective porosities are 46.5 and 50.1 percent. Because of the disturbance involved in sampling, these values may not be representative of the material's properties in place.

6) In the LRL, material finer than 1 millimeter size obtained from the lunar bulk sample was placed loosely in a container and the bulk density of the material was found to be 1.36 grams per cubic centimeter. In a second test, the soil was compacted to a dense state with a bulk density of 1.80 grams per cubic centimeter. In the compact state, the bearing capacity of the material was determined by a small penetrometer. From these tests the cohesion of the material was estimated to be in the range between 0.05 and 0.20 pound per square inch. The above experiments were performed in a nitrogen atmosphere.

In summation, the lunar soil is similar in appearance, behaviour, and mechanical properties to the soil encountered at the Surveyor equatorial landing sites. Although the lunar soil differs considerably in composition and range of particle shape from a terrestrial soil of the same particle size distribution, it does not appear to differ significantly in its mechanical behaviour.

Mineralogy and Petrology

The lunar sample returned by Apollo 11 totals 22 kilograms, of which 11 kilograms are rock fragments over 1 centimeter in diameter and 11 kilograms are small particulate material. The documented sample box was filled by picking up selected rocks by tongs and therefore contained a variety of large rocks (total weight, 6.0 kilograms). The bulk sample totals 14.6 kilograms. It contains 4.2 kilograms of rock fragments over 1 centimeter in size, and 10.4 kilograms of material in the range below 1 centimeter.

The following discussion is based on stereomicroscopic examination of the samples aided by random grain mounts under the polarizing microscope. Some of the provisional identifications were reinforced by limited further investigation with the aid of spindle stage and x-ray powder diffraction methods, together with a study of thin sections of two of the crystalline rocks which became available near the close of the preliminary examination.

In spite of the handicap of an adherent layer of dust, all the rocks were examined. Only the contingency samples and small chips taken from the samples in the rock boxes were free of dust when they were examined.

The returned samples may be divided into four groups: (i) type A, fine-grained vesicular crystalline igneous rock; (ii) type B, medium-grained vuggy crystalline igneous rock; (iii) type C, breccia; and (iv) type D, fines. The term "rocks" is applied to fragments larger than 1 centimeter in diameter; "fines" applies to fragments smaller than 1 centimeter. All the rocks and many smaller pieces show unearthly surface features that are discussed in the following paragraphs.

Rocks. The crystalline rocks are volcanic. The term as used here implies surface lavas or near-surface igneous rocks. It carries no connotations regarding impact-generated or triggered volcanism as opposed to volcanism in the common terrestrial sense.

The rocks contain pyrogenic mineral assemblages and gas cavities, an indication of crystallization from melts. The major minerals can be assigned to known rock-forming mineral groups. The unique chemistry of the magmas has resulted in mineral ratios unlike those of known terrestrial volcanic liquids, yet not greatly different from some terrestrial cumulates, at least in the major elements.

Twenty crystalline rocks, most of which are over 50 grams in weight, were returned. The largest rock weighed 919 grams. These rocks have been classified as belonging to a fine-grained vesicular type (type A) and a coarser-grained, vuggy microgabbroic type (type B), but they may be members of a textural and compositional series.

A chip from a dark gray vesicular rock with subophitic texture (type A) has a bulky density of about 3.4 grams per cubic centimeter. Vesicles are mostly spherical, but some are ovate and they range between 1 and 3 millimeters in diameter. Coalescence has modified other vesicles, thus creating irregular-shaped cavities larger than single vesicles. The vesicles are faced with brilliant reflecting crystals of the groundmass minerals. Such vesicles contain no transecting crystals or sublimate minerals. In addition to the spherical vesicles, there are minor irregular-shaped cavities or vugs into which groundmass and accessory minerals locally project. Vugs tend to take the place of spherical vesicles in the more coarse-grained rocks; euhedral crystals projecting into vugs are common.

Preliminary modal analysis of this type-A specimen, recalculated for 15 percent void space, yields: clinopyroxene, 53 percent; plagioclase, 27 percent; opaques [abundant ilmenite and minor troilite (?) and native iron (?)], 18 percent; other translucent phases (at least two), 2 percent; and minor olivine. Notable are rare grains of olivine showing marginal transformation to clinopyroxene. The olivine grains are as much as 0.5 millimeter long, whereas most other mineral grains range between 0.05 and 0.2 millimeter in diameter. In vuggy regions, there is a slight increase in grain size. Except for the very high content of opaques, which reflects the high Fe and Ti content of the magma, the rock resembles some terrestrial olivine-bearing basalts. Mineral grain sizes and vesicle sizes, shapes, and distribution suggest that the rocks originated near the top or bottom of a lava flow or lava lake.

Nine other rocks of type A are similar to the one described above; although most have smaller vesicles. The most notable variation among them is in their olivine content which ranges from zero in some to approximately 10 percent in others.

The dark brownish-gray speckled rock of type B has irregular cavities and a bulk density of about 3.2 grams per cubic centimeter. The texture is granular; in general appearance, it resembles the microgabbroic textures of segregation veins and pods in some terrestrial basalts.

The grain size in rocks of type B varies from 0.2 to 3.0 millimeters. Preliminary modal analysis yields: clinopyroxene, 46 percent; plagioclase, 31 percent; opaques (mainly ilmenite), 11 percent; low cristobalite, 5 percent; and others, 7 percent. The largest crystals, many of which are euhedral, project into cavities. Olivine is not present in this rock or others like it. The others include an unidentified yellow mineral that seems to be concentrated in vuggy areas of the rock and a colorless phase with a high refractive index.

The crystalline rocks present a series based on groundmass grain size ranging from about 0.1 to 1 millimeter, with larger crystals in vuggy zones up to 3.0 millimeters in the coarser-grained rocks. In general, abundance of vugs increases and abundance of vesicles decreases with increasing grain size. Olivine is found only in the finer-grained rocks and the unidentified yellow phase is found only in the coarser-grained rocks. Ilmenite seems less abundant and low cristobalite more abundant in the coarser-grained rocks. The three major minerals (clinopyroxene, calcic plagioclase, and ilmenite) are present in all of the rocks.

The apparent complete absence of hydrous mineral phases is notable, as is the extremely fresh appearance of the interiors of all crystalline rocks, in spite of their microfractures and high K-Ar age.

All the breccias examined (type C) are mixtures of fragments of different rock types and are gray to dark gray in color, with specks of white, light gray, and brownish-gray rock fragments. Most breccias are fine-grained, with fragments smaller than 1 centimeter in diameter, and mostly smaller than 0.5 centimeter. Only a few fragments in the breccias are rounded.

The fragments consist of either rocks or minerals, similar to those described previously but with the distinction that a large number show a greater population of closely spaced microfractures and various degrees of vitrification. In addition, angular fragments and sperules of glass in a wide range of color and refractive indices are present which also are characteristic components of the lunar fines. In several specimens, vesicular fine-grained crystalline rock constitutes a major fraction of the larger fragments. In other specimens, mineral fragments and small fragments of the coarser microgabbroic type predominate.

Although the rock fragments are small, they seem to have a wider range of variation in modal mineral composition and shock metamorphism than the large crystalline rock samples. Several minor rock types, one predominantly light gray in color and one predominantly pale yellow, occur in breccia but are not represented among the larger individual rocks. Some breccias contain crystal fragments larger than 3 millimeters in diameter, thus indicating that there exist on the moon more coarsely crystalline rocks than those returned.

The finer fraction of the breccias is gray and granular in appearance and consists largely of glass particles (both angular and rounded) and fragments of birefringent minerals, coated in part with glass or with opaque or fine-grained dusty material. The glass particles, forming most of the matrix, are similar to the glass of the fines. Many single glass particles are composed of more than one type of glass and therefore are unlike glass shards of common terrestrial volcanic processes. Some of the breccias are transected by vesicular "glass" veins or contain particles of glass either formed in place or injected along fractures.

The degree of induration and the history of subsequent deformation of the breccias are varied. Some breccias are very poorly consolidated and are soft and friable. Others have coarse layering. Still others have closely spaced fracture systems and are as hard, if not harder, than the hardest of the crystalline rocks. Many of the broken fragments of crystalline rocks in the breccias, and the breccias themselves, are composed of impact ejecta.

Two types of unique surface features occur on all rocks of the lunar samples. These are small pits lined with glass and glass spatters not necessarily associated with pits. In addition, the crystalline rocks show a generally lighter-colored surface compared to the interior, which appears to be related to microfracturing of surface crystals.

The diameter of pits averages somewhat less than 1 millimeter. Diameter-to-depth ratios of the pits have a range of values, but it appears that the ratio is smaller for pits in the breccias than for pits in crystalline rocks. A few of the rocks examined show pitting on rounded sides but no evident pitting on one (generally flat or irregularly rough) surface. The surfaces of the glass in the pits are bright-reflecting and commonly uneven and botryoidal. Botryoidal surfaces are more common in pits in breccias than in crystalline rocks. Raised glassy rims occur in greater abundance in surrounding pits in the breccias. The glass extends beyond some pit rims. Fractures and rare glass veinlets radiate out from some pits. The pits are presumably caused by the impact of small particles on the surfaces of the rocks.

In addition to glassy pits, thin glass crusts occur that appear to be the result of spattering. Spatter crusts more than 1 centimeter in diameter occur both on breccia and crystalline rock surfaces. These may be related to nearby impact events.

The surfaces of the crystalline rocks show whitish blotches and halos around the glassy pits. This whitish color is at least partially attributable to intense microfracturing of minerals, particularly feldspar and pyroxene, and it does not penetrate more than 0.5 to 1.0 millimeter below the surface in most cross sections examined. In some crystalline rocks, whitening may be so widespread on some surfaces that the whole surface is lighter in color than the interior. This feature is particularly noticeable in fine-grained rocks, which are dark gray on freshly broken surfaces.

