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MERCIAN NEWS

Update on the Deeping Elephant

The last issue of *Mercian Geologist* (Volume 14 Part 2) reported how members of the Stamford Geological Society had found and excavated part of a well-preserved example of a straight-tusked elephant, *Palaeoloxodon antiquus*, in the Deeping Bank gravel pit, north of Peterborough. This all took place in the summer of 1996, but excavation is only the start of the job. What has happened since?

Two years of work by a team of volunteers has restored most of the bones, many requiring re-assembly and gluing. The tusks were most difficult, as they were badly crushed and broken. Steve Coles has restored the smaller one, though the large tusk, some ten feet long, is still in its plaster jacket. Both tusks have been modelled from styrafoam which, with a coat of Plaster of Paris and a final covering of fibreglass, paint and varnish, look like the real thing. Replication of all the other bones has commenced. A mould is made of silicone rubber, supported by Plaster of Paris to protect the shape. Casting is in fibreglass. The process is slow and will take another couple of years to complete. Cost is also a problem; the estimate for the total replication is about £7,000, of which £1,200 has been raised already through donations. Unless the remainder can be found the job will grind to a halt.

The Deeping elephant will form the centrepiece of a major exhibition in Peterborough Museum from May to November 1999. A life-sized cut out of the beast and illustrations of Ipswichian, Devensian and Flandrian environments have been prepared. Fossil bones of the fauna from each period will be also on show, including elephant and hippopotamus from the Ipswichian, woolly mammoth, woolly rhinoceros, horse, bison and deer from the Devensian, and an auroch from the Flandrian peats of some 4,000 years BP. It is anticipated that the exhibition will attract a very large attendance.

Those Magnificent Men . . .

During August and September 1998, East Midlands residents may have been startled by a rather squat-looking, twin-engined aeroplane flying at remarkably low altitudes over their houses. The plane, a Shorts Skyvan for the enthusiasts, was in fact a flying 'platform' for a geophysical project entitled 'High-Resolution Airborne Resource and Environmental Survey' (Hi-Res-1), a collaborative venture by the British Geological Survey and World Geoscience (UK) Ltd. Based at Tollerton, near Nottingham, the first phase of the survey covered an area of around 14,000 square km. of central England, extending from Shropshire and Cheshire in the west to Lincolnshire in the east. The plane flew as low as 90m over rural areas, increasing to a minimum of 240m over built-up areas.

The instrument package on the aircraft consisted of a spectrometer to measure gamma radiation, a magnetometer to measure the magnetisation of the underlying rocks and an electromagnetic receiver to map electronically conductive zones. When processed, the resulting data will have a wide range of applications, including geological interpretation, exploration for coal, gas, oil and minerals, delineation of areas of radioactive waste contamination and radon-prone areas, and estimates of natural or 'background' radiation. Preliminary results show a greatly increased resolution of magnetic data compared with earlier surveys, as well as confirming the distribution of outcropping, uranium-enriched strata. Further information can be found on the BGS Website (http://WWW.bgs.ac.uk/bgs/w3/rgg/rgw3/html).

Asfordby Colliery closes

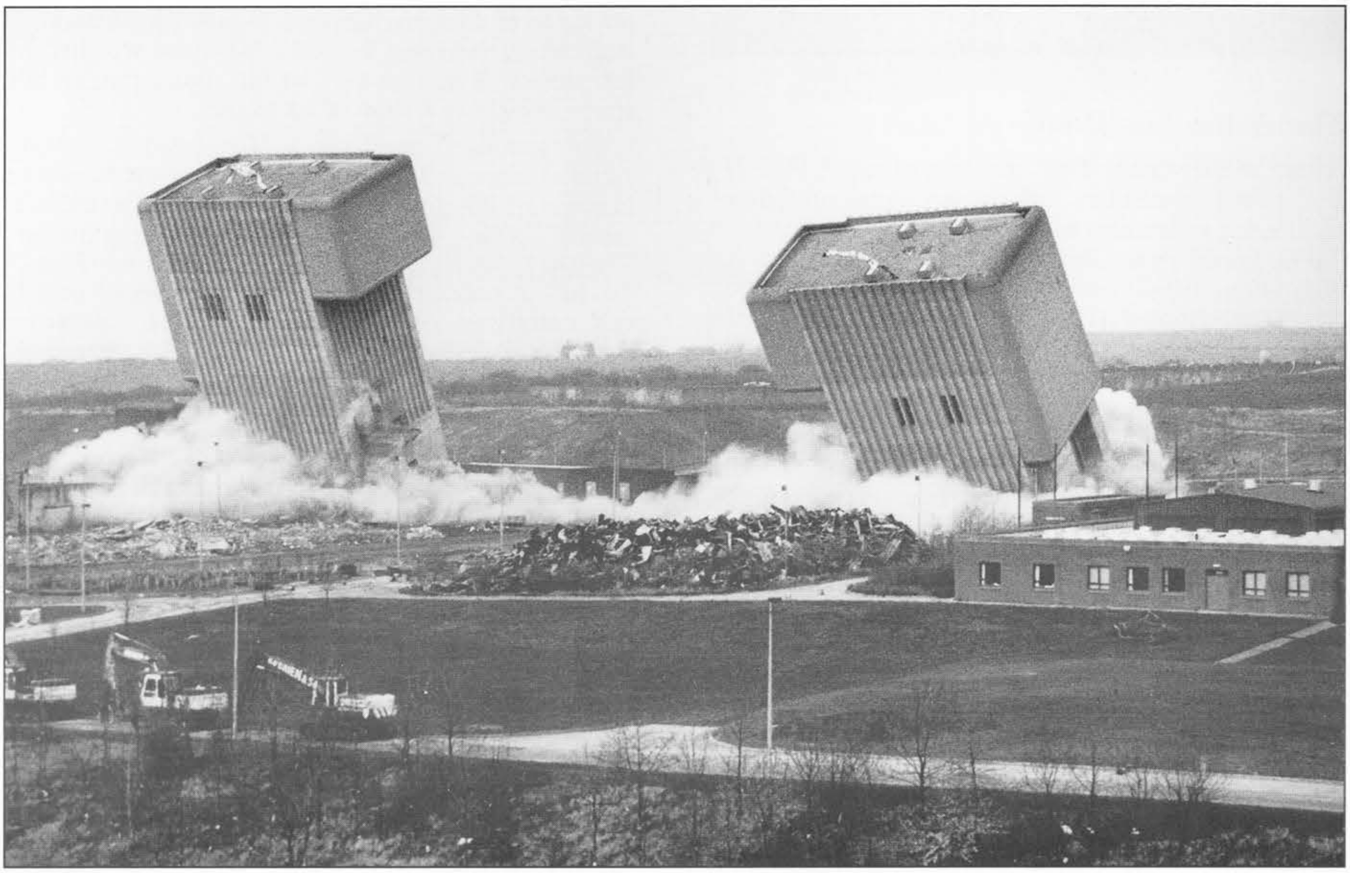
Tony Buck writes: On the 18th August 1997, RJB Mining (UK) Ltd announced the closure of Asfordby Mine, which is located near Melton Mowbray, Leicestershire. Asfordby was the biggest new mine project to be approved by the then National Coal Board for the Midlands coalfields. The original concept was to develop a mine employing 1,100 miners, mainly from the Leicestershire coalfields, producing over three million tonnes of coal a year.

Development of the mine, which employed approximately 490 people, started in 1984, with full production on the first longwall face in the Deep Main seam commencing in April 1995. The mine was equipped with the most modern machinery, but by the Autumn of 1995 the face was encountering severe difficulties due to the effects of geological conditions not encountered elsewhere in the United Kingdom. A series of intrusive sills, which lie above the operating seams, created unusual rock fracturing patterns, resulting in heavy weighting of the face, severe damage to the face equipment and ingress of water.

Several alternative mining systems were considered and in February 1996 the lowest risk option of narrow faces was tried. It was known that this was not a viable long-term option, so a slightly wider, 120 metre face was developed. It soon became apparent that conditions similar to those encountered on the initial face were developing and severe weighting problems were occurring. On the 12th August 1996 there was an ingress of water, which with the existing geological problems made the face unsafe.

The face equipment was abandoned, and RJB stated that 'We now have to accept that we cannot sustain economic mining operations while providing a safe working environment for our workforce. We have therefore, with some considerable regret, had to conclude that there is no sensible alternative but to cease mining at Asfordby'.

At the time of closure, Asfordby had produced 1.5



Demolition of Asfordby Colliery winding towers on 28 March 1998 (photo courtesy of Tony Waltham).

million tonnes of coal. Although initially sustaining operating losses, success with the revised mining plan prior to the latest geological setbacks resulted in a small operating profit in the first six months of 1997. Following closure some underground and surface plant was recovered and transferred to other mines, and as of late 1998 the two shafts have been filled and capped for safety.

REPORT

The Aston Log Boat

After the December 1997 meeting of the E.M.G.S., Dr Chris Salisbury made an announcement requesting volunteers to help with surveillance of the Trent gravel pits. Chris, a retired G.P., is also an amateur archaeologist of note and has been studying the palaeochannels and other features of the Trent valley for more than 20 years. His expertise in the identification of trees has led to several publications in this field and at present (1998) he is working with the Sheffield and Nottingham University Dendrochronology labs on a project investigating the Neolithic and Bronze age bog oaks from the Trent gravels. This report recounts my experience as a volunteer. The project has opened up a whole new area of interest which is still keeping me very busy. Having recently retired from a complex job, my knowledge of recent sedimentary geology has a number of gaps, though a series of lectures by Dr Peter Worsley several years ago, supplemented by field trips, has saved me from exhibiting complete ignorance. Chris Salisbury is also a good teacher and very patient. The archaeology has proved to be quite fascinating.

The flood plain of the River Trent is over three kilometres wide, with numerous abandoned channels and oxbow lakes. The underlying gravel deposits extend to a depth of 5-7 metres and contain abundant pebbles derived from nearby outcrops of Triassic sandstone, Carboniferous limestone and sandstone and Quarternary till. The gravels are made up of two distinct layers. The lower is Late Devensian in age and contains ice wedge casts. The upper layer is Flandrian in age, ranging from a few thousand to a few hundred years old. The gravels are extensively exploited for aggregate by numerous pits along the Trent valley, and often reveal artefacts and structures of considerable archaeological importance. Chris Salisbury has a very good rapport with quarry operators who keep him notified of finds. As the gravels are below the water table, constant pumping is required to keep the quarries dry. Because of the rate of extraction of gravel the quarries need visiting on a regular basis. For example, one day a classic ice wedge feature was seen, cleaned, documented and photographed; the next day it had gone.

In Shardlow Quarry (ARC), near Aston-upon-Trent, a 12m wide causeway constructed of vertical oak posts and brushwood was exposed in Autumn 1997. Associated with this structure were groups of large, flat sandstone boulders which, unlike other cobbles and boulders in the gravels, showed no signs of having been transported or worn by flowing water. Most of the boulders appeared to be similar in composition and were identified by Allan Brandon and Keith Ambrose of the BGS as having originated from the Bromsgrove Sandstone. This formation crops out at King's Mill, about 2km upstream. The presence of so many unworn stones was intriguing, suggesting transport by man. We have weighed all the stones of this type — so far amounting to 800 stones weighing a total of 12 tonnes.

The gravels contain clasts of organic-rich muds, some as large as 2m across. They are very numerous in parts of the pit. The quarrymen refer to them as 'muck' because they interfere with gravel production. They are derived from the erosional re-working of the fills of palaeochannels. A palaeochannel near to the causeway contains some of the sandstone boulders described above, together with sharpened oak piles and brushwood, indicating that the causeway was partly swept away by scouring.