The most noticeable surface feature of the rocks is the rounding of one or more edges and corners. The most striking example of rounding, and perhaps the most common, is that in which one side of a rock is nearly flat and the remainder of its surface is rounded. Rounding appears to be more pronounced in the softer, more friable, breccias than in the crystalline rocks. The original surfaces of breccias commonly have coarser grains projecting above the surface, which suggests that the finer grains surrounding them have been eroded away. The appearance is thus similar to that of friable sedimentary rocks of a wide range of grain size which have been sandblasted. Both the rounding and the detailed surface appearance indicate that some sort of erosional process has acted on the rocks.

The surface features of some rocks allow conclusions to be made regarding the orientation of the rock on the surface.

Fine material. Two core samples, each 2 centimeters in diameter, were returned: core tube 1 contained 10 centimeters, and core tube 2 contained 13.5 centimeters of material. The cores are composed predominantly of particles with diameters from 1 millimeter to 30 micrometers, with admixed angular rock fragments, crystal fragments, glass spherules, and aggregates of glass and lithic fragments in the coarser-sized fraction. When the upper half of the split-tube core liner was removed, the material sustained its cylindrical shape perfectly. Both the material in the tubes and the fines in general are medium to dark gray with a tinge of brown.

When prodded with a small spatula, the material disintegrates particle by particle or forms extremely fragile ephemeral units of subangular blocky shapes.

Neither core sample shows obvious grain-size stratification. The core from tube 2 has a slightly lighter zone about 6 centimeters from the top surface which is 2 to 5 millimeters thick with a sharp upper boundary and a gradational lower boundary. This lighter zone is not megascopically different in grain size or texture from the dark material.

Sieve analyses of material from the two core tubes, a sample from the documented Apollo lunar surface return container (ALSRC), and a sample from the bulk ALSRC are shown in Fig.11 [not reproduced here]. These distributions are replicable by simple dry sieving but may be biased by aggregation of fines. Core 1 has a bulk density of 1.66 ± 0.03 grams per cubic centimeter, and core 2 has a density of 1.54 ± 0.03 grams per cubic centimeter.

The fines consist chiefly of a variety of glasses, plagioclase, clinopyroxene, ilmenite, and olivine. Very rare spherules and rounded fragments of Ni-Fe up to 1 millimeter in size were observed. The glass, which constitutes about half of the material, is of three types: (i) botryoidal, vesicular, and globular dark gray fragments; (ii) pale or colorless, or more rarely brown, yellow, or orange, angular fragments ranging in index of refraction from about 1.5 to about 1.6; and (iii) spheroidal, ellipsoidal, dumbbell-shaped, and teardrop-shaped bodies, most smaller than 0.2 millimeter, which range in color from red to brown to green to yellow. Indices of refraction range from somewhat less than 1.6 to more than 1.8 and are generally higher for the more intensely colored glass. Material with a refractive index above 1.7 is less common than that with a lower index. The colorless or pale angular glass, by far the more abundant type, is in part turbid or weakly birefringent. Unlike normal droplets from quenched magmas and glasses from terrestrial volcanic sources, many single glass particles are inhomogeneous.

Shock or impact metamorphism of lunar samples. Evidence of impact metamorphism is widespread in the lunar samples, particularly in the loose fine-grained materials and in the breccias. In contrast, most of the crystalline rocks, although commonly fractured or crumbled on the surface, show negligible or weak shock effects on their interior. A small number show evidence of strong shock. Crystalline minerals underlying glass-lined pits are crushed or powdered, but not strongly shocked. Such areas are of limited to wide distribution on the surface of the crystalline rocks.

Many phenomena were observed in the loose material and breccias that are strongly suggestive of melting induced by strong and intense shock. These include: (i) glass dumbbells, teardrops, and other forms of evolution; (ii) vesicular and flowed glass containing at least two types of glass; and (iii) Ni-Fe spherules. The abundance of vitrified mineral fragments is evidence of moderate to strong shock. Unshocked minerals or lithic fragments are found in the loose materials and in breccia, but such fragments are less abundant. Most of the birefringent crystal fragments in the fines show pronounced straight to mosaic undulatory extinction, and some lamellar microstructures, an indication that these fragments have suffered weak to strong shock.

Clear evidence of a multiple shock history is shown by fragments of breccia within breccia, and by breccias containing spherules of glass from prior impact events which are splashed with glass from subsequent impact events. Each breccia sample contains a wide variety of mineral and lithic fragments of various degrees of shock, and each sample appears to have a complex history.

Mineralogy. Clinopyroxene is present in all of the rocks examined. The most widespread variety is cinnamon-brown to resin-brown in reflected light and pale reddish-brown to pinkish-brown in transmitted light, with little or no pleochroism. The habit of clinopyroxene in the crystalline rocks is generally stubby prismatic or anhedral, but sheaflike intergrowths with feldspar are also present. Some crystals are strongly zoned from the center outward, as indicated by an increasing positive optic angle from near 0° to near 50° together with an increasing refractive index and intensity of color. Optical properties so far determined would appear to fit the pigeonite-augite series and do not exclude titaniferous varieties. Cinnamon-brown pigeonite in samples of fines was identified by x-ray diffraction measurements.

Olivine containing between 65 and 75 mole percent forsterite is a subordinate phenocrystic constituent of several of the finer crystalline rocks and occurs sporadically as crystal fragments in the breccias and dust. It is clear and pale greenish-yellow in the crystalline rocks but may range in color from greenish-yellow through honey-yellow and orange-yellow in the breccias and dust. The presence of olivine was confirmed by x-ray diffraction methods.

Plagioclase is likewise widespread but generally subordinate in amount to the ferromagnesian minerals. Optical properties indicate it to be calcic (mostly between 70 and 90 mole percent anorthite), with compositional zoning in some rocks. The habit is commonly lath- and plate-shaped, with lamellar twinning parallel and transverse to the plates. The presence of calcic plagioclase was confirmed by x-ray diffraction methods.

Ilmenite, as identified optically and by x-ray diffraction methods, is present in relatively large amounts in the crystalline rocks, where it occurs as plates and well-formed skeletal crystals. Ilmenite is also common in the breccias and dust, as a constituent of the lithic fragments and as isolated crystal fragments.

Low cristobalite is present as thin clear coatings and euhedral crystals. It occurs in cavities, and fills interstices between plagioclase plates in some of the coarser crystalline rocks. It is characterized by a crackly surface and complex twinning.

Unidentified yellow transparent crystals occur interstitial to the plagioclase crystals and in cavities. The mineral is a characteristic accessory in several of the more coarsely crystalline rocks.

Troilite(?) occurs in small amounts as rounded masses in the interstices separating plagioclase, clinopyroxene, or ilmenite of some coarser crystalline rocks. Native iron (?) occurs as scattered blebs up to 10 micrometers in diameter within the troilite masses. Several other accessory minerals occur which have not yet been identified.

[The Introductory sections and those describing Chemistry, Rare-gas Analytic Results, Gamma-Ray Spectrometry, Magnetic Measurements, Investigations in Organic Chemistry, and Biology are not included.]

Conclusions

The major findings of this preliminary examination of the lunar samples are as follows:

1) The fabric and mineralogy of the rocks divide them into two genetic groups: (i) fine- and medium-grained crystalline rocks of igneous origin, probably originally deposited as lava flows, dismembered and redeposited as impact debris, and (ii) breccias of complex history.

2) The crystalline rocks, as shown by their modal mineralogy and bulk chemistry, are different from any terrestrial rock and from meteorites.

3) Erosion has occurred on the lunar surface in view of the fact that most rocks are rounded and some have been exposed to a process which gives them a surface appearance similar to sandblasted rocks. There is no evidence of erosion by surface water.

4) The probable presence of the assemblage iron-troilite-ilmenite and the absence of any hydrated phase suggest that the crystalline rocks were formed under extremely low partial pressures of O_2, H_2O, and S (in the range of those in equilibrium with most meteorites).

5) The absence of secondary hydrated minerals suggests that there has been no surface water at Tranquility Base at any time since the rocks were exposed.

6) Evidence of shock or impact metamorphism is common in the rocks and fines.

7) All the rocks display glass-lined surface pits which may be caused by the impact of small particles.

8) The fine material and the breccia contain large amounts of all the noble gases which have elemental and isotopic abundances almost certainly indicative

of origin from the solar wind. The fact that interior samples of the breccias contain these gases implies that the samples were formed at the lunar surface from material previously exposed to the solar wind.

9) The ^{40}K-^{40}Ar measurements on igneous rocks show that they crystallized 3×10^9 to 4×10^9 years ago. The presence of nuclides produced by cosmic rays shows that the rocks have been within 1 meter of the surface for periods of 20×10^6 to 160×10^6 years.

10) The level of indigenous organic material capable of volatilization or pyrolysis, or both, appears to be extremely low (that is, considerably less than 1 part per million).

11) The chemical analyses of 23 lunar samples show that all rocks and fines are generally similar chemically.

12) The elemental constituents of lunar samples are the same as those found in terrestrial igneous rocks and meteorites. However, there are several significant differences in composition: (i) some refractory elements (for example, Ti and Zr) are notably enriched, and (ii) the alkali and some volatile elements are depleted.

13) Elements that are enriched in iron meteorites (that is Ni, Co, and the Pt group) were not observed or such elements are very low in abundance.

14) Of 12 radioactive species identified, two were cosmogenic radionuclides of short half-life, namely ^{52}Mn (5.7 days) and ^{48}V (16.1 days).

15) Uranium and Th concentrations lie near the typical values for terrestrial basalts; however, the ratio of K to U determined for lunar surface material is much lower than such values determined for either terrestrial rocks or meteorites.

16) The high ^{26}Al concentration observed is consistent with the long exposure age to cosmic rays inferred from the rare-gas analysis.