Close to the causeway, a large oak log boat was exhumed by quarrying operations. The bulldozer driver first thought that the boat was one of the many large bog oaks that are commonly found in the Trent valley gravels. Some damage consequently occurred to the bow and stern, although the bow was later recovered. Unfortunately, the stern has not been found, though it is possible that it was lost when the boat originally capsized. The boat contained about 500kg of Bromsgrove Sandstone cargo within its hull (Fig. 1), resembling the stones found near the causeway.

The boat was 10.5 metres long even without the stern, and the complete boat may have been 12-13 metres in length. It must have represented a considerable effort and expertise in its construction. It could be considered to be a specialised barge. The

Fig. 1. Bromsgrove Sandstone boulders within the hull.

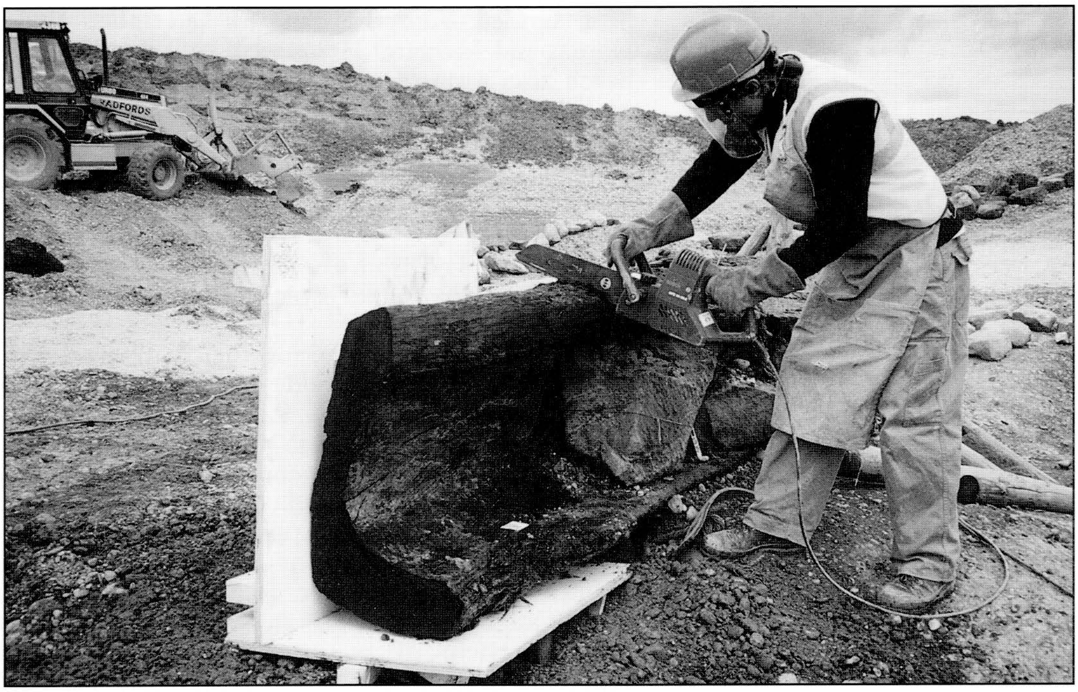


Fig.p107 2. Cutting the hull into sections.

bow has a well-designed integral carved hole or cleat, possibly for mooring or towing. This vessel would have been very difficult to manoeuvre when fully loaded with stone, especially in rough water or currents. It may have been propelled using poles or paddles and was carrying stone when it capsized, possible at the same time as the destruction of the causeway.

This is an important find because of the size of the vessel and the presence of cargo in-situ. Only a small number of such log boats have ever been recovered and properly recorded in Britain. In 1938, two boats were found in the Trent valley which were about 9m in length and flatter and lighter in construction than the Aston boat. Both had sterns bearing slots for a transom. Oak trees often have pre-existing rot in the lower trunk and boat-making thus required a transom of sound wood to add strength and make the boat watertight. Whether or not the stern of the Aston boat had a transom can only be speculated. Despite the damage, the Aston log boat has retained its shape and structure well due to the massive thickness of the timber used in construction and the good preservation resulting from the anaerobic conditions at the bottom of the palaeochannel. The bow is carved and shows a clear understanding of how to reduce water resistance. The boat has a uniform, smooth shape inside and out and a flat bottom for stability when beached. The fact that this was carved from such a large oak log must invoke respect for the craftsmen who built it. The date of the boat has not yet been confirmed but wood and other organic material from the causeway gives a calibrated radiocarbon date of 1300 B.C.

The survival of such a boat is remarkable. It is among the oldest and largest of its type ever found in Britain. The diameter and length of the straight tree trunk used for its construction is also impressive (<80cm by 12m). The tree would have been felled and then carved out within a fairly short space of time because oak becomes very hard as it dries. Although the boat is Bronze Age, shaping of the hull may have been effected using a combination of bronze and stone tools. Other oak logs on the site show very clear tool marks. Bronze weapons have been found in other parts of the same quarry.

The boat was fully excavated by expert archaeologists from the Trent and Peak Archaeological Trust led by Daryl Garton and Lee Elliott. A decision has been made to preserve the hull as it is so exceptional. Waterlogged wood must be kept wet to stop it breaking up and so a boat-watering rota was set up. For storage, the boat had first to be cut into sections (Fig. 2) which fit into special supports. Directed by the archaeologists, I had the responsibility for carefully cutting up the sections using a reciprocating saw. Each section is being immersed in fresh water tanks at the quarry site. Increasing concentrations of a soluble preservative, probably Poly Ethylene Glycol (PEG) will be added to the water to stabilise the wood. Several major wooden vessels have been preserved in this manner e.g. Vasa in Stockholm and Mary Rose in Portsmouth.

Further treatment and reconstruction will be expensive and take up to ten years to complete, but to those of us who have been involved in the project, it will be well worth the wait to see the final reconstruction of this splendid vessel.

My sincere thanks go to Chris Salisbury, Daryl Garton, Lee Elliott and Robin Woolley (the very helpful manager of Shardlow quarry).

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REPORT

The West Runton Elephant

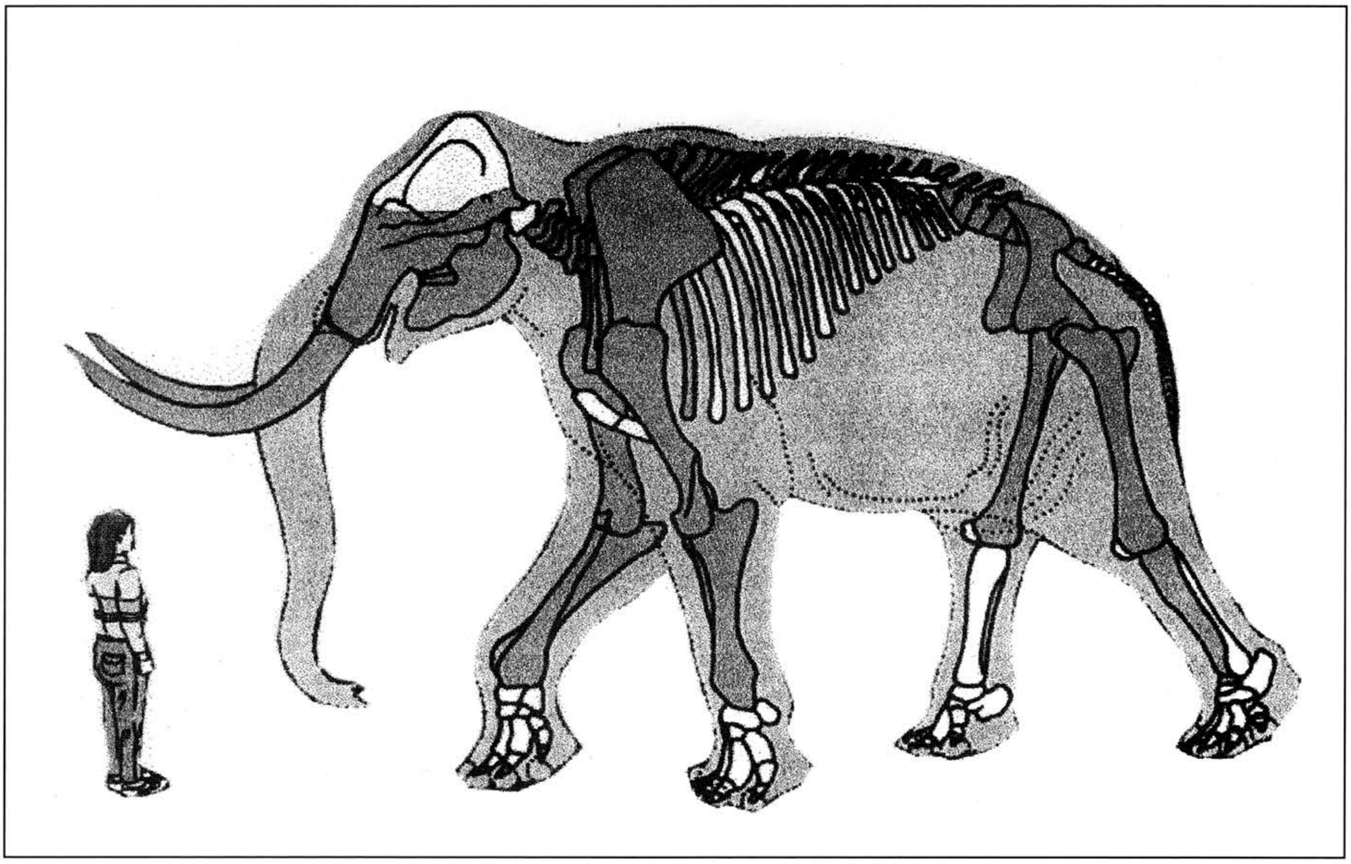
This article is a report of a lecture given to the Society by Dr Tony Stuart of the Norfolk Museum Service on 17 January 1998. The lecture described the discovery and excavation of the oldest fossil elephant skeleton ever to have been found in Britain. This was of particular interest to members who had participated in the Society's weekend trip to the North Norfolk coast at the end of September 1995. Their visit to West Runton, led by Martin Warren, the curator of Cromer Museum, had coincided with the day that excavation commenced to remove part of the cliff, working down from the top, with the aim of recovering the more deeply buried part of the skeleton. Although only part of the elephant had been recovered at the time of the trip, participants were shown a fibreglass replica of one of the thoracic vertebrae, nearly 80cm long, that dramatically illustrated the enormous size of the beast.

Much of Norfolk is underlain by late Cretaceous Chalk. Above the Chalk are extensive Quaternary deposits of sand, gravel, clay and other soft sediments of Early to Middle Pleistocene age. The beds exposed at West Runton form part of the Quaternary sequence. The Cromer Forest Bed Formation occurs on the foreshore and forms the base of the cliff. It is exposed at intervals along the coast from Weybourne to Kessingland and is made up of two distinct parts. The early sediments, which are marine shelly sands dating from one and a half million years BP lie at beach level and are known as Weybourne Crag. Above, forming the lower part of the cliff, is the West Runton Freshwater Bed, which was laid down 700,000 to 600,000 years BP during the Cromerian Interglacial. The Bed was deposited in a river channel and is composed of dark organic matter with silts, clays, sand, clasts of reworked silt, flint pebbles and lots of fossils. Examples of many different species of vertebrate have been found, including birds, fish, mice, voles, rhinoceros, deer, hyena and elephant. Shells, beetles, ostracods and plant remains are also present. The West Runton Freshwater Bed is overlain by marine sands and gravels, deposited during a transgression. The junction is undulating and marked by a marine gravel with occasional freshwater shells — this is named the Monkey Gravel after a find of a macaque bone. The rest of the cliff is formed of Anglian glacial deposits dating from about 400,000 years BP. They are composed of till with clay, sand, gravel and boulders. In cliffs farther along the coast to the east, the till contains spectacular rafts of Chalk, thrust up over each other by glacial pressure. The cliffs along this coast are soft and erode easily when battered by North Sea storms. On average they are receding by 0.3m per year.