17) No evidence of biological material has been found in the samples to date.

18) The lunar soil at the landing site is predominantly fine-grained, granular, slightly cohesive, and incompressible. Its hardness increases considerably at a depth of 15 centimeters. It is similar in appearance and behaviour to the soil encountered at the Surveyor landing sites.

Discussion

The data and descriptive information given here were obtained to characterize the materials that will now be distributed to principal investigators and their associates for specialized and detailed study. The usefulness of this information in the selection of material for particular experiments is well illustrated by the rare-gas data. It would have been impossible to select material suitable for a careful study of the isotopes of Ne, Ar, Kr, and Xe produced by cosmic rays or even for a straightforward determination of the age by K-Ar dating without knowledge of the variations in rare-gas content ...... Similarly, the analyses of organic matter provide invaluable guidance in the selection of material for further experiments and the study of organic matter in lunar materials.

In spite of the limited and specific objectives of the preliminary examination, it has provided some significant results on long-recognized questions, as well as a few surprises. The existence of an erosion process on the lunar surface was clearly indicated by both the Ranger and Orbiter photographs. These pictures frequently show very fresh block craters interspersed among smoothed craters. Photographs of individual rocks on Surveyor photographs give further evidence of the rounding and abrasion of hard rocks on the lunar surface. The surface morphology, glass pits, and splashes seen on both hard and fragmental rocks suggest that samples are now available for detailed laboratory examination that may make possible the elucidation of a widespread and important mechanism on the lunar surface. The evidence provided by the first examination of these rocks indicates that this process is unlike any process so far observed on earth.

The chemical composition of the Tranquility Base fines and igneous rocks are unlike those of any known terrestrial rock or meteorite. The unique characteristic is the unusually high Ti, Zr, Y, and Cr content compared to that of other rocks with this approximate bulk composition. Also of great interest is the low Na, K, and Rb content. It is particularly significant that the unique composition is that of a silicate liquid. If this liquid has a volcanic origin, the unique composition implies either that the composition of the rock from which the liquid was derived differs significantly from that of the mantle of the earth, or that the mechanism by which the liquid was formed may also differ from analogous terrestrial processes. The nearly identical composition found for the fines, fragmental rocks, and igneous rocks suggests that the unique composition observed for the materials at Tranquility Base is characteristic of this part of the moon and not due to a local isolated flow or intrusion.

Several specific geochemical observations on the igneous rocks can be made from the present data. The ratio of K to U (2,400 to 3,200) of the lunar materials is unusually low, both by comparison with chondritic meteorites (45,000) and to most common earth rocks (10,000). This ratio is not readily changed by terrestrial igneous processes [2]. If this generalization is extended to lunar igneous processes, one can infer that ratios observed here are characteristic of the whole moon. Similarly, the Rb/Sr ratio is much more like that of the earth and achondritic meteorites than that of chondritic meteorites and the sun. Both of these chemical characteristics suggest that the moon, like the earth, is depleted in alkali metals above atomic number 11 relative to chondrites [3].

Variations in other elemental ratios that are easily fractionated during igneous differentiation processes (for example, Ni/Mg and Ba/Sr) suggest that there has been some chemical differentiation in the formation of the igneous rocks. The abundance of radioactive elements (K, U, and Th) in the surface materials is much greater than that inferred for the mean content of radioactive elements on the moon from thermal models of the moon [4]. This suggests that the surface materials are chemically differentiated with respect to the whole planet.

The unusually high abundance of elements with high atomic numbers (Fe and Ti) is clearly consistent with the unusually high densities (3.1 to 3.5 grams per cubic centimeter) reported previously. Both the Surveyor alpha-scattering analyses [5] and optical studies [6] indicate that mare materials may have significantly higher Fe contents than highland materials. Assuming the rather plausible generalization that the densities of rocks at Tranquility Base are characteristic of other mare regions, one can infer that large areas of the lunar surface, in particular the mare regions, may be made up of materials with densities in excess of the mean density of the moon.

Perhaps the most exciting and profound observation made in the preliminary examination is the great age of the igneous rocks from this lunar region. The age determined from K-Ar dating is both intrinsically and experimentally uncertain; nevertheless, there is a very good chance that the time of crystallization of some of the rocks returned by Apollo 11 may be earlier than that of the oldest rocks found on earth. It seems quite likely that if the rocks from Apollo 11 do not take us back to the time of formation of our sister planet, then rocks from other regions on the moon will.

References and Notes

1. E.M. Schoemaker, E.C. Morris, R.M. Batson, H.E. Holt, K.B. Larson, D.R. Montgomery, J.J. Rennilson, E.A. Whitaker, Jet Propulsion Lab.Tech.Rep. 32-1265 (1969), p.21.
2. F. Birch, Bull.Geol.Soc.Amer. 68, 483, (1958); G.J. Wasserburg, G.J.F. MacDonald, F. Hoyle, W.A. Fowler, Science 143, 465 (1964).
3. P.W. Gast, History of the Earth's Crust, R.A. Phinney, Ed. (Princeton Univ. Press, Princeton, N.J., 1968), pp.15-27.
4. D.L. Anderson and R.A. Phinney, Mantles of the Earth and Terrestrial Planets, S.K. Runcorn, Ed. (Interscience, London, 1967), p.113.
5. A.L. Turkevich, W.A. Anderson, E.E. Thanasis, E.J. Franzgrote, H.E. Griffin, S.L. Grotch, J.H. Patterson, K.P. Sowinski, NASA (Nat.Aeronaut.Space Admin.) TR 32-1265 (1968), p.303.
6. J.B. Adams, Science 159, 1453 (1968).

Welsh Geological Quarterly, vol.5, no.1, pp.31-45.

FIELD NOTES ON THE COASTAL SECTION FROM OGMORE-BY-SEA TO DUNRAVEN, GLAMORGAN

Trevor M. Thomas

(with a note on the Liassic mollusc Gryphaea by Michael G. Bassett)

INTRODUCTION

The coastal section extending south-eastward for 3 miles from the mouth of the Ogmore river shows several features of considerable geological interest.

The stratigraphical interest is heightened by the presence, at a number of points, of well-defined planes of unconformity marking the contact between Mesozoic and Carboniferous Limestone deposits. In these junction zones the Mesozoic rocks are invariably of a littoral character with limestone breccias or conglomerates predominating. Between Ogmore-by-Sea and Southerndown a south-westerly projecting tongue of littoral Lower Lias and outlying exposures of Upper Trias limestone breccias show irregularly-overlapping contacts with southerly-dipping Carboniferous Limestone beds of the Lower and Upper Caninia Zones. In places, where erosion of the shore platforms has been rapid, it is possible to identify segments of exhumed sub-Mesozoic surfaces. The diachronous nearshore deposits lying within the lower zones of the Lower Lias have been arbitrarily subdivided into the Sutton Beds and the Southerndown Beds. These littoral variants do not occur to the east of the small bay lying south-east of the site of Dunraven Castle where the high cliffs stretching to Nash Point, and beyond, are composed of a somewhat monotonous succession of thin limestones and shales of the more normal Lower Lias facies.

Structurally the area lies on the southern flank of the broad Candleston Anticline, a westerly member of the group of en echelon folds which form the western half of the Cardiff-Cowbridge anticlinal fold belt. A well-defined thrust plane runs along the northern shore of the Trwyn y Witch peninsula whilst faults of a lesser order can be recognised in the cliff-face at other points. Closely associated with this thrust plane and lying immediately adjacent on the northern side in the south-eastern corner of Seamouth Bay is a close group of minor folds which die out rapidly in a seaward direction. The Carboniferous Limestone exposed below a low dome of Sutton Stone in the western half of the Trwyn y Witch peninsula is also intensely folded in a rather complex manner.

Some of the Carboniferous Limestone beds of the Upper Caninia Zone immediately south-east of Ogmore-by-Sea are exceptionally fossiliferous. Excellent specimens of corals, brachiopods and gastropods are frequently weathered in relief on the freely-exposed bedding planes of the shore platforms. More locally the Sutton Stone also shows a profusion of fossil corals and lamellibranchs. Within the normal facies of the Lower Lias complete specimens of the zonal ammonites are by no means common but the lamellibranch Gryphaea may be found in countless numbers. A brief outline of the history of investigation into the stratigraphical and palaeontological significance of Gryphaea is given separately at the end of the descriptive itineraries.

It is not generally appreciated that the Mesozoic rocks and the Carboniferour Limestone of the Vale of Glamorgan contain, at scattered points, minor veins of galena whilst the common occurrence of calcite is sometimes varied by its associated with barytes. In the coastal sections under review, minor ore shoots containing galena and veinlets or larger concretionary masses of barytes are fairly common near the junctions of the Sutton Stone and the Trias breccia with the underlying Carboniferous Limestone.

This stretch of coastline also shows several features of geomorphological or physiographic significance. The eastern half forms the more westerly section of the prominent line of vertical or sub-vertical cliffs of Lower Lias which typify so much of the Vale of Glamorgan coast. Minor hanging valleys and residual blocks of distinctive marker bands lying well out on the shore below High Water Mark provide ample evidence that this cliff-line is retreating fairly rapidly under the ravages of marine erosion. The minor headland of Trwyn y Witch is the only noteworthy disruption in an almost straight coastline in which minor faults and major joints largely determine the local topography. The low cliffs near Ogmore-by-Sea are locally interrupted by a few small pebbly beaches, whilst successive minor rock faces with intervening rock benches or platforms give the cross profiles a stepped aspect. Eastward from Pant y Slade, with Lower Lias beds of normal facies overlying the Sutton and Southerndown Beds, the height of the cliffs rises steadily to about 145 feet near the Dancing Stones. Beyond this they end abruptly near the northern limit of the steeply-banked pebble beach at Seamouth, to be resumed once more, with higher beds coming in, to the south-east of the pebble beach and immediately west of the site of Dunraven Castle.