During the last 200 years, many isolated teeth and bones of a wide range of Pleisocene mammals have been eroded from the cliff. In December 1990, Harold and Margaret Hems were walking along the beach after a storm when they spotted a large bone protruding from the Freshwater Bed. The Museum Service was informed and excavation revealed that it was the pelvis of a huge male elephant. A much smaller ankle bone, also from an elephant, was found nearby. Evidence of three kinds of extinct elephant, two species of mammoth (*Mammuthus meridionalis* and *Mammuthus trogontherii*), and the straight-tusked elephant (*Palaeoloxodon antiquus*) had previously been found in the Cromer Forest Bed. To make an identification of the new specimen, more bones would be needed.

In December 1991, Rob Sinclair noticed that heavy seas had exposed several more, large bones in the same part of the cliff and contacted the Museum Service. It now became apparent that this might represent a find of major significance. In the following January a rescue excavation was carried out by staff from Cromer and Norwich Museums with the help of volunteers. This excavation recovered about a quarter of the skeleton, including most of the backbone, parts of the right front limb and importantly the lower jaw. The jaw bone enabled the elephant to be identified as *Mammuthus trogontherii*. It would have stood about 4 metres high at the shoulder and weighed about 10 tons, about twice the size of a present day African elephant. The right humerus was partly uncovered but could not be excavated for safety reasons as it might have caused the cliff to collapse. From this dig, coprolites from hyenas were also found, together with teeth marks on an elephant foot bone, suggesting scavenging after the animal had died. At this point the excavation was stopped. The concentration of bones in such a restricted area suggested that more of the skeleton might well be present, but further progress would require the removal of 20 metres of cliff. This would be very expensive and would require planning permission, local support and a lot of organisation. The site was returned to normal and the prospects of completing the excavation were investigated. This took some time. In the autumn of 1993, small-scale defences were erected to protect the cliff from further erosion until the excavation could begin.

Eventually, major funding was secured from the Heritage Lottery Fund and Anglian Water. The necessary permission was obtained from English Nature and the landowner. Work started on 30 September 1995 with the removal of overburden from an area 15m × 5m at the top of the cliff by North Norfolk District Council. On 9 October, the Norfolk Archaeological Unit started to mark out the site and begin excavating. As well as traditional recording methods, the Swedish consultancy Arkeologikonsult provided state-of-the-art surveying and computer processing of data. After two weeks of digging there was great relief when the bones were reached. Many were orientated steeply to the horizontal and at first seemed to be scattered



Outline of the West Runton Elephant showing bones found 1990-95, from an illustration by Ashley Sampson.

randomly. For safety reasons the site was excavated piece-meal and bones removed after support and plaster encasement. The site reconstruction was thus built up over time. By the end of November 1995 the archaeologists had completed their work on the site. This left the skull, with one tusk attached, to be removed by the remaining museum staff. A steel cage was built on site and — as the weather deteriorated — the skull was lifted to safety by crane.

It is generally unusual to find the skull preserved with the rest of an elephant skeleton as it usually floats away due to its buoyancy in water. The top half of the cranium was shattered, but most of the animal seems to have been recovered except for the feet and tail, which were probably scavenged by hyenas. Over 10 tonnes of Freshwater Bed sediments were also removed for a variety of research specialists to investigate all aspects of the environment in which the elephant lived over half a million years ago. Evidence so far suggests it was very like the present Norfolk Broads, with reeds and willow growing in marshland in low lying areas and temperate forest on high ground. A rich variety of wildlife abounded.

Comparison with modern elephants suggests that the animal was about 40 years old when it died. The knee of the right rear leg shows a healed break and deformity, probably caused by fighting. The disabled creature may have got stuck in the muddy reed bed and been unable to get out. This may explain why it died with its front end upright, rather than on its side as might be expected. The unusual angles and relationship of some of the bones suggests that they were disarticulated and jumbled before burial. It has been suggested that members of the herd may well have returned to the site some time later and trampled the bones into the soft sediment. This may also account for the hundreds of tiny scratches on some of the bones. Modern elephants often behave in this way, returning to the remains of their dead relatives and trampling and rolling their bones. The position of the head in an upright posture near the rear end of the beast is explained by its buoyancy, causing it to break free from the rotting carcass and drift a few metres with the current. The disintegration of the top of the skull probably followed sometime later due to exposure to the elements.

Excavation is only the beginning of the job. Preparation of an elephant for display typically takes several years. The bones have to be removed from their plaster jackets and conserved before reconstruction can take place. It is hoped that the skeleton and a full-sized replica will be on display in Norwich Museum within the next few years.

We are grateful to Dr A. J. Stuart, BSc, PhD, DSc for allowing us to make use of his Norfolk Museum Service publication: The West Runton Elephant, Discovery and Excavation, *from which the illustration was taken, and for editing the first draft of this report.*

Alan Filmer, Inga Filmer and Judy Small

REPORT

Microgravity in Nottingham

Expansion of the ice stadium is creating various engineering works on the eastern edge of Nottingham's city centre. A main sewer draining from the Lace Market underlies Barker Gate, and is unwelcome where it lies beneath the site of the expanded stadium. It was therefore proposed to divert it northwards under Belward Street to join the existing sewer under Hockley.

Belward Street was only created in 1970 by cutting through old houses and factories between Barker Gate and Hockley (Fig. 1) to create the last link in the northbound inner ring road. A conventional trench to install the sewer beneath the road would require excavation through a complex of old building foundations, floor slabs, ditches and backfilled cellars; the natural 1-2 metres of sand formed by weathering probably survives nowhere along this stretch of road. The trench would then need to be sunk through another 3-5 metres of Sherwood Sandstone. With night working and severe access restrictions on the busy road with no scope for traffic diversion, the proposed sewer diversion was becoming an expensive item.

A straight, small diameter, bored tunnel was therefore considered as an alternative to the sewer. This would require a small boring machine to cut through the sandstone for the 130 metres between shafts sunk in Barker Gate and Hockley; a tunnel lining of concrete rings would then be jacked into place behind the advance of the boring machine. In sound intact rock beneath the old foundations, this operation would be very simple, but there was a serious prospect of encountering caves in the sandstone. Recovering a boring machine that had dropped into a cave would have been prohibitively difficult and costly.

In this part of Nottingham there was a strong likelihood that caves would be encountered along the tunnel line. Unfortunately, there were no records of caves beneath the buildings that were demolished in 1970, except for the cistern cave under the old mill west of the tunnel line, and the position of this was known only roughly (Fig. 1). It was therefore decided that a geophysical survey was the best means of exploring the possible existence of caves beneath the street; a microgravity survey was the most appropriate, and was completed in April 1998.

A LaCoste and Romberg Model D gravimeter was used to measure the Earth's gravitational field strength. This small, portable and very expensive instrument contains a weight on a spring, whose length is therefore proportional to gravitational pull. It is read to 1 microgal (one millionth of normal gravity), and was operated by one technician over five nights to complete the survey. He had to work at night because lane closures on the busy road were not acceptable during the day; this did have the benefit of reducing artificial vibrations which interfere with reading the very sensitive instrument. A passing car was no problem, and he had to wait less than a minute for the ground to settle down after any heavy truck passed.

The geophysicist took three readings every five minutes at each of 401 stations, spaced 2 metres apart on lines 3 metres apart to produce a grid of data. He also took 117 readings at a base station to detect temporal changes, and levelled each station to ±5mm. The data was then computer processed to produce a contoured map of the local gravitational field strength. Effects of altitude, latitude and Earth tides were removed to produce a Bouguer gravity map that indicated geological anomalies. Small shallow caves produce negative anomalies with a

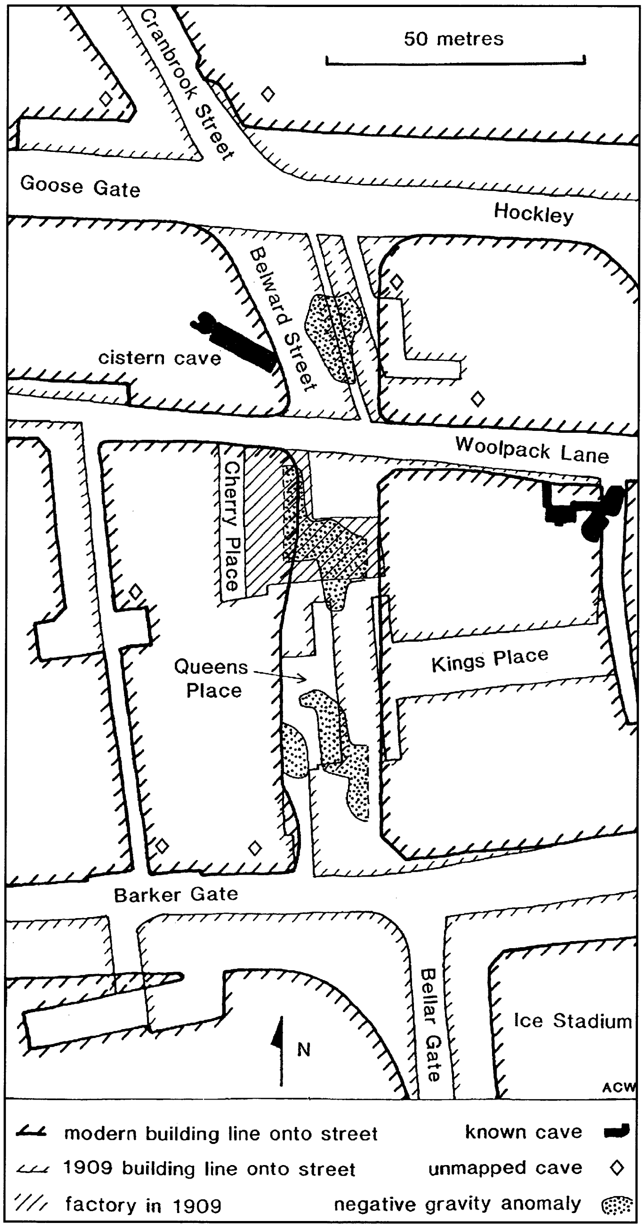


Fig. 1. Simplified map of the area around Belward Street, Nottingham, showing the relationships between the modern streets, the old streets (as on a map of 1909), the known caves, and the negative gravity anomalies (shaded where more than 40 microgals below background values).

total width (wavelengths) of about 20 metres, so the data was filtered to remove all anomalies with wavelengths >50 metres (which could have been due to deeper geological structures). The resulting map revealed a series of significant, small negative anomalies (Fig. 1). A typical cave 3 metres in diameter beneath 4 metres of cover produced a negative anomaly about 50 microgals deep and about 8 metres across; the anomaly decreases and widens as the depth of cover increases, and also decreases if the cave is full of water or uncompacted debris.

The gravity anomalies revealed by the survey may be related to the sizes of caves that are characteristic of the Nottingham sandstone, and also matched the old street pattern of the site (Fig. 1). The large central anomaly is probably due to caves, now under 5 metres of cover, that were beneath a factory east of the old Cherry Place; in size and extent the caves may resemble those known just to the east, south of Woolpack Lane. The southern, double anomaly appears to relate to a group of caves that was under Queens Place and the terrace of houses between it and Kings Place; these now have a cover of about 4 metres, and could have been domestic cave cellars or caves from adjacent factories. The northern anomaly is an odd shape and its data could not be modelled for depth as it extended out of the survey area, but it lies under the site of old houses and factories either side of an alleyway south from Hockley. No anomaly was found under the north side of Barker Gate, where old, house cellar caves might have been expected; any caves may have been unroofed or tightly filled with demolition rubble which would almost eliminate their gravitional effect.