The details of the geology are described as they would be encountered in a traverse from the mouth of the Ogmore to the small bay lying south-east of the site of Dunraven Castle.

RIVER OGMORE TO BWLCH Y BALLRING

For a mile south-east of the mouth of the Ogmore river the low cliff-line and the rocky reefs lying between high and low water marks show three separate main exposures of Triassic breccias (Fig.1) which have highly irregular junctions with the underlying standard and crinoidal limestones of the Upper Caninia Zone, or with the Caninia Oolite.

(a) Triassic breccia (northern outlier)

In the more northerly of these Trias outliers, between Bwlch Ffynnon Orange [861754] and the Bwlch Cae Halen [861752], the breccias are only moderately coarse with relatively small angular fragments but showing a number of pebbles with long axes up to 2 feet in length. Immediately beyond the northern limit of the breccias, readily-distinguishable thin dyke-like fissure-infillings, containing red calcareous sandstone, red breccia with sharply-angular limestone fragments and much calcite veining near their margins, closely follow enlarged north-south joint planes. One particularly large dyke, up to 5 feet wide and traceable for 60 yards along the rock foreshore, is associated with a WNW-ESE joint plane.

(b) Triassic breccia (central outlier)

Extending south-eastward from Bwlch Bach [861751] to Bwlch Kate Antony [864746], a distance of 800 yards, an uninterrupted exposure of breccia displays a maximum thickness of 60 to 70 feet. The rock is characterised by a predominance of angular flattened fragments, one inch or less in diameter, cemented together by fine calcareous debris, and, very locally, by grey-green marl. This breccia was probably originally deposited as an "alluvial" fan.

(c) Triassic breccia (southern outlier)

The most interesting outlier is the one immediately east of Bwlch y Ballring [865745]. It has an average width of 60 yards and exposes 40 to 50 feet of predominantly coarse and irregularly brecciated beds. In the upper half of the sequence there are many blocks of Carboniferous Limestone. Examples of 8 feet in diameter are very common whilst a few are 15 to 19 feet across and have the aspect of "islands" of Carboniferous Limestone. Some sections, particularly in the eastern half of the outlier, show crudely-bedded rubbly breccia without any enclosed boulders.

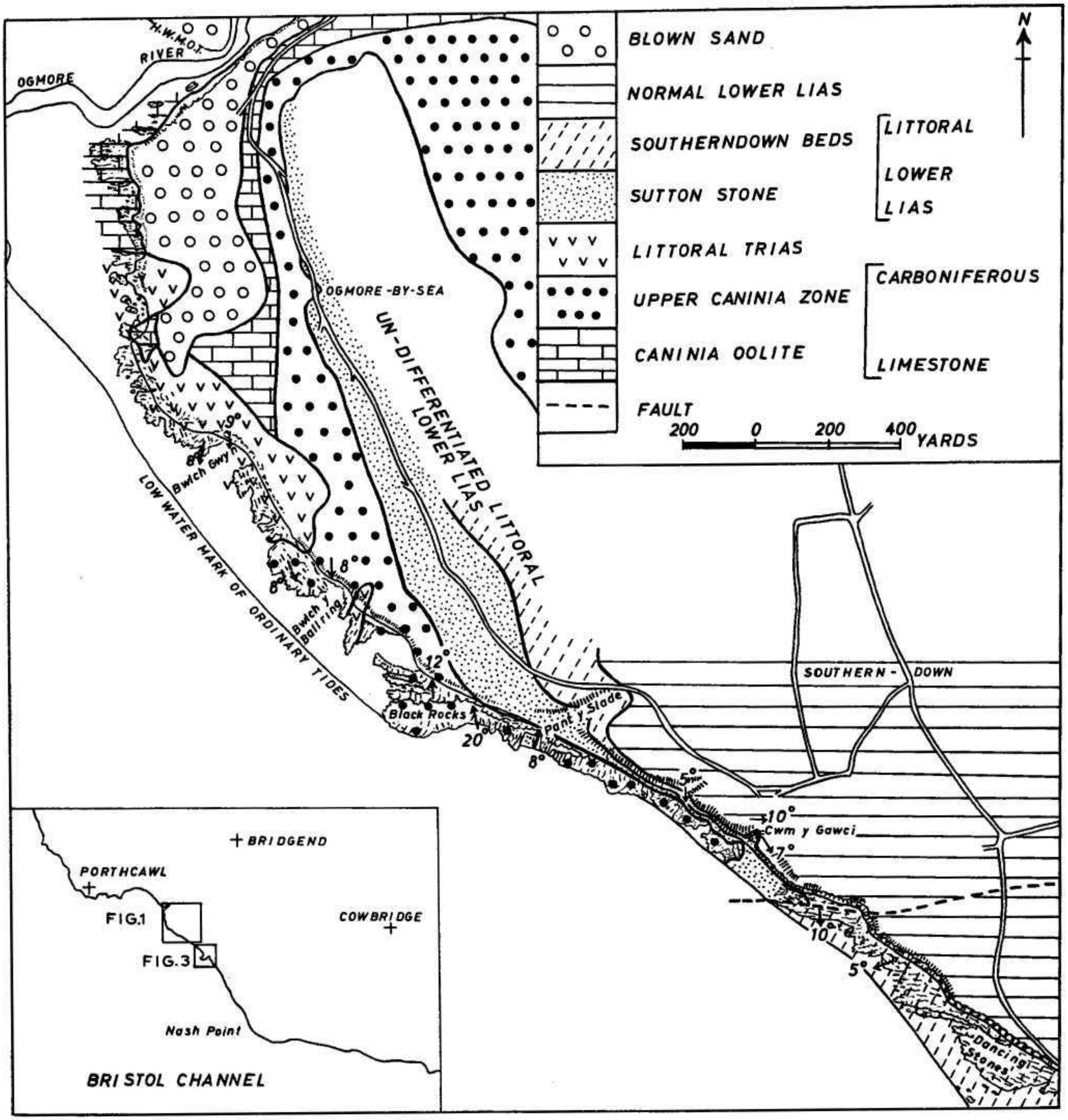
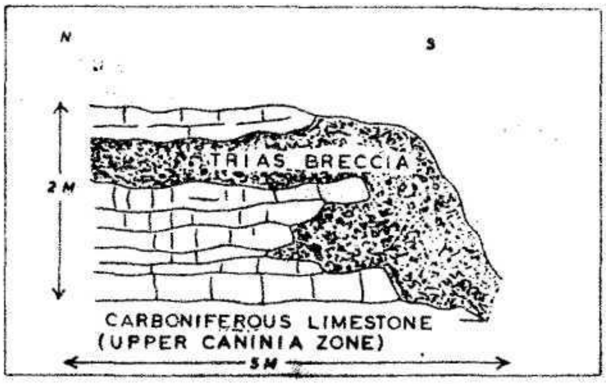

BLOWN SAND
NORMAL LOWER LIAS
SOUTHERNDOWN BEDS
SUTTON STONE
LITTORAL LOWER LIAS
LITTORAL TRIAS
UPPER CANINIA ZONE
CANINIA OOLITE
CARBONIFEROUS LIMESTONE
FAULT
200 0 200 400 YARDS
N
OGMORE RIVER
H.W.M.O.T.
OGMORE-BY-SEA
UN-DIFFERENTIATED LITTORAL LOWER LIAS
LOW WATER MARK OF ORDINARY TIDES
Bwlch Gwyn
Bwlch y Ballring
Black Rocks
Pant y Slade
SOUTHERN-DOWN
Cwm y Gawci
Dancing Stones
BRIDGEND
PORTHCAWL
FIG.1
FIG.3
COWBRIDGE
Nash Point
BRISTOL CHANNEL

Fig. 1

In places, as illustrated in the adjacent diagram, the breccia penetrates along the bedding planes well into the Carboniferous Limestone, thus indicating that these planes had been enlarged and fissured by solution before Late Trias times.



This southern outlier of "boulder" breccia is interpreted as a rock-debris cone built up by successive flash floods channelling down an ancient wadi and augmented at irregular intervals by major rock-falls from adjacent precipitous side walls.

Calcite veins occur containing flecks of galena and concretionary swellings of platy barytes, particularly near the junction with the adjacent Carboniferous Limestone.