A small incomplete anomaly on the edge of the survey (not marked on Fig. 1) lies over the approximate position of the corner of the cistern cave. Though this cistern is not accessible it is known to lie at the water table; it is therefore beneath about 7 metres of rock, and at that depth would create a less detectable gravity anomaly.

The gravity survey produced useful data, but all the anomalies required drilling to prove their interpretation. However it had already become clear that a bored tunnel was not going to be practicable through such cavernous ground. It was thus found more economical to realign the Barker Gate sewer so that it lies beneath non-critical parts of the expanded ice stadium. The survey had cost several thousands of pounds (including the costs of traffic control), a sum which approached 4% of the project cost; this proportion is not unusual for a tunnel project where "unforeseen ground conditions" can be disastrously expensive. Drilling was abandoned, and more about these caves will probably never be known.

Many thanks to City of Nottingham Environmental Services for providing access to their survey data, which was produced by Geotechnology (of Aberdulais, Neath).

Tony Waltham
Nottingham Trent University

REPORT

Prehistoric mining at Ecton

Ecton Hill, in Staffordshire, is well known for the copper-rich mineralisation in its Carboniferous limestone. The site has long been recognised as a centre for post-medieval mining, but recent explorations have revealed an even longer history of working. An antler tool has been discovered, and has been radiocarbon dated to 1880-1630 BC. The antler was found in Dutchman Mine about 11 metres below the ground surface, in what may be a prehistoric working but which is more probably later, the antler tool having been displaced by post-medieval mining. It does however confirm that there was Bronze Age mining on the hill. The antler tool and its context are described in full in a paper in *Mining History*, the Bulletin of the Peak District Mines Historical Society.

Two areas of probably surface and underground workings have now been tentatively identified on Ecton Hill. One is around the top workings of Dutchman Mine on the high northern spur of the hill, while the other is a little further south on the hilltop. The date of the antler tool is consistent with the majority of other radiocarbon-dated prehistoric copper mines in Britain, which concentrate in the first half of the second millennium BC. These largely occur in Wales and Ireland, but also include the mines at Alderley Edge in Cheshire.

The limestones of Ecton Hill are extensively folded and faulted. Mineralisation at and near surface around the prehistoric mines appears to have been mainly in the form of thin mineralised deposits in the bedding planes of the steeply dipping limestone. Westwards from these areas of mineralised beds there are east-west trending veins; these are recognisable at the surface by the lines of small mined hollows and hillocks, and are seen underground in the workings above Dutchman Level. The bedded zones and the veins seem to have been equally poor in mineral, and the main concentration of ore was in the Ecton Pipe, a huge pipe deposit that was exploited at depth in the 18th century; it is not yet clear if the pipe was mined in prehistory.

Many thanks to Geoff Cox for permission to investigate the Ecton mines, and to those who have helped underground. Note that none of the Ecton workings should be entered without the owner's consent; parts are dangerous, and uncontrolled digging above or below ground could deplete the archaeological resource of the site.

John Barnatt
Peak District National Park Authority

REPORT

Joint meeting of the East Midlands Geological Society/Yorkshire Geological Society, 17th October, 1998

Recent Advances in Understanding the Geology of the East Midlands

This meeting, jointly organised by the EMGS and the Yorkshire Geological Society, was held in the De La Beche Conference Centre at the British Geological Survey, Keyworth on 17th October, 1998. The meeting was well attended with upwards of 80 people present. A welcome address by Dr Peter Allen (BGS) launched the morning session, which concentrated on 'basement' geology.

The first talk, by John Carney (BGS), was devoted to the Late Precambrian Charnian Supergroup. Accounts of the Bardon and Whitwick volcanic centres of north-western Charnwood Forest were followed by a discussion on the precise age of Charnian volcanism; this focused on a discrepancy of 20 million years between the faunal and radiometric evidence. In the final part of the talk, new Ar/Ar radiometric data was presented confirming the Acadian (Siluro-Devonian) age of the Charnian cleavage.

The next talk was due to have been given by Helen Boynton (formerly Leicester University, now retired), but unfortunately her voice had still not recovered from the effects of a bad cold. Trevor Ford, also formerly of Leicester University and a co-collaborator on Charnian Precambrian palaeontology, deputised and delivered a wide-ranging talk on the morphology and likely origins of the Ediacaran (Late Precambrian) fossils of Charnwood Forest. New discoveries have confirmed that these faunas are present in the Ives Head Formation, about 3km stratigraphically below the youngest fossiliferous horizon in the Charnian Supergroup.

In the final talk of the morning session, Ian Hill of Leicester University discussed how geophysical techniques reveal details of basement rocks when they are deeply buried beneath younger strata. There are still many problems, but the integration of geophysical interpretation with geological control from outcrop and/or boreholes points the way forward.

At lunchtime, most participants visited the core store, where samples from the new BGS boreholes at Ticknall and Worthington were on display and demonstrated by BGS staff.

The afternoon session commenced with a linked series of presentations by Keith Ambrose and John Carney both of BGS. Keith began with a review of the Dinantian (Carboniferous Limestone) and Namurian (Millstone Grit) sequences around Breedon, Ticknall and Melbourne. This highlighted recent revisions to nomenclature and regional correlations, and discussed the significance of a major intra-Dinantian (Early Chadian-?Holkerian) unconformity exposed in Cloud Hill Quarry, near Breedon on the Hill. In the overlying Namurian strata, further important sedimentary breaks are indicated by correlations between boreholes, which include the new BGS Worthington Borehole. John Carney then talked briefly about syn-Dinantian structure, revealed as spectacular slump folds above the unconformity in Cloud Hill Quarry, and discussed the role of end-Variscan compression that tilted strata to the vertical at the Breedon quarries. Keith then returned to describe recent investigations on the mode of formation and age of Trias-filled caves in Breedon Hill Quarry. The principal finding of this work is that the caves had formed by the end of the early Triassic and were filled with sediments by the beginning of Middle Triassic times.

After tea, Andy Howard (BGS) reviewed aspects of the stratigraphy and sedimentology of the Mercia Mudstone Group — one of the most areally important units in the East Midlands. Following recent lithostratigraphical revisions it is now possible to map the distribution of several formations within this group throughout the East Midlands. These formations can also be traced further afield in eastern England and below the southern North Sea because of their distinctive 'profiles' on gamma-ray and various other type of borehole geophysical log. These geophysical properties reflect the changing proportions of the types of clay minerals that are present within the mudstones, and this in turn may provide clues to the environments in which they originally accumulated.

For the final talk of the day, Allan Brandon (BGS) gave a wide-ranging review of the evolution of the Trent basin during the Quaternary. Major drainage systems, of probable Plio-Pleistocene age, were destroyed by the Anglian glaciation which commenced about half a million years ago. The present landscape evolved after the retreat of this ice and it is clear from the evidence of sequential river terraces that a delicate balance existed between fluvial deposition and tectonic uplift, the consequence being a complex history of landscape rejuvenation involving major drainage diversions. With the help of well-correlated and dated river terraces, it is now possible to view these events against the Quaternary chronological framework provided by the deep sea oxygen isotope stages.

Trevor Ford's return to summarise the meeting was particularly appropriate, since he was co-editor of the 'Geology of the East Midlands' volume, published by Leicester University exactly 30 years ago. As Trevor noted, the geology has not changed but our perceptions and techniques for resolving its complexity certainly have. Doubtless there are many new discoveries to be made in this fascinating and geologically diverse region.

John Carney

REPORT

The EMGS at Minerals 98: a tale of three very different events

Minerals 98 is a promotional event organised by the mining and quarrying industry to present their activities, and the associated benefits, in a positive light to the public. The environmental impact of quarrying remains the subject of much debate and planning dispute, but most sites nowadays are subsequently restored and may become wildlife refuges, nature reserves or recreational amenities. Even during quarrying, birds benefit from the cliffs created and the lack of public access. In the Trent Valley gravels, archaeological remains are often revealed which shed considerable light on both the history and pre-history of human settlement in the region.

The EMGS participated in three open days at local quarries, described in turn below.

Breedon on the Hill Quarry

This Carboniferous Limestone quarry is excavated in one of the six small Limestone inliers in the extreme south-east of Derbyshire. It was visited by the Society in 1997 as an evening trip led by Keith Ambrose and Albert Horton (reported in this issue). Albert Horton became aware of the open day when preparing for the Society's visit to the adjacent Cloud Hill Quarry, which is operated by the same company, Breedon Quarries.

Breedon Quarries is a family concern and pictures of successive generations of the owning family were displayed in the main marquee, along with the history of the quarry and many other historic photographs of quarrying activity at Breedon. The event was very much a family fun day, with many events for children. The Society's display was staged beside an interpretation of the geology of the quarry by Keith Ambrose of BGS and the quarry's own display of minerals and fossiliferous rocks. The latter must have been placed by machine, and rather dwarfed Les Hall's excellent collection which formed the centre piece of the Society's display.

There were several hundred visitors during the day, many of whom were quarry workers past and present who visited the EMGS display with their families. They were very keen to learn about the geology of the rocks that they had spent much of their working lives excavating. Children were able to clamber over the vast dumpers and other equipment on static display. There was also a continuous demonstration of the heavy equipment in operation and an excellent viewing platform had been set up, from which the large scale geological structures in the main quarry could be seen.

The Company's managers Terry and Roger worked unceasingly to ensure that everything was running smoothly and everyone had an enjoyable day. We left with numerous helium-filled balloons, day-glow vests, key rings, mugs, hats, etc., most of which were consolation prizes from our failed attempts to win anything on the tombola.

Hoveringham Quarry

This is a large quarry for aggregate in the sand and gravel of the Trent Valley. Considerable archaeological information and artefacts have been discovered and most of the extracted areas have been reclaimed as excellent sites for birds and recreation. The operators (Tarmac) were keen to present these achievements to the public.

Tony Morris learnt of this open day a few days beforehand when he was asked to attend on behalf of the local MP. The presentations were to be entirely archaeological but the quarry management willingly agreed to the Society being represented. Tarmac have spent in excess of £1 million supporting archaeological investigations and conservation at its four local sites in Nottinghamshire. This work is carried out by the Trent and Peak Archaeological Trust.

The formal proceedings for the invited guests consisted of addresses by Tarmac's archivist, the Reverend Fenn and the Nottinghamshire County Archaeologist, Michael Bishop. This was followed by a most interesting presentation by Dr David Knight of the Trent and Peak Archaeological Trust, describing the results of the excavations at the Company's four local sites and demonstrating the archaeological value of the objects on display.

The EMGS volunteers joined in the consumption of the lavish buffet and wine provided. The invited guests then left and there was a chance to study the interpretative boards on the four sites and talk to the archaeologists about the finds on display while waiting for the public to arrive. The Society's display included fossils provided by Tony Morris and Jack Brown. Among the latter were various bones and teeth that were rapidly identified by the archaeologists. We were amazed at the quality of the pottery and weapons in the archaeologists' display and they were likewise amazed that most of our fossils were millions of years old. The publicity for this event was, unfortunately, not very effective. Only about a dozen members of the public attended, each of whom was outnumbered by geologists and archaeologists and received a lot of attention.

A second lavish buffet was provided and we left feeling rather full and having learnt a great deal about Trent Valley archaeology.

Besthorpe Quarry

This is also an aggregate extraction operation in the Trent gravels, operated by Lafrage Redland. The open day was designed solely for 200 local school children. The event was organised jointly by Vicky Mason of the Wildlife Trusts, who are based nationally at Lincoln, and the quarry manager, Alan

Perkins. Part of the site is now a large nature reserve run by Nottinghamshire Wildlife Trust (Warden: Jenny Kent).