(d) The Carboniferous Limestone

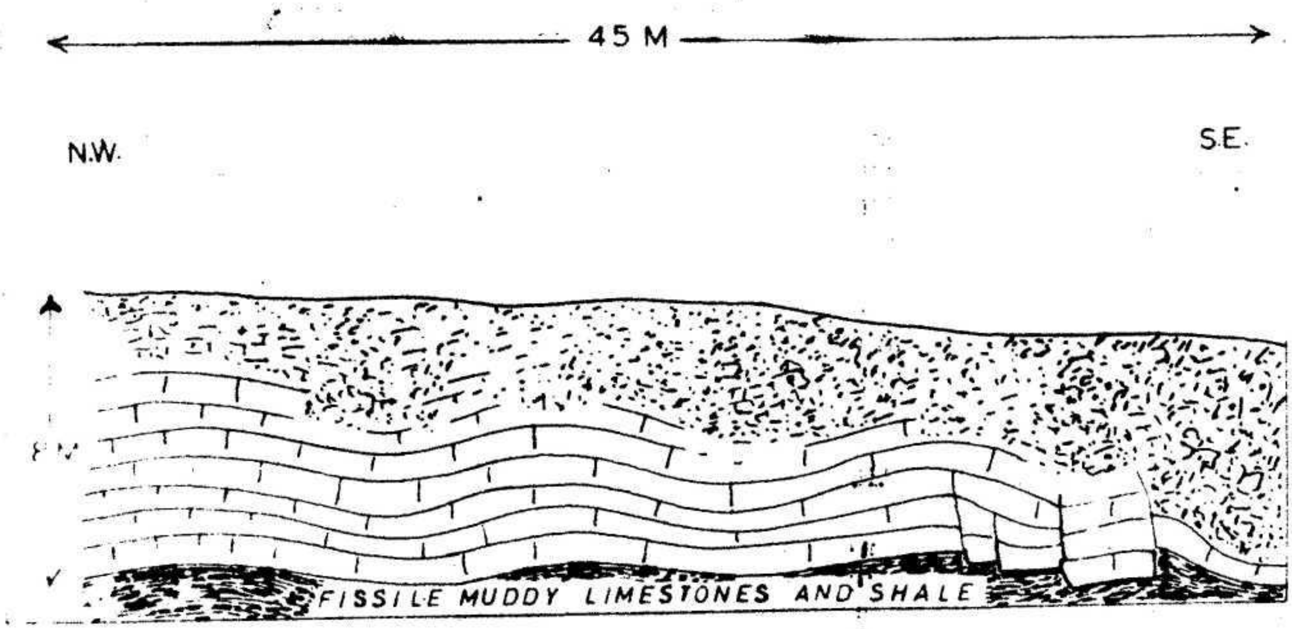
The coarse Triassic breccias are located near the axial regions of a broad syncline in the underlying Carboniferous Limestone beds of the Upper Caninia Zone. These comprise standard and crinoidal limestones exposed on rock platforms, largely submerged at high tide, and in the cliff face. The limestones are richly fossiliferous, the bedding planes, in particular being crowded with excellent specimens of Siphonophyllia [Caninia] gigantea (Michelin), Zaphrentites konincki (Edwards and Haime), Lithostrotion martini Edwards and Haime, Michelinia grandis M'Coy, Syringopora sp., Delepinea [Chonetes] destinezi (Vaughan), Gigantoproductus latissimus (J. Sowerby), Athyris expansa Davidson, Bellerophon sp., Euomphalus sp. and other brachiopods and gastropods. Near the top of the succession there is an 18-inch bed of rubbly limestone intermixed with red clay.

The cliff sections reveal an overburden, up to 10 feet thick, comprising a light loamy soil passing downward into a more clayey deposit containing small rounded pebbles which include fragments of Old Red Sandstone material and dark-grey or black volcanic ashes or tuffs showing porphyritic crystals of feldspar.

BWLCH Y BALLRING TO PANT Y SLADE

This part of the section is of significance because it reveals the descending base of the Sutton Stone, with a declination hardly measurable at first, but then falling rapidly so that eventually a cliff face of increasing height is composed wholly of beds of Lower Lias.

Mid-way along this section, immediately north of Black Rocks [867742], the north-westerly dipping dark-grey limestones of the Upper Caninia Zone show a 50-yard wide belt of buckling containing minor flexures and sag structures with small displacements where the cliff face displays 10 to 15 feet of well-bedded limestones overlying a lenticle of fissile muddy limestones and alternating thin shaly seams.



The bedding planes on the adjoining rock platform are characterized by prominent red staining and frequent chert bodies, occurring in thin plates or stem-like masses of limited cross-section. The contact between the Sutton Stone and Carboniferous Limestone is first seen immediately east of Black Rocks. The Sutton Stone here appears to be at least 50 feet thick. It is irregularly bedded and some wedge-bedding is apparent, but in the lower half of the succession the beds are generally massive. Rather lighter in colour than the Carboniferous Limestone, the typical Sutton Stone is a conglomeratic or coarse-grained creamy limestone containing many rounded pebbles of chert and of Carboniferous Limestone with a few of the latter being of "boulder" dimensions. Recent erosion of the rock bench east of Black Rocks has exhumed parts of a sub-Liassic surface (150 x 16 yards). Much of this lies just above High Water Mark. It transgresses thinly-bedded Carboniferous Limestone and is slightly irregular with minor hummocks and hollows and also some grikes.

The Carboniferous Limestone is traversed by major SSW-NNE joints, etched out by marine erosion and in places giving rise to blow-hole features.

Pant y Slade itself is a steeply-graded minor dry valley with discontinuous exposures of Southerndown Beds on its flanks. These blue-grey limestones, slightly nodular in aspect and with relatively thin shale partings, have a total thickness of 70 to 80 feet in this vicinity. They are better exposed in the high cliff face to the east of Pant y Slade where they overlie 40 to 50 feet of Sutton Stone displaying more massive bedding and featured by a line of prominent sea caves.

In the vicinity of Pant y Slade the basal beds of the Sutton Stone contain nests, geodes and irregular thin veins of calcite, in places intermixed with platy barytes and containing some flecks of galena. At one point the joint-faced walls of a narrow chasm etched out by the sea in the underlying Carboniferous Limestone are coated with a strip of red-brown and tea-green marls up to 6 inches thick. These fine-grained sediments could well be of Late Triassic age.

Minor flexures are evident within the Sutton Stone, but generally this formation has a south-south-easterly dip so as to bring its base well below High Water Mark when traced eastward along the cliff face.

PANT Y SLADE TO SEAMOUTH

This impressive cliff section, one mile in length, is wholly accessible only around low water. Showing a few minor indentations, which are joint or fault-controlled, this stretch of coastline has a general NW by W to SE by E trend which differs little from that of the master joints of the area. A feature of note are the extensive rock platforms, covered at high tide, composed of Sutton Stone in the extreme west but with the succeeding Southerndown Beds forming the bulk of the exposures in the central and eastern sections. The rock platforms formed of Sutton Stone can sometimes be distinguished from those in the Southerndown Beds by their deeper solution pits, which average 1 to 2 feet in diameter and are bordered by pinnacles 9 to 18 inches high. On the Sutton Stone platforms major joints orientated within the WNW to NW sector are also often griked to a depth of 1 to 2 feet. The courses of a few of these joints can be traced for 100 yards, or more. On the Southerndown Bed rock platforms lying immediately north-west of Seamouth, joints aligned from W by N to E by S are of fairly common occurrence and may be spaced only 2 to 4 feet apart.

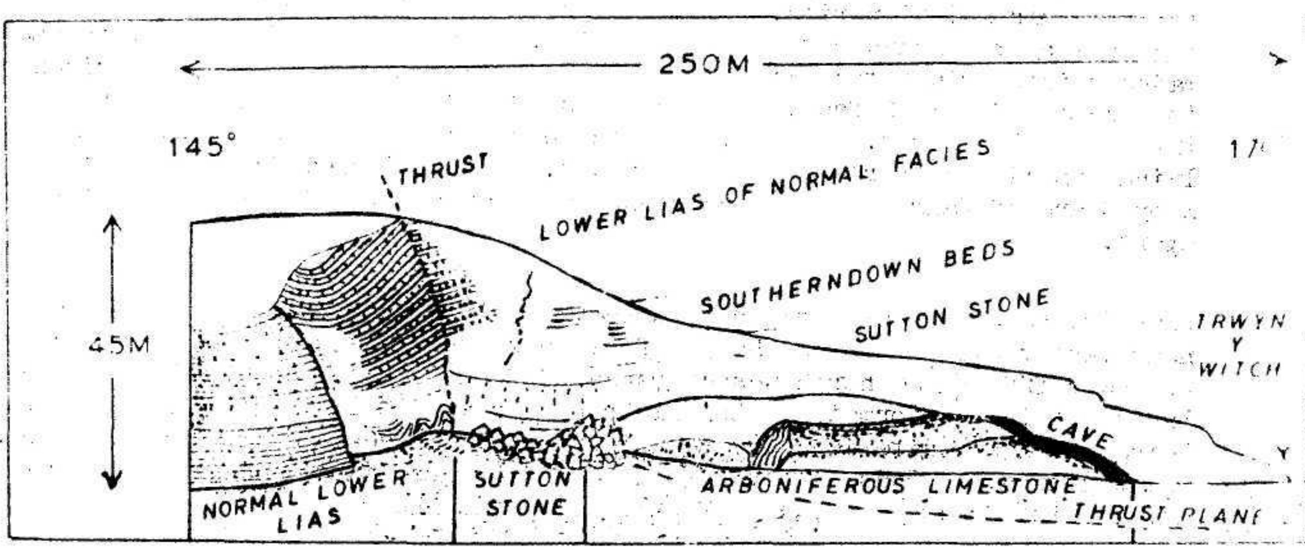
When traced south-eastward the Southerndown Beds thin from about 80 feet near Pant y Slade to less than 30 feet where they disappear below the base of the cliff on the north-western side of Seamouth. Individual limestone bands within the formation normally range from 4 to 10 inches in thickness, being given separate identity by intervening thin seams of indurated shale. The Southerndown Beds, however, become rather more massive and conglomeratic, with frequent nodules of chert, towards their base.

Midway along this section the continuity of the Southerndown Beds is clearly disrupted by three easterly trending faults, the most southerly of which has a demonstrable downthrow to the south of 15 feet. In places the fault planes are conspicuously coated with cream or light-pink stalagmitic material (dripstone) with some associated barytes and minor traces of galena. Adjacent to the most southerly of these faults the beds undulate slightly with individual beds being affected by minor displacements; some of the beds are also lenticular.

Towards the south-east an increasing thickness of Lower Lias beds of normal facies, belonging to the Planorbis to Bucklandi zones, succeeds the Southerndown Beds. These are affected by an anticlinal flexure, the crest of which lies about 100 yards north-west of the main storm beach at Seamouth (Fig.3) and the limbs of which dip at generally less than 5 degrees. About 70 feet above the top of the Southerndown Beds is a prominent group of slightly harder limestones with a combined thickness of 6 to 7 feet. Collapsed blocks indicate that this group contains as many as 16 recognisable limestone bands separated by very thin seams of indurated shale. Some 50 to 60 feet below, and again sharply differentiated from the more normal sequence of alternating thin limestones and shales, is a further group of concentrated limestones with a total thickness of 8 feet which includes a conspicuous basal bed of between 18 inches and 2 feet in thickness. This lower group is only evident on the north-western side of Seamouth.