A variety of participatory demonstrations were planned, including bird ringing and environmental activities run by the Wildlife Trusts, archaeological activities run by The Trent and Peak Archaeological Trust, trips to the quarry machinery run by the quarry management, and pebble identification exercises run by Rockwatch assisted by the EMGS volunteers. In the event there was heavy rain for the entire day and most activities had to be cancelled or re-planned. Fortunately, three marquees containing large numbers of chairs had been provided.

The ten EMGS members assisted Rockwatch's Duncan Friend and John Aram of The Wildlife Trusts on pebble and fossil exercises. I was surprised how much geology can be learnt from a small tray of randomly chosen pebbles using the well-designed exercises provided by Rockwatch. The children were very interested and seemed to enjoy their day in a tent in the rain! The exercises and favourite pebbles were taken away for more work at school. The fossil displays provided by Neil Turner (Wollaton Museum), Ben Bentley, Jack Brown, Tony Morris and Jean Morris created a lot of interest and provided an invaluable additional resource to mitigate the disappointments caused by the weather.

The Society's purpose is to further research, education and conservation in geology and, by attending and reporting on events like these, geology can be brought to a wider and interested public. It also brings the EMGS closer to other bodies having complementary activities in archaeology and wildlife conservation. Many thanks to all the EMGS helpers mentioned above plus Inga Filmer, Hella Tasker, Muriel Wright and Philip Small.

Alan Filmer

Gold in the Klondike

A. C. Waltham

Abstract: The Klondike Valley lies deep in the Yukon Territory of northern Canada. In 1896, gold was found on one of its tributary creeks, and this prompted the world's greatest gold rush. The stampede of gold seekers endured awful hardship in hauling their supplies over the snowbound Chilkoot Pass before sailing down the Yukon River in fragile hand-made boats, but they arrived in Dawson after all the claims had already been staked by prospectors who were already on the Yukon River. The rich gold ores were formed by low temperature hydrothermal mineralisation of alluvial gravels and the upper zone of bedrock schist; some was reworked and further enriched as true placer deposits. Mining was originally by hand-dug shafts and adits in the frozen gravels; this was later replaced by hydraulic washing and large scale dredging.

Just 100 years ago, the largest, craziest and richest gold rush that the world has ever known descended on the Klondike — which lay in an almost unbelievably remote location in sub-arctic Canada. Between 1896 and 1904 thousands of fortune seekers endured the most awful conditions in the unforgiving wilderness, to dig for gold in placer deposits of staggering richness. The story of the Klondike is one of wild adventure, stunning extravagance and dreadful hardship — laced into a geological background which is no less remarkable. The Klondike was unique — unprecedented and never to be repeated.

Environments in the Yukon

The Klondike is a relatively small river within the Yukon Territory of northwestern Canada. It is a tributary of the Yukon River, entering its right bank about 100km before it crosses into Alaska, on its way out to the Bering Sea. This mighty river drains most of the interior of Alaska and the Yukon, its basin trapped between the coastal mountains along the Pacific rim and lesser ranges on the Arctic side (Fig. 1).

The Yukon basin is today a periglacial environment — and most of it has been so throughout the Quaternary. In each cold phase of the Pleistocene, a Cordilleran ice sheet developed in the basin's southern sector, by the coalescence of glaciers and ice caps on the coastal mountain ranges. Farther to the east, the huge Laurentian ice sheet advanced in the same cycles, but at its maximum only covered the upper reaches of the Yukon River (Fig. 1). Most of the Yukon basin was not glaciated, due to the lack of snowfall in its land-locked rain shadow. The periglacial zones are distinguished by the high plateaus and minimal relief of altiplanation; river valleys are minor, and hollows are filled and aggraded by solifluction. This cold environment is characterised by very low erosion rates — critical to the preservation of the Klondike gold deposits.

Continuous permafrost occurs where the mean annual air temperature is lower than about –8°C; this covers the Arctic coast zone and also the higher mountain areas of the interior. In most of the Yukon basin, there is discontinuous permafrost, and in the

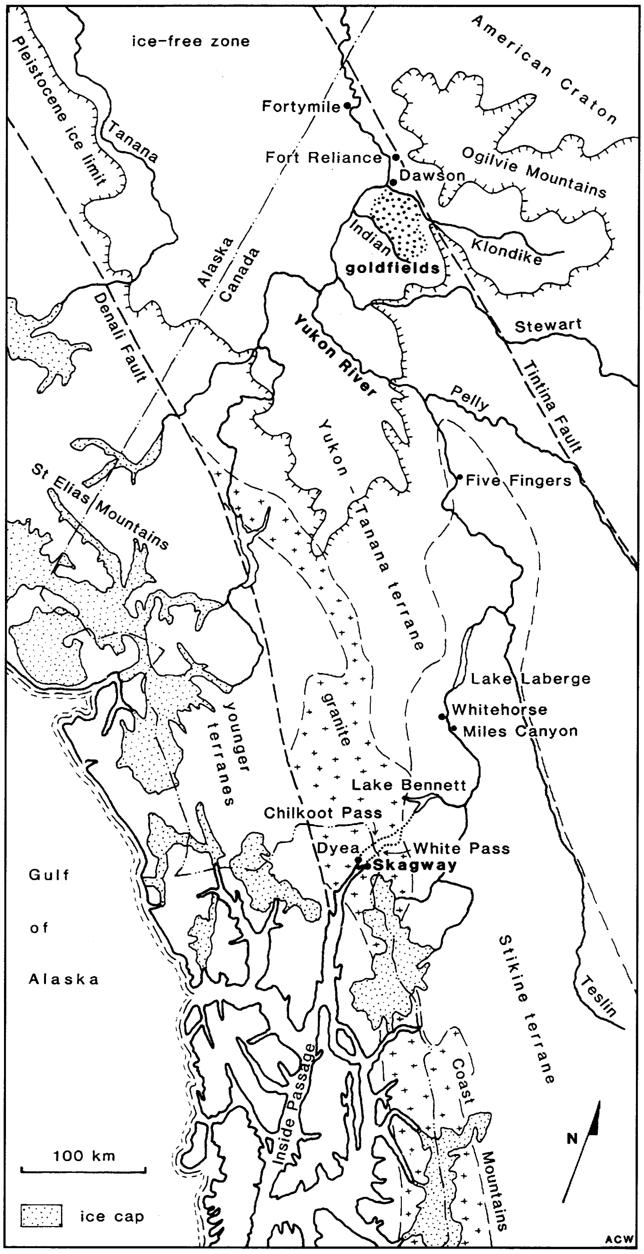


Fig. 1. The upper Yukon Valley and the gold rush routes in from Skagway and Dyea on the Pacific coast. The coast batholith and the faults bounding the Yukon-Tanana terrane are shown. The Pleistocene periglacial zone had Laurentian ice to the east and Cordilleran ice to the south.

Klondike it is about 20m deep. Above the permafrost, the active layer has its winter ground ice thawed by the summer sun; it becomes an undrained, unstable quagmire just a few metres deep during each short Arctic summer. In the Klondike's marginal permafrost zone, frozen ground only survives under an insulating blanket of undisturbed vegetation; clearance or destruction of the trees and their organic soils leads to ground thawing — and was often intentional to facilitate mining operations.

Until the great gold rush, very few people penetrated beyond the coastal mountains into the sub-arctic wilderness of Alaska and the Yukon. It is a seriously hostile country, with vast expanses of wetland, forest and mountain defended by a climate that is rarely comfortable. The coastal mountains provide an almost continuous line of peaks, with many rising to over 4000m between glaciers and icefields; only a few passes provide routes to the interior.

Beyond the mountains, the vast lowland of the Yukon River basin is largely covered by forests of spruce and birch; farther north these thin out to the taiga — a ragged cover of low shrubs and isolated trees. Higher on the hills, or even farther north, the tundra is a treeless landscape of mosses and dwarf vegetation.

The climate is severe by any account. Exposed to the Pacific Ocean, the coastal mountains can receive 30m of snowfall in a single winter. The interior lies in the rain shadow, and has a comparatively thin snow cover in winter, and little summer rain. Winter lasts from October to May, and temperatures can stay below –40°C for weeks at a time. With the summer thaw come voracious mosquitoes, which thrive until August. September offers a brief respite, with its explosion of autumn colour before the snows return.

Into this alien environment of horrendous cold, deep snow, bog, mosquitoes and frozen ground, came thousands of fortune seekers. Nobody in their senses would set off unprepared and on foot into the Arctic wilderness, but gold is the ultimate lure.

The Klondike gold rush

Hardened prospectors and trappers were the first into the Yukon valley, and a trading post known as Fort Reliance was established on the river bank in 1874. Seven years later, gold was found on the Stewart River, but the first significant discovery was on the Fortymile River in 1887. Though this river was largely in Alaska, it joined the Yukon just inside Canada, where a mining camp grew and took the name because it was 40 miles from Fort Reliance.

By 1895 there were hundreds of prospectors and miners on most of the creeks draining into the Yukon River. Robert Henderson was the first man to pan a little gold in Rabbit Creek (now known as Bonanza Creek), which is a tributary of the Klondike just above its confluence with the Yukon. On his advice, George Carmack and two Indian friends camped on Rabbit Creek 15km up from the big river. On August 16th 1896, they found gold richer than their dreams in the creek gravel. They staked their claims, and went to Fortymile to record them.

Within days, hordes of other miners from up and down the river followed the stories; by the end of 1896 most of the Klondike creeks had been staked as claims. The next year, 1897, the river terraces high above the creek beds had also been prospected, had again been found to be rich in gold, and had subsequently been staked. Claims cost just $15 to register, and more than 30 claims on Bonanza and Eldorado Creeks each yielded a million dollars in gold.

The Stampede. On July 17th 1897, a ship docked in Seattle carrying 68 miners and $700,000 in gold, and the world's most frantic gold rush began. More than a rush, it was a headlong stampede, and its ill-prepared participants were known as stampeders. Every ship on the west coast sailed north, packed with optimists and opportunists, each with his own mountain of supplies. Few had any idea of what lay ahead. A few wealthy adventurers took the long ship route around the Alaska Peninsula and up the Yukon River from the Bering Sea (Berton, 1990). But for most the sea journey ended at the head of one of the two most northerly fiords in Alaska's Inside Passage. Unloading the boats onto the tidal flats was just the first desperate task, but by the end of autumn 1897, there were 30,000 stampeders in the sprawling fiord-head camps at Skagway and Dyea, just 2km apart (Fig. 1).

Directly out of Skagway, the White Pass took a pack-horse trail through the mountains. Although it was the easiest route north, 3000 horses died on its trail during the first winter. By July 1899 there was a railway over the White Pass, and Skagway thrived as the port town, while Dyea died. But that was too late for the stampeders of 1897, of whom few could afford the tolls on the original horse trail.

So most of the stampeders set off north from Dyea, on the old Chilkat Indian trail which climbed over the Chilkoot Pass (Fig. 1). Throughout the winter of '97-98, some 25,000 of them hauled their supplies through deep snow over the Chilkoot trail, and over the 990m high pass. Dyea is in Alaska, and the Canadian border was marked by an outpost of the North West Mounted Police on the crest of the pass. As there were no supplies in the Yukon wilderness, stampeders were only allowed to enter Canada if they had a year's supplies with them. Essential items included 160kg flour, 70kg bacon, 1 box candles, 2 heavy blankets, 2 wood saws, 10lbs pitch; the list was long, but gave no room for comfort.