SEAMOUTH TO TRWYN Y WITCH (WITCH'S POINT)

Fine panoramic views (as in the accompanying sketch) of this section may be obtained from the cliff top and the adjoining road leading from Seamouth to Southerndown village. They reveal an exceedingly sharp contrast in structure and lithology between the high cliffs of Lower Lias of normal



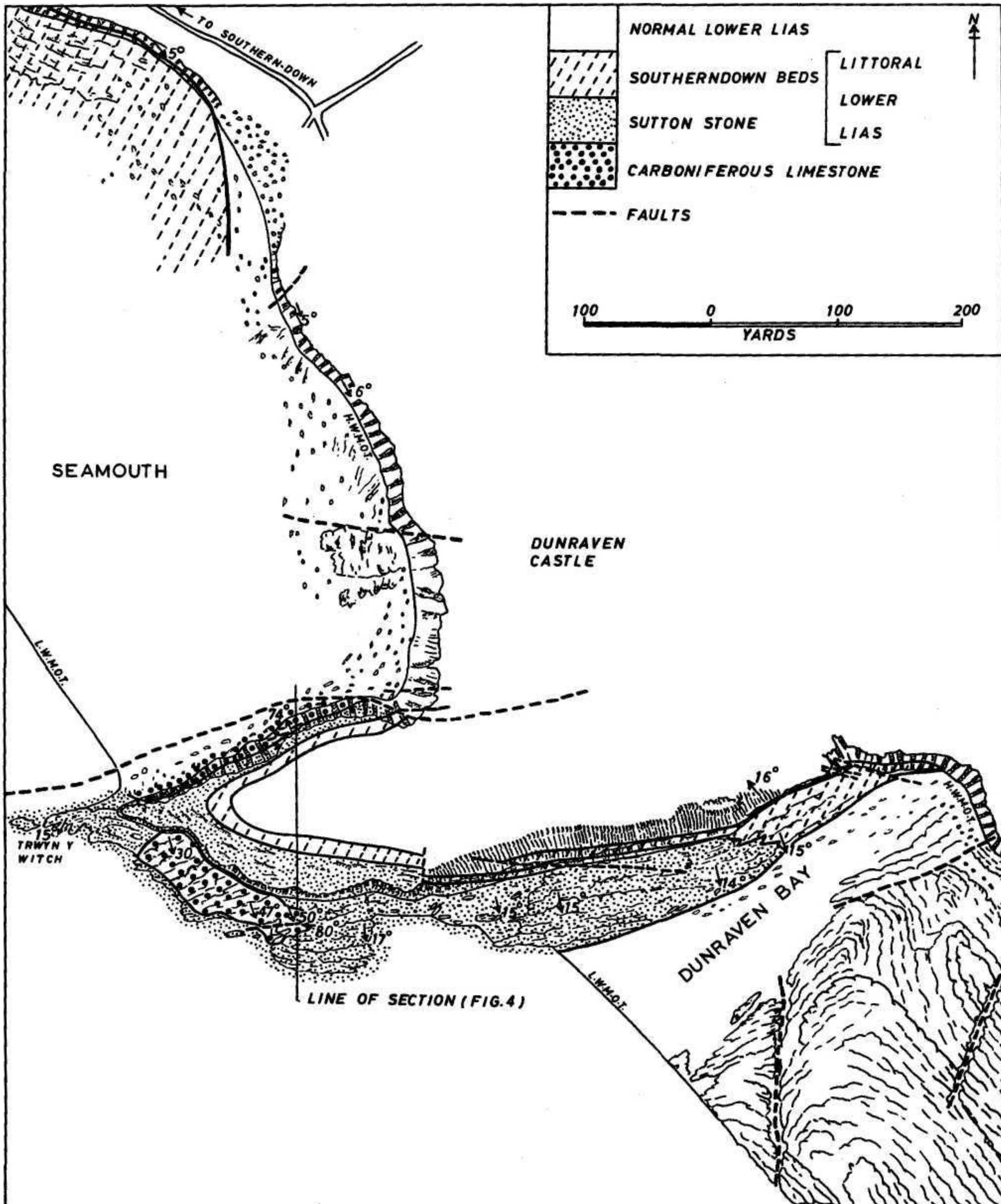

NORMAL LOWER LIAS
SOUTHERNDOWN BEDS
SUTTON STONE
LITTORAL LOWER LIAS
CARBONIFEROUS LIMESTONE
FAULTS
N
100 0 100 200
YARDS
TO SOUTHERN-DOWN
SEAMOUTH
DUNRAVEN CASTLE
H.W.M.O.T.
L.W.M.O.T.
TRWYN Y WITCH
DUNRAVEN BAY
LINE OF SECTION (FIG. 4)

Fig. 3

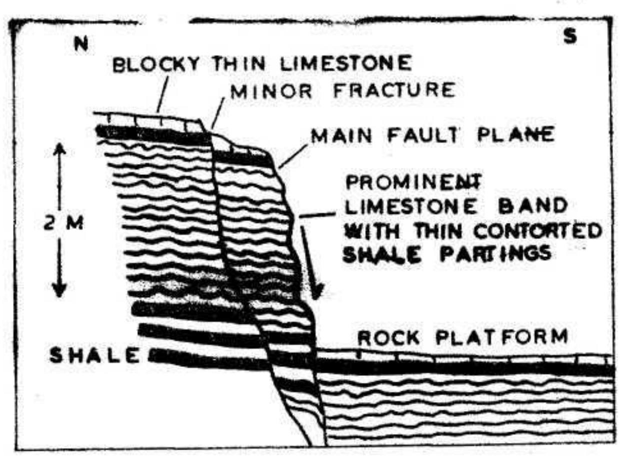
facies extending to the south-eastern corner of Seamouth Bay and the cliff line of steadily diminishing height on the northern edge of the Trwyn y Witch peninsula where the exposed base of a truncated dome in very massive Sutton Stone demarcates a plane of major unconformity with underlying highly-folded Carboniferous Limestone.

The normal facies of the Lower Lias succession has a maximum thickness of just over 300 feet in the Vale of Glamorgan, but in the Southerndown area the succession does not reach the Semicostatum Zone so that only about 240 feet is exposed.

In the southern half of Seamouth Bay the thinly-bedded limestones occurring in the lower half of the cliff face are not nearly so crumbly and are less affected by minor joints or fracturing than those at the high levels.

The beds have been folded into a shallow syncline with southerly dips of 4 to 5 degrees on its northern limb and a rather steeper northerly tilt on its southern limb which is abruptly terminated by a major E-W thrust fault, for the most part running just off-shore from the northern coastline of Trwyn y Witch.

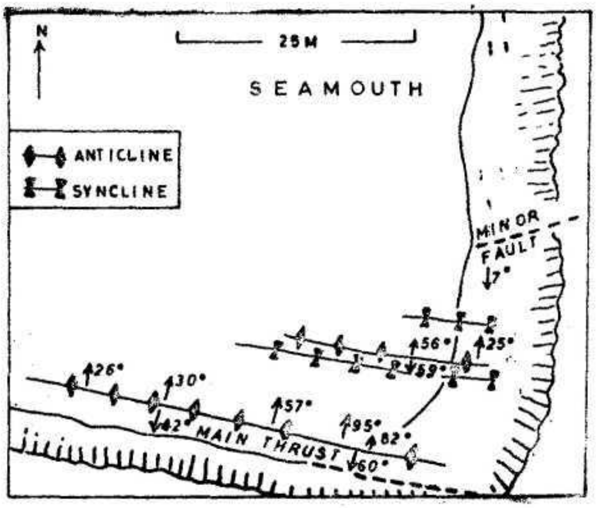
The prominent 6-foot thick group of limestone bands on the north-western side of Seamouth mentioned above, is present on the limbs of this shallow syncline, but towards the south it is thrown down by a W by N to E by S fault, with a southerly throw of 10 feet, to form the cap rock of a prominent shore pavement.



Accelerated erosion along N-S joints and the weathering out of shale bands immediately below this more resistant layer has resulted in several recent major cliff falls involving hundreds of tons of rock, with some blocks weighing up to 80 tons. Remnants of such joint-faced blocks deriving from this 6-foot sequence of concentrated limestones now lie well removed from the base of the cliff and suggest a fairly rapid recession of its face, perhaps up to 100 feet, or more, in a few hundred years.

A few of the shale bands in the Angulatum Zone are up to 18 inches thick and contain plant remains, traces or streaks of lignite and thin layers, up to an inch or so thick, of coal which is surprisingly hard and anthracite-like in general appearance. The origin of the limestone-shale sequence within the Lower Lias of normal facies has been the subject of considerable speculation.

Repeated epeirogenic movements as the basic mechanism for producing this sedimentary alternation has been mentioned as a possible explanation. The zonal ammonites now appear to be comparatively rare, at least as complete specimens. Lamellibranchs are fairly common with <u>Gryphaea arcuata</u> occurring in great abundance. The best preserved specimens, with distinctive beekitized walls, occur in the finer beach shingle towards the south-eastern corner of Seamouth Bay.



In this same area and immediately north of the E-W thrust fault running along the northern edge of the Trwyn y Witch peninsula is a highly disturbed zone in normal Liassic beds. This belt of intense crumpling is some 60 feet wide and dies out within a distance of 100 feet in a westerly direction. Up to 10 feet from the thrust fault the component limestone bands of the Lower Lias have been squeezed, fractured and drawn out into lenticles, whilst within the intervening shales there appears to have been some measure of redistribution and concentration of their carbonaceous content accompanied by a limited degree of anthracitisation to produce lustrous films of coal. Northward from the thrust fault the folds within this narrow belt of disturbance (as illustrated in the accompanying sketch plan and in Fig.2) successively comprise a slightly overturned anticline, a very sharp syncline, a steep-flanked symmetrical anticline and a shallow trough-like syncline. These structures for the most part plunge to the west.