Each man therefore had to haul about 700kg of food and essential materials — mostly on their backs, as no horse could make the steep, rough trail. So the kit was ferried load by load, cache to cache,

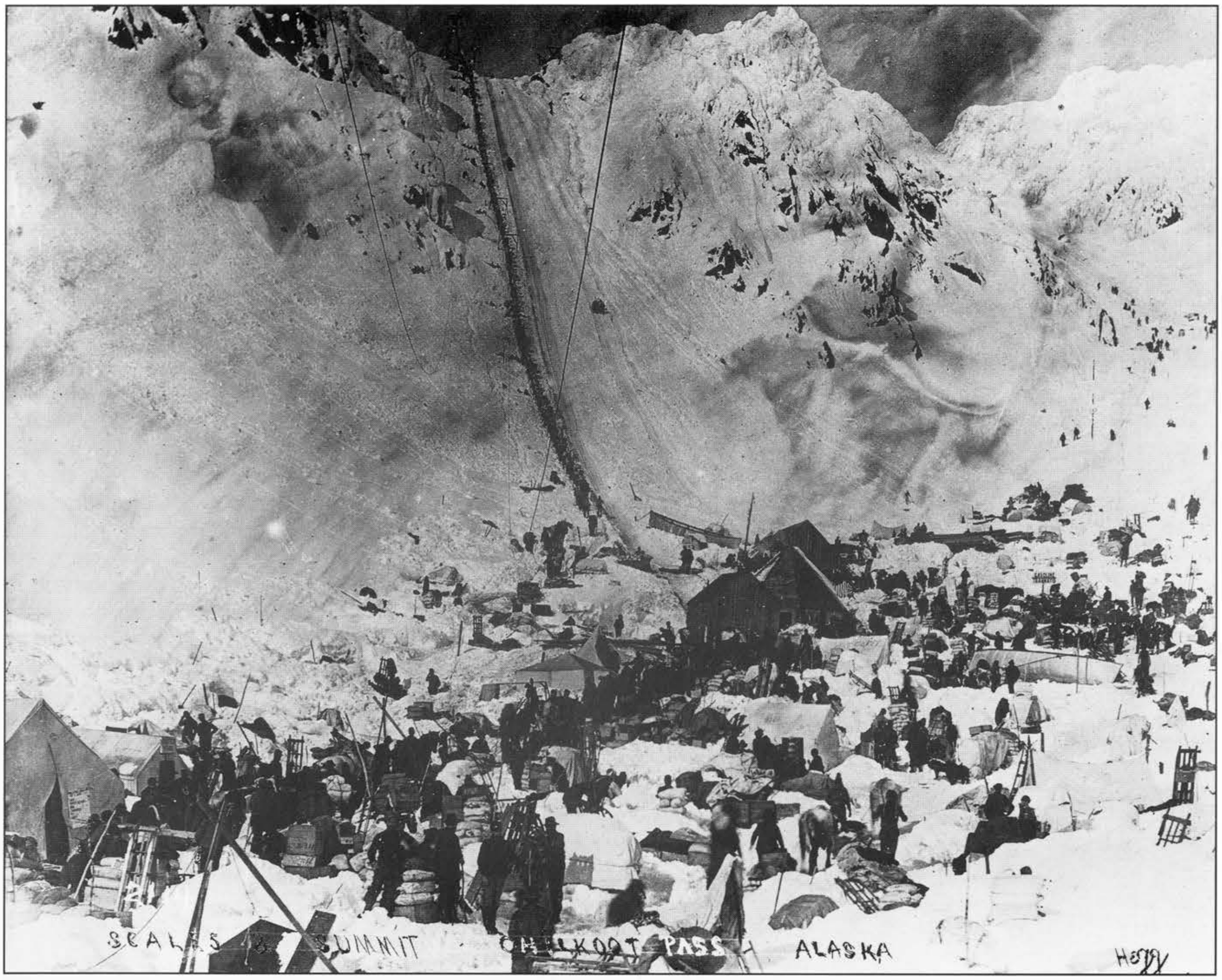


Fig. 2. Stampeders' supplies stockpiled on the Chilkoot Pass, while an unbroken line of men haul them up the snow slope of the Golden Stairs in the centre background. These stampeders were late in the Rush, as the first of the aerial tramways was being built at the time (photo by E. A. Hegg, courtesy of Dawson City Museum).

and it took up to 3000km of trudging to and fro with a backpack to cover the 53km to Lake Bennett. The suffering and endurance of that winter on the Chilkoot were legendary (Berton, 1983, 1990; Morgan and Hegg, 1967). The final ascent to the pass was a 40° ascent on a snow covered scree slope (Fig. 2). An endless line of men carried their heavy packs up the steps stamped in the snow, and known as the Golden Stairs; only in 1898 were aerial tramways built to improve the route for the traders who came after the stampede.

Once over the Chilkoot Pass, the stampeders descended to the banks of Lake Bennett, where a huge tent city grew steadily through that winter. There they cut down most of the surrounding forest — and used their saws, oakum and pitch to make boats which could survive a trip down the Yukon River. On May 29th 1898, the ice broke up on the lake, and within a few days 7124 boats were counted by the Mounted Police as they set off down the outlet river. The current carried them downstream, to start an unpowered journey of 900km to the Klondike. Much of the Yukon River provided easy and steady floating, but there were some rude interruptions. Miles Canyon had wild water between walls of columnar basalt, and the Whitehorse Rapids were equally wild (but now lie submerged behind the dam at the town of the same name); Five Fingers Rapids, over a band of hard conglomerate, were not so troublesome.

In June 1898 the armada of stampeders floated into Dawson, the miners' town at the mouth of the Klondike River. Only then did the ultimate tragedy hit them — by the time that they arrived, every claim in the goldfields valleys had already been staked. The 30,000 new arrivals could only work for wages from the prospectors who had got there before them. Many departed, broke and broken. One stampeder wrote home:- "Martha. All the ground is taken. Everyone is a king but me. I'm off to Nome on the last boat out. Affectionately, Henry". Those who did make it rich were mostly not gold-diggers — they were the thoughtful ones who had come equipped for trade in the Dawson boom-town (Berton, 1983).

Dawson and the Klondike camps. The miners' camp on the mudflats at the mouth of the Klondike River had expanded steadily since 1896; its collection of tents and a scatter of log buildings was named Dawson, after a Canadian government geologist (Fig. 3). With the arrival of the stampeders, Dawson became Canada's largest town west of Winnipeg. An initial chaos of ragged tents in a sea of mud slowly evolved in the wake of the mining boom. A fleet of sternwheelers, brought endless supplies up the river from Alaska — along with a few thousand more gold seekers. Timber buildings and raised sidewalks lined the muddy streets — which have never been tarred to this day.

The gold diggings started in the Klondike valley right at the back of town. They stretched up each and every creek that drained into the Klondike from the south. Every claim had its own collection of log cabins, tents and makeshift shacks, and traders established posts wherever they could. Grand Forks became a key town with hotels, shops, saloons and a floating population of over 5000 above the junction of the two richest creeks, Bonanza and Eldorado (Fig. 4). From 1906 to 1914, it was linked to Dawson by a railway through the heart of the goldfields.

The wildest days of the gold rush ended in August 1899, when word came up the river of new gold discoveries on the beaches of Nome, on Alaska's Bering Sea coast. There was a new rush for the boats as most of the stampeders and itinerants without a claim of their own headed out of town. A slightly less crowded Dawson continued to thrive with the highs and lows of the mining industry. In 1953 the Yukon government moved from Dawson to Whitehouse, but there are still miners on the Klondike today.

Geology of the goldfields

The Yukon terranes. The geology of the north-western tip of North America is essentially the product of convergent plate boundary activity and terrane accumulation, complicated by massive oblique shearing. The Western Cordillera, including the Rockies, the Coast Mountains and the Alaska Range, was formed largely in Mesozoic times as an orogenic belt above the eastwards subducting, eastern Pacific plates. This orogenic belt was accreted to the western edge of the very old continental craton known in part as the Laurentian Shield. In the early Tertiary, the divergent boundary of the Pacific Rise was overridden by the advancing North American plate. Thereafter, the subducting Pacific plate was moving west of northwards — and most of the plate boundary along the Pacific coast of North America became a massive transform fault

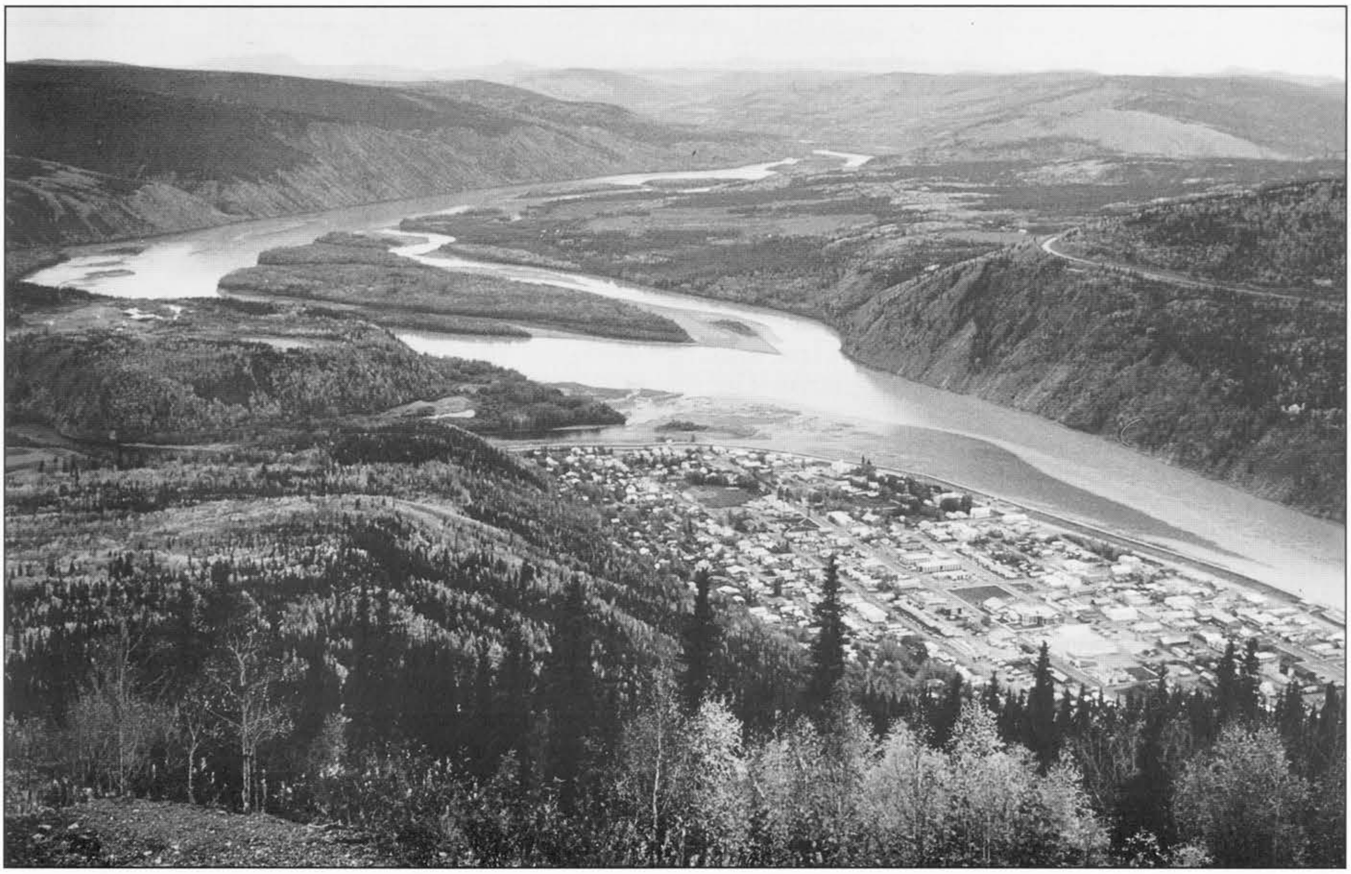


Fig. 3. The present town of Dawson, on its mudflat beside the Yukon River. The Klondike River enters between the high terraces at the far end of the town, and produces the dark wedge of clear water against the pale, muddy water of the Yukon River. The goldfields lie upstream on the Klondike, just off to the left. The view is to the southwest, looking up the Yukon River where it is entrenched between the periglacial plateaus (photo by the author).