The E-W thrust fault has an estimated throw of 150 to 200 feet to the north. On the north-eastern coastline of the Trwyn y Witch peninsula the fault plane itself is exposed over a considerable area where the exceedingly massive basal bed of the Sutton Stone forms the lower half of the cliff face. The fault plane overhangs to some extent and is by no means a cleanly-cut feature. To the east, in the high cliff of crumbly Lower Lias shale and limestones of normal facies, its presence is not readily apparent and one must assume that the fault dies out quite rapidly in an easterly direction. Irregular networks of fresh fractures within the Sutton Stone, on or immediately adjacent to the fault plane, suggest that some slight movement of the fault is still periodically taking place. In this vicinity the Sutton Stone has an average vertical thickness of approximately 40 feet, with possibly more localised thickening to 60 feet. Its basal bed is 15 feet thick with the lowest 6 feet containing an abundance of chert nodules.

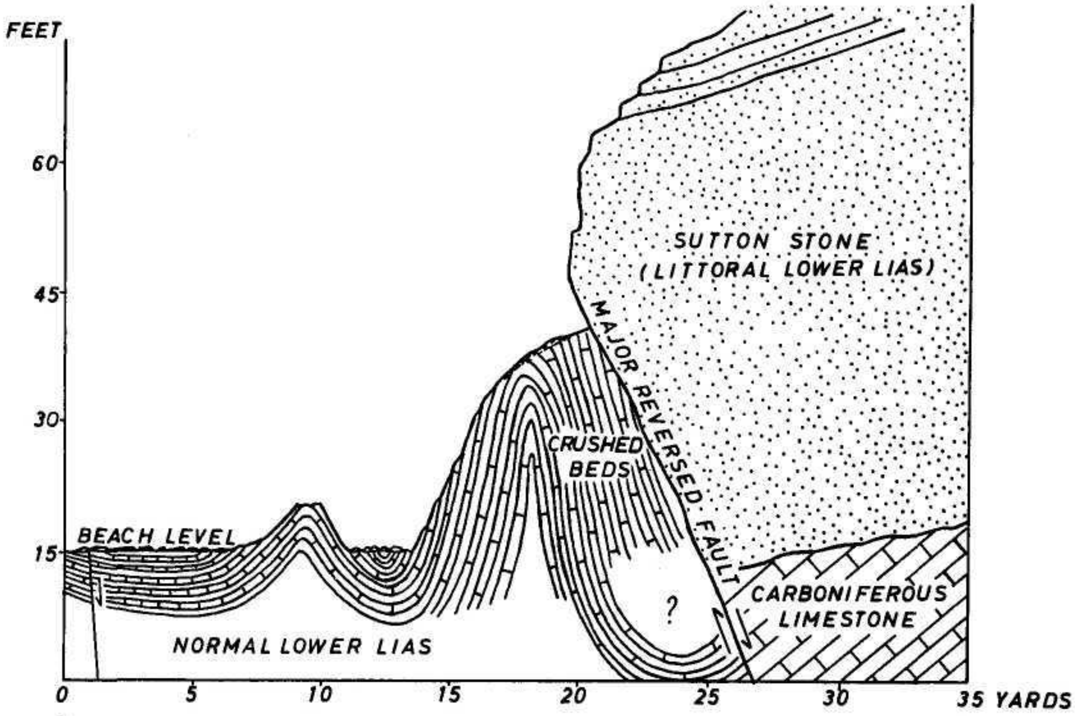

FEET
60
45
30
15
BEACH LEVEL
SUTTON STONE
(LITTORAL LOWER LIAS)
MAJOR REVERSED FAULT
CRUSHED BEDS
?
CARBONIFEROUS LIMESTONE
NORMAL LOWER LIAS
0
5
10
15
20
25
30
35 YARDS
N
S

Fig. 2

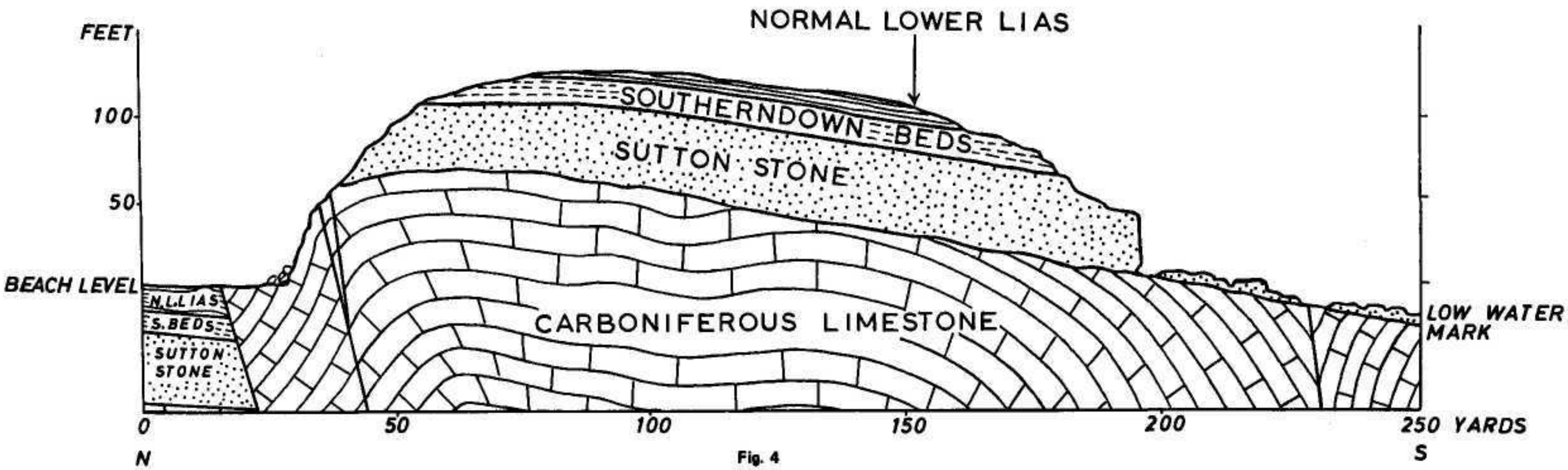

NORMAL LOWER LIAS
FEET
100
50
BEACH LEVEL
SOUTHERNDOWN BEDS
SUTTON STONE
N.L.LIAS
S.BEDS
SUTTON STONE
CARBONIFEROUS LIMESTONE
LOW WATER MARK
0
50
100
150
200
250 YARDS
N
S

Fig. 4

On the northern coastline of the Trwyn y Witch peninsula a narrow inlier of Carboniferous Limestone beds is exposed in the lower half of the cliff section, being unconformably overlain in an irregular stepped fashion by the gently-domed Sutton Stone (Fig.4). It must be presumed that this inlier would be seen to terminate against the seaward extension of the E-W fault if the adjoining beach was stripped of its sand. No zonal fossils have been found in these Carboniferous Limestone beds, but general structural relationships suggest that they might belong to the lower horizons of the Lower Caninia Zone or to the uppermost levels of the underlying Zaphrentis Zone. In the easternmost third of this inlier the Carboniferous Limestone is exceedingly massive with no bedding planes being discernible in a vertical thickness of nearly 50 feet. Other than by chipping fresh specimens with a hammer it is extremely difficult, in this particular location, to pick out the junction with the overlying, almost equally massive, Sutton Stone. The beach immediately below is littered with the remnants of former cliff-falls, containing blocks of both Sutton Stone and Carboniferous Limestone up to 10 feet cube. These massive Carboniferous Limestone rocks have in places a slightly 'gashed' or pseudo-brecciated aspect; freshly-exposed surfaces show numerous thin ramifying or irregular veinlets of calcite and minor fracture faces with haematitic films or staining.

Within the central portion of this inlier an underlying 70-foot sequence of thinly-bedded Carboniferous Limestone is exposed in a complexly-folded belt approximately 100 feet in width. The axes of the component minor folds, contained within an overall anticlinal structure of some magnitude, trend E-W or slightly north of west. Proceeding westward, a sharp anticline with dips on its northern limb ranging up to 75 degrees is followed by an asymmetrical minor syncline and a monocline with nearly vertical dips on its northern side. In longitudinal section these folds are gently buckled so that they display variable plunge within relatively short distances. A number of minor strike faults with throws usually less than a foot and of ESE-WNW or E-W alignment, running slightly oblique to the axes of the folds, traverse the full vertical thickness of the Carboniferous Limestone, but are not apparent in the overlying Sutton Stone. A sea cave etched out along its axis has given an added impress to the northern anticline. Part of the northern limb of this fold contains a series of pinnate shears so that much of the rock succession has a lenticular aspect with clear-cut bedding planes largely obliterated. The fault planes are slickensided whilst movement has also obviously taken place along bedding planes.

The westernmost point of Trwyn y Witch is composed of massive Sutton Stone but with the Carboniferous Limestone at no great depth. The contact between the two formations is clearly evident immediately to the east. This rises in sharp steps of varying heights towards the east and has been emphasised in places by marine erosion to form shallow sub-Sutton Stone caves. In this westernmost third of the Carboniferous Limestone inlier the beds have a fairly consistent northerly dip of 5 to 10 degrees. In the overlying massive Sutton Stone, nodules or rod-like masses of chert are particularly abundant in the lowermost 8 feet; some of these concentrations might be described as thin impersistent nodular seams. Slickensided irregular fracture planes occur within the massive basal bed of the Sutton Stone of this area whilst the network of minor fracturing is so concentrated in places that the rock has assumed a rubbly aspect.