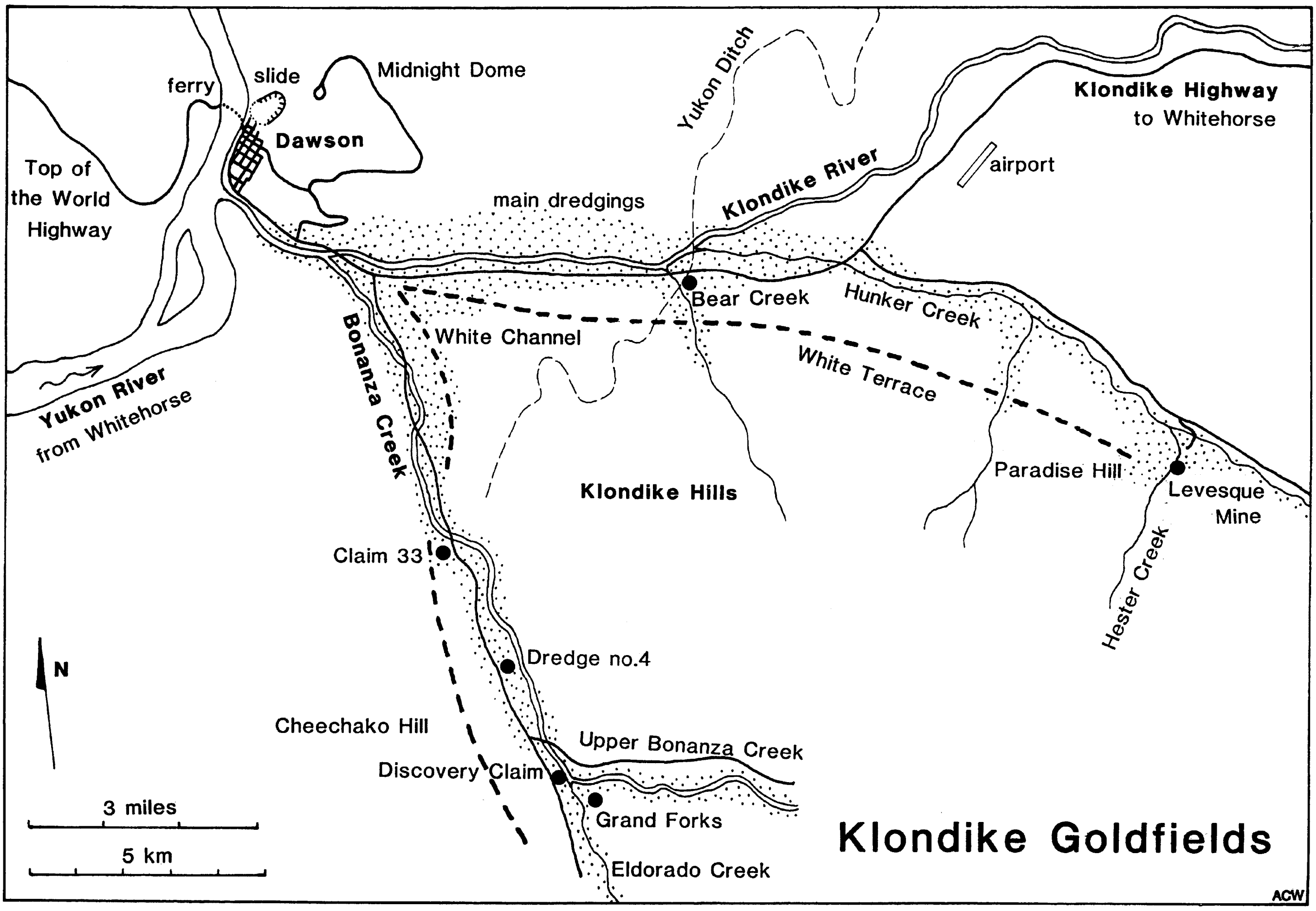


Fig. 4. Outline map of the heart of the Klondike goldfields on the Bonanza and Hunker Creeks. The stippled areas are those most thoroughly worked by dredging and hydraulicking operations. The heavy broken line traces the richest zones of the White Channel within its high terrace, and was also heavily mined across Cheechako Hill.

system dominated by shear movement. However, plate convergence continued along Alaska's southern coastline.

The long period of northward movement of the Pacific plate had the effect of a massive conveyor belt that carried various terranes from distant sites northwards, to be accreted onto the south coast of Alaska where the plate boundary turned sharply to the west (Waltham, 1995). Much of the terrane material was derived from huge greywacke sequences that accumulated along the western margin of the North American craton. Individual terranes have been recognised by detailed mapping along with an overview of the metamorphic facies (Dusel-Bacon *et al.*, 1898-94).

Early Jurassic times saw the arrival of the Yukon-Tanada terrane; this was a chunk of Precambrian-Paleozoic schists, drawn out into a long strip by the shearing of the oblique collision. The boundaries of the terrane are major faults (Fig. 1). On the south side, the Denali Fault has a shear displacement, whose continued activity threatens to create a lateral offset of the Alaska oil pipeline which crosses it just north of the Alaska Range (Waltham, 1995). On the north side, the pattern of oblique slip has created an element of tension across the Tintina Fault throughout its Tertiary history, when a narrow graben developed along it. This is recognisable as the Tintina Trench; it is now partly filled with Tertiary sediments, but is recognisable where it is occupied by segments of the Yukon, Klondike, Stewart and Pelly Rivers (Fig. 1). Subsequent terrane arrivals trapped and compressed intervening greywacke belts, and the impact of the collisions with the American continental slab was great enough to generate partial melting of the crust, thereby creating the huge coastal batholith of granite, now exposed around Skagway.

Origins of the Gold. Within the Yukon-Tanada terrane, the Lower Paleozoic Klondike Schist is the ultimate source of the Klondike gold. But as in all the world's great gold rushes, the miners' targets on the Klondike were the enriched placer deposits. The richest gold was found as flakes and grains in loose alluvial sediments. As worked both in the first rush and today, most grains are less than a millimetre across, some is the finest of dust, and some is in nuggets formed where smaller grains are annealed together in the riverbed. All the gold occurs as the native metal, though it is alloyed with a little silver and traces of copper.

The placer deposits occur along most of the creeks in an area of over 1000 square kilometres. The richer gravels, just a few metres thick, are mostly covered by up to 12m of barren gravel, loessic silt and organic peat (locally known as muck). Late Tertiary gravels, 2-50m thick, occur as terraces on the higher valley sides, at levels up to 100m above the creeks; these also contain gold, with the richest in the White Channel, named after its clean, white, quartz sand (Fig. 5).

It had long been assumed that all the gold, in both the White Channel and in the modern gravels, was typical alluvial placer material, derived by mechanical erosion of gold-bearing quartz veins within the bedrock and then concentrated by selective deposition. But this is not entirely the case, as much of the gold is found in enriched zones within the schist just below rockhead.

The marine clays which now form the Klondike Schist originally contained low levels of gold. This was mobilised during Cretaceous metamorphism, at temperatures around 300°C, and was concentrated into numerous, widely dispersed quartz veins (Rushton *et al.*, 1993). Few of these are large enough or rich enough to warrant underground mining on even the smallest scale.

Overlying the schist, the oldest drift sediments, occupying the highest topographical positions, are the braided channel sediments of the White Channel terrace. These are of Plio-Pleistocene age; they are also mineralised (Morrison and Hein, 1987). Their lower parts show clear signs of low-temperature hydrothermal alteration; most notably there is kaolinisation with new growths of clay minerals. Similar alteration also occurs in the top few metres of the immediately underlying bedrock — the quartz chlorite sericite schists. This second phase of gold mobilisation concentrated the metal to economic levels just above and below rockhead (Fig. 5); its medium of transport was largely rainwater draining through the drift and weathered bedrock, but it is distinct from conventional secondary mineral enrichment that occurs purely by weathering processes. Gold/silver ratios vary from creek to creek, indicating local variability in the sources of the metals and their emplacement systems.

Erosion and reworking of both the mineralised sediment and the shallow bedrock, by the contemporary early Pleistocene rivers, produced further gold concentrations in the White Channel; these were traditional placer deposits, which provided the richest pay streaks in the terrace gravels. All the White Channel alluvium was left above the valley floors by a phase of incision and rejuvenation that probably occurred when local base level declined in response to downward movements on the rifts along the Tintina Trench. Fortunately, Pleistocene ice did not reach the Klondike; if it had, it would have dispersed the gold into glacial till spread over huge areas. Instead, fluvial erosion of some of the mineralised schist and terrace sediments produced successive generations of placer deposits in the modern creek gravels, in various intermediate terraces, and in the modern creeks (Fig. 5).

Within the placer gravels of both the modern valley floors and the terraces, the pay streaks with the very richest gold lie immediately above the rockhead and follow ancient channels cut into the bedrock. This is typical of placer deposits, and the exact positions of the channel floors cannot be predicted from surface observation. To the frustration of the weary miners, the rich paystreaks were only found by sinking shafts through the entire thickness of the muck and gravel, and then digging adits immediately above rockhead until gold-rich ground was discovered.

This interpretation of the ore enrichment mechanism explains the lack of any mother lode in the Klondike. Most of the world's richer placer deposits were created by fluvial deposition after erosion of hydrothermal minerals in one or more veins — the mother lodes; these were generally found merely by tracing the placer ores to their upstream limits. The veins commonly provided a second phase of mining, albeit not as rich or as easily worked as the placer ores. But hard-rock mining in the Klondike has only ever revealed a few isolated and rather meagre vein deposits.

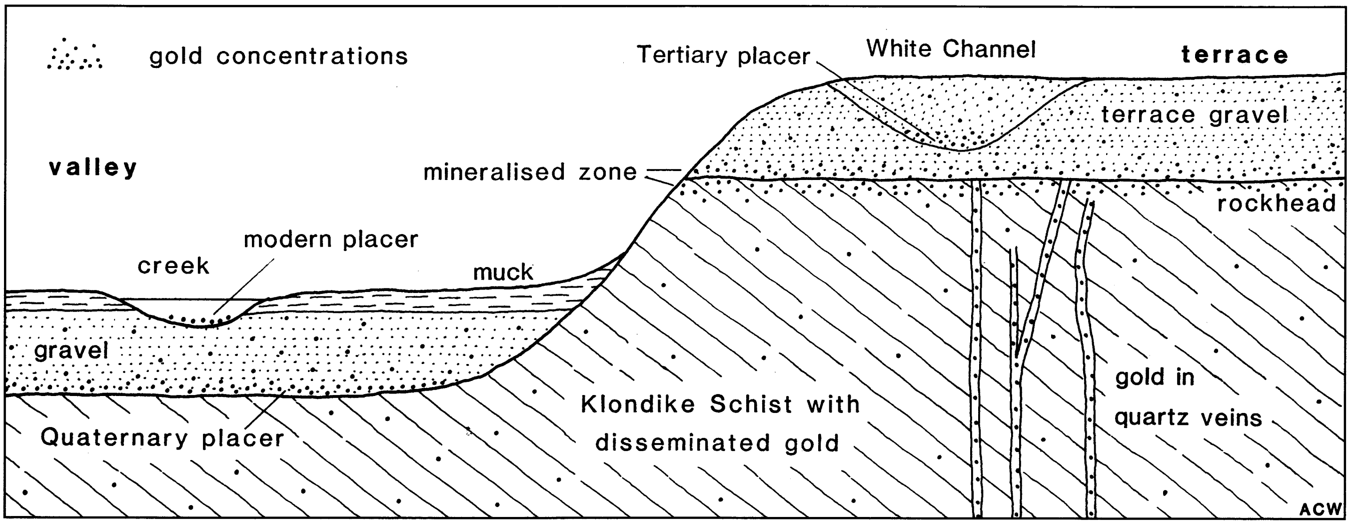


Fig. 5. Diagrammatic profile to show the various features of gold mineralisation in the Klondike schists and gravels.