TRWYN Y WITCH TO DUNRAVEN BAY (EAST)*

On the southern side of Trwyn y Witch it is possible at low tide to scramble from the westernmost point to the cliff-top through the full succession of the Sutton Stone. This becomes decidedly less massive but more fossiliferous upward. Corals (particularly Isastrea and Montlivaltia spp.) can be collected without undue effort as well as pleurotomarian gastropods. Complete or fragmentary specimens of Terquemia arietis (Quenstedt), Chlamys valoniensis (Defrance), and species of Plagiostoma, Cardinia and 'Pecten' are evident on the bedding planes. A further exposure of Carboniferous Limestone emerges from below the Sutton Stone in the lower half of the cliff section and extends southward (Fig.4) over the adjacent wave-cut platform. On this platform the Carboniferous Limestone is again mainly thinly-bedded but the dips are consistently steep and for the most part to the south-east. Small rafts of Sutton Stone form minor outliers on this platform; their relatively fresh appearance again suggests a rapid recession of the cliff-line.

Much of the low cliff line on the south-eastern edge of Trwyn y Witch is composed of Sutton Stone with the Southerndown Beds freely exposed only very locally on the steep slopes above. However, with a persistent south to south-easterly dip of some 5 to 10 degrees, the Sutton Stone is eventually succeeded in the actual cliff face (Fig.4) by the Southerndown Beds. Two hundred yards south-south-east of the site of Dunraven Castle these have been reduced to a vertical thickness of 12 to 15 feet, comprised of some 25 recognisable limestone bands with only very thin separating shale seams. Some of the bedding planes exhibit excellent specimens of Plagiostoma giganteum (J. Sowerby).

Towards the northernmost corner of Dunraven Bay a disturbed zone, 30 feet wide, is evident in the lower beds of the normal facies of the Lias. succeed the Southerndown Beds. This narrow belt of disturbance displays an easterly-plunging syncline and a complementary anticline, dying out

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*The small bay lying less than 200 yards south-east of Dunraven Castle is given no name on the Ordnance Survey sheets. To avoid possible confusion it is thus referred to as Dunraven Bay (East).

within 20 yards, a sub-parallel E-W fault and a number of minor NNE-SSW faults of limited throw. A short distance to the east a further E-W fault is evident in the cliff face. This has a downthrow of 20 feet to the south. The fault plane forms the northern face of a minor inlet or chasm where about 10 feet of Sutton Stone, dipping to the east at 12 to 15 degrees and passing under Southerndown Beds and normal Lower Lias, are exposed.

To the south-east of Dunraven Bay the 150-foot cliff section shows a sequence of thinly-bedded Lower Lias of normal facies and within which there are no readily discernible lithological variations or distinctive marker bands. A shallow dome structure is evident but within this there are minor flexures with variable plunge values as well as several faults of limited throw. A few of the faults are low-angled with dips of less than 45 degrees. The cliff sections in this immediate vicinity give a false impression of structural simplicity, because the extensive wave-cut platform reveals a complex pattern of shallow folds with no regular continuity and disrupted by the traces of minor faults. These structures can be mapped with a degree of precision not normally possible in sea cliff or inland exposures.

SUGGESTED ADDITIONAL READING

Bluck, B.J. 1965. The sedimentary history of some Triassic conglomerates in the Vale of Glamorgan, South Wales. Sedimentology, 4, 225-245.

George, T.N. 1933. The Carboniferous Limestone Series in the west of the Vale of Glamorgan. Q.Jl.geol.Soc.Lond., 89, 221-272.

Hallam, A. 1937. Primary origin of the limestone-shale rhythm in the British Lower Lias. Geol.Mag.,Lond., 94, 175-176.

______ 1960. A sedimentary and faunal study of the Blue Lias of Dorset and Glamorgan. Philos.Trans., s.B, 243, 1-44.

Kent, P.E. 1957. The limestone-shale rhythm in the British Lower Lias. Geol.Mag.,Lond., 94, 429-430.

Owen, T.R., Rhodes, F.H.T., Jones, D.G. and G. Kelling. 1965. Summer (1964) Field Meeting in South Wales. Proc.Geol.Ass.,Lond., 76, 463-495.

Strahan, A. and T.C. Cantrill. 1904. The geology of the South Wales Coalfield. Part Vl. The country around Bridgend. Mem.geol. Surv. U.K.

Thomas, T.M. 1968. The Triassic rocks of the west-central section of the Vale of Glamorgan with particular reference to the 'boulder' breccias at Ogmore by Sea. Proc.Geol.Ass.,Lond., 79, 429-439.

Trueman, A.E. 1930. The Liassic rocks of Glamorgan. Proc.Geol.Ass., Lond., 33, 245-284.

CAPTIONS

Fig.1. Map of the Ogmore-by-Sea to Dancing Stones area.

Fig.2. North-south section across the disturbed zone in the south-eastern corner of Seamouth.

Fig.3. Map of the Seamouth, Trwyn y Witch and Dunraven Bay (East) areas.

Fig.4. North-south section across the Trwyn y Witch peninsula.

A NOTE ON THE LIASSIC MOLLUSC GRYPHAEA

Michael G. Bassett

The bivalve genus Gryphaea is a common and well known member of Liassic faunas in Britain. Few fossils have been studied more critically since its evolution was first discussed objectively in any detail by the late Sir Arthur Trueman. At that time Trueman was Professor of Geology at University College, Swansea and was particularly interested in problems of correlation within the Lower Lias of South Wales, including the Southerndown area described in the above paper by T.M. Thomas. Gryphaea had long been known to geologists on account of its distinctive shape (it is still referred to in many parts of the country as the 'Devil's toenail'), and a number of authors had attempted to account for its wide variation, but Trueman was the first to attempt to trace any variation in its morphology with time and hence to suggest that the evolutionary lineage that he recognised was of value in correlation. His work on Gryphaea was started initially as no more than a supplementary technique in solving problems of correlation in beds where ammonites were scarce, but it soon led him to analyse the nature of fossil populations and their place in an evolutionary sequence. Some of the results of his studies were presented statistically and graphically, and though it would be wrong to suggest that he was the first to employ such techniques, there is little doubt that his work provided much of the stimulus for later statistical systematic studies in palaeontology.

Working mainly with specimens from the lower part of the Lias in South Wales and Somerset he suggested that successive populations of Gryphaea were characterised by gradual but progressive changes, the most important of which involved an increase in the incurvature of the left valve, a reduction in the area of attachment, a thickening of the left valve, the development of a posterior sulcus in some forms and a general increase in size with time; he also presented data to support the idea of some earlier workers that the coiled genus Gryphaea had evolved directly from the flat genus Liostrea

Trueman's paper soon became widely quoted as a classical study in evolutionary palaeontology and his hypothesis remained unchallenged until 1959. Since that time, however, it has been the subject of a good deal of controversy, particularly in the interpretation of the trends of coiling in Gryphaea and the postulated evolution of Gryphaea from Liostrea. A number of palaeontologists have employed detailed statistical methods to study the trends of coiling or incurvature in the left valve; some of these studies have supported the early conclusions while others have used the same data to suggest alternative interpretations.

The most recent study, by Dr. A. Hallam of Oxford University in 1968, has extended Trueman's original work to include species of Gryphaea from throughout the Liassic succession in many parts of Britain. Hallam recognised the following morphological changes of the Liassic succession, which he interpreted as evolutionary trends:-

1. Size increase in two species of Gryphaea (arcuata and gigantea).
2. Lessening of the degree of incurvature of the left valve.
3. Broadening of the shell.
4. Thinning of both valves.
5. Increase in the length of the attachment area.
6. Development of a well-marked posterior sulcus in the left valve of the early form G. arcuata incurva, followed by loss or reduction in stratigraphically higher forms.

Conclusions 2, 4, 5 and 6 (in part) are at variance with those suggested earlier by Trueman. The evolution of Gryphaea from Liostrea, now supported by Hallam clearly involved an initial and rapid increase in the coiling of the left valve, but the subsequent history of the lineage in the upper part of the Lias was mainly one of uncoiling.

The relatively sudden change from the flat Liostrea to the incurved Gryphaea was probably the result of a simple genetic change in the direction of transverse growth, in response to a change from a hard to a muddy substrate in Lower Liassic times. This would lead to the early breaking-away of the left valve from the surface of cementation and the growth of a transversely coiled shell which would raise the margin of the mantle above the sea-floor to reduce the danger of suffocation and maintain efficiency in the feeding process. However, the development of a tightly coiled spiral must have led to a reduction in stability and the subsequent history of the lineage can be best understood as an attempt to rectify this, coupled with an increase in size which is a common evolutionary trend in invertebrates.

Initially a sulcus was developed, and experiments conducted by Hallam suggest that this could have increased stability to some degree. This must have been more or less outweighed by the greater incurvature of the adults resulting from size increase and so was inadequate for the purpose. The subsequent increase in relative broadness was far more effective in conferring stability and hence the sulcus was reduced or lost. Decrease in incurvature, also aiding stability, was the result of a gradual decrease in the transverse growth component, with the result that the area of attachment increased in size. The need for a massive shell having diminished, much less metabolic energy was expended in the secretion of calcium carbonate; the end product of these changes was a thin-shelled, saucer-shaped Gryphaea which expressed a good balance between stability and the need to keep the mantle margin above the muddy bottom.

The Gryphaea lineage appears to have ended towards the end of Liassic times, being subjected to extinction together with most other benthonic invertebrates by the widespread onset of stagnant bottom conditions early in Middle Jurassic times.

SUGGESTED READING

Hallam, A. 1968. Morphology, palaeoecology and evolution of the genus Gryphaea in the British Isles. Philos.Trans., s.B, 254, 91-128.

The present note has been compiled very largely from this paper, parts of which have been quoted verbatim.

Trueman, A.E. 1922. The use of Gryphaea in the correlation of the Lower Lias. Geol.Mag.,Lond., 59, 256-268.

William Lewis (Printers) Ltd, Cardiff