Fig. 6. Early summer on the creeks, with a group of miners shovelling the sediment from a winter's underground digging into their long timber sluice. The photographer's inscription refers to the 21st claim downstream of the first claim on Hunker Creek (photo from the Turnbull Collection held by Dawson City Museum).

Mining the Gold

Panning for gold entails washing water across a shallow bowl fast enough to remove the light sediment and leave behind the heavy gold. With this quick and simple technique, the prospector worked his way up the creeks, panning the streambed gravels, until he produced a rich pan. Then he staked his claim, to 500 feet (150m) along the creek and 1000 feet (300m) up each side, and had to start digging into the deeper gravels, largely frozen solid in the permafrost, as the richest gold was always down at the rockhead. Panning has always been the tool of the prospector, but methods of mining have evolved through the years, largely in response to the nature of the gold ores which were the best available at any particular time.

Hand mining. This was the technique of the frantic Gold Rush years, but was employed on the Klondike only until 1904. A shaft was sunk straight down until bedrock was reached, and then horizontal adits were driven to find and then follow the pay streaks. Permafrost ice cemented the drift sediments to the extent that these tunnels could not be dug without powered machinery. At first the ground ice was melted by fire-setting, but this was horribly inefficient. More effective was steam from boilers at the mine entrance, but its production needed huge quantities of wood — and contributed to the complete removal of the forest in the entire Klondike region. The permafrost did keep the mine galleries stable, but the entrance shafts through the thawed active layer became unsafe during the summer, when they were best avoided. So the miners worked underground through the winter, and the gravel that they dug out was stockpiled on the surface, where it froze solid. Then in summer, the stockpiles were sluiced in running water — which was not available during the winter.

Separation of gold and waste. Sluicing was and still is the main method of separating the gold from the barren quartz and rock gravel. The original sluices used in the Gold Rush were inclined wooden channels about 400m wide and deep, with wooden riffle bars across their floors; water cascaded through them, and the channels were as long as the miners could afford to make them (Fig. 6). Gravel and dirt from the stockpile was shovelled into the sluices, where the lighter quartz and rock was washed down the channel by its cascading water. The gold was trapped behind the riffles, as it was too heavy to be washed over by the water flow; the finest gold dust was trapped on coconut matting beneath the riffle bars. A modern sluice works on similar principles, but it is a shorter and wider steel table which is vibrated by an electric motor, and it catches the finer gold on a carpet of nylon. In both the old and the new, the sediment from behind the riffles is subsequently panned to separate the gold from the other heavy minerals that are also trapped by their weight.

Most of the first miners used rocker boxes to recover the gold. Each box was about 500mm wide and 800mm long, with riffles on its base. Loaded with water and a few shovel loads of dirt, it was rocked back and forth by hand until the gold was trapped on its floor. A rocker box was a cross between a pan and a sluice; it was popular with miners of limited resources because it required less water and timber, but it was hard work to run.

As all the gold is of dust, sand and small nugget size, the separation process is improved by removing the very coarse material before sluicing. This is particularly valuable in working the leaner ores after the first rush had picked out the riches. Sieves, or screens, normally remove all the gravel coarser than about 10mm. Plane vibrating screens, a few metres across, are used on smaller mines. Larger operations feed the dirt, rock and gravel into rotating cylindrical screens known as trommels; these are 2-3m in diameter and generally 10-15m long. Both the plane screens and the trommels have hole sizes, gradients and feed rates which are selected to be most efficient for the grain size distribution of the particular deposit being worked.

Hydraulicking. Powerful water jets, blasted out of monitor pumps, are very effective at washing gravel and dirt from an exposed slope (Fig. 7). The washed debris is then scooped up and dumped into sluices just as in hand mining. The technique was introduced on the Klondike in 1902, long remained the favoured method on the terraces, and is still used on the largest mines that are worked today. It is quicker than digging, but requires a good water supply. A major step forward in the early mining was the construction of the Yukon Ditch, a sequence of canals, flumes, iron pipe syphons and vast timber aqueducts, totalling 115km in length, that brought water into the Klondike valley from unused rivers to the north.

Fig. 7. Monitor pumps in the hydraulicking operation at the Levesque Mine above Hunker Creek. The water jets are cutting into a thick cover of organic muck overlying gold-bearing gravels. Dark Klondike Schist forms the lower half of the bluff to the left of the pumps; its altered and mineralised zone is also being washed out by the water jets. The loose debris is scooped up by a front-end loader and dumped into a sluice off to the left (photo by the author).

Cat mining was started on the Klondike in 1973. It uses a caterpillar bulldozer to clear away the muck and barren gravel, before piling up the gold-bearing gravel ready for sluicing. Crude and simple, it is still used on small exploratory operations and where there is not enough water for hydraulicking.

The Levesque Mine is mainly a hydraulicking operation currently worked by two men on a tributary to Hunker Creek. Overburden of 5-20m of muck and gravel is washed away, frequently revealing very large bones and tusks from Pleistocene mammoths (Fig. 8). The lower gravels have good gold values, but, unlike in true placer ores, the richest gold occurs over bedrock ridges where it is associated with hydrothermal graphite mineralisation in the schist. Monitor pumps, blasting out 5000 litres of water per minute, rapidly cut through the unfrozen sediments and into the upper zone of altered and mineralised schist (Fig. 7). The ground is already thawed because earlier miners dumped their tailings and killed the insulating blanket of moss. In winter, the organic muck refreezes to depths of 2m deep underneath a snow cover. Left alone a bare exposed face freezes inwards to 5m from the surface, and this would delay the spring start-up until it had thawed. To prevent this, the monitor is used to undercut and slump the face before winter, to leave a low profile on which an insulating cover of snow can accumulate; this effectively prevents the ground freezing to more than a minimal depth.

The gold dredges. Dredging was the great gold producer in the years 1905-66, when up to 35 dredges operated on the creeks (Neufeld and Habiluk, 1994). A typical floating dredge weighed up to 3000 tons, and sat in a lagoon of its own making. At its front, a chain of 75 buckets, each holding half a cubic metre, scooped up 8000 cubic metres of gravel per day (Fig. 9). It could reach to a depth of 17m, and scraped up the top 3-4m of altered schist — which had the high gold values. All the broken rock and alluvium was fed into a huge

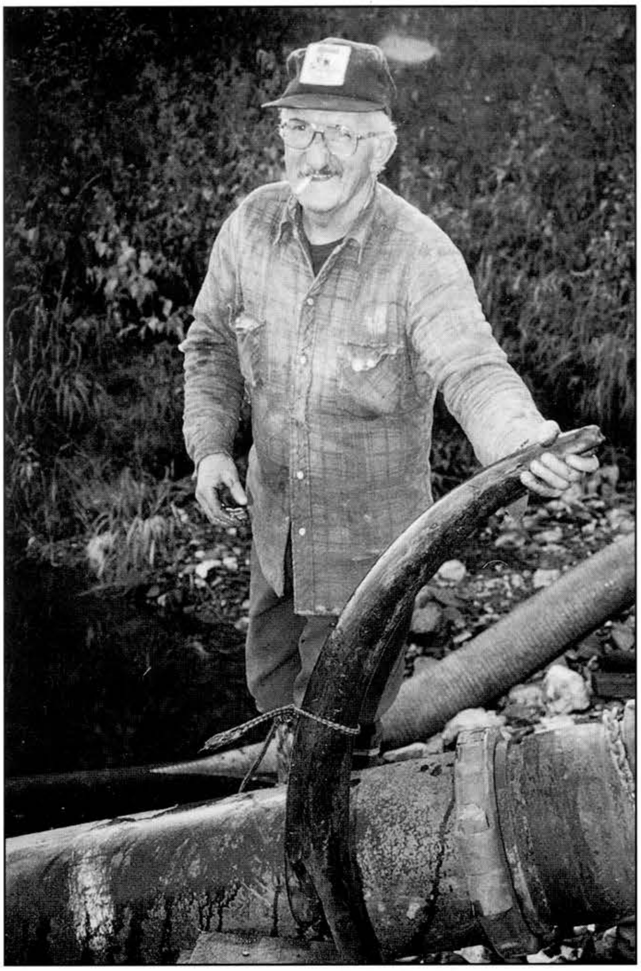


Fig. 8. Emil Levesque holds one of the Pleistocene mammoth tusks which he washed out of the gravel in 1996 at his hydraulicking mine. The string around it allows him to pull the tusk out of the pond where he keeps it underwater to stop the ivory breaking up as it dries out (photo by the author).

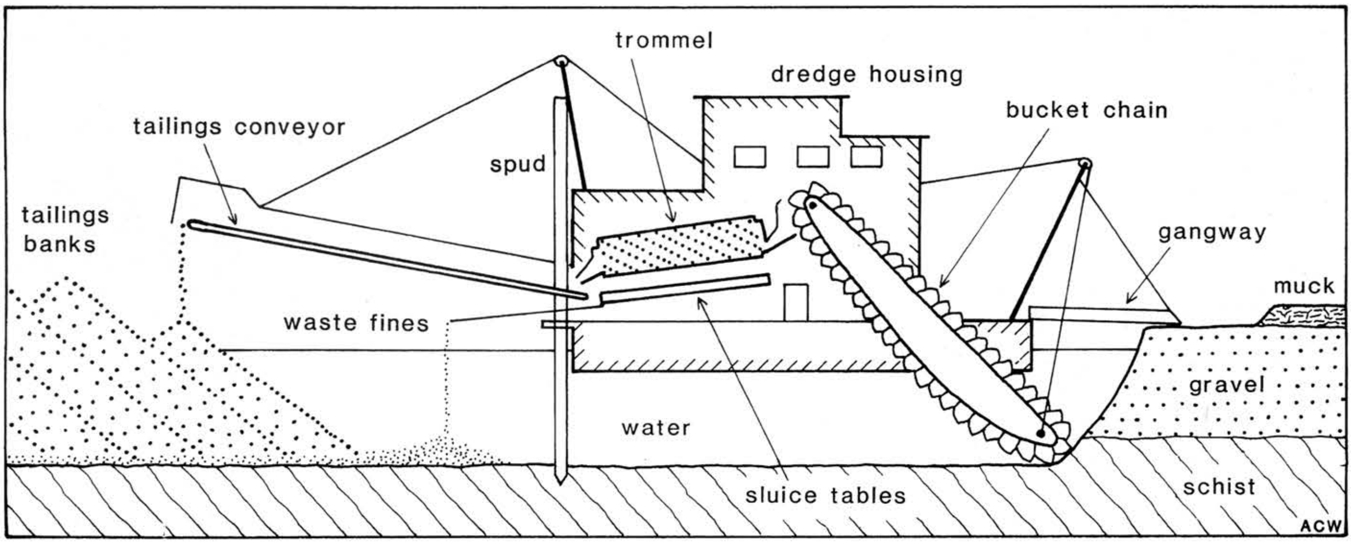


Fig. 9. Sketch drawing of the main features of a Klondike gold dredge.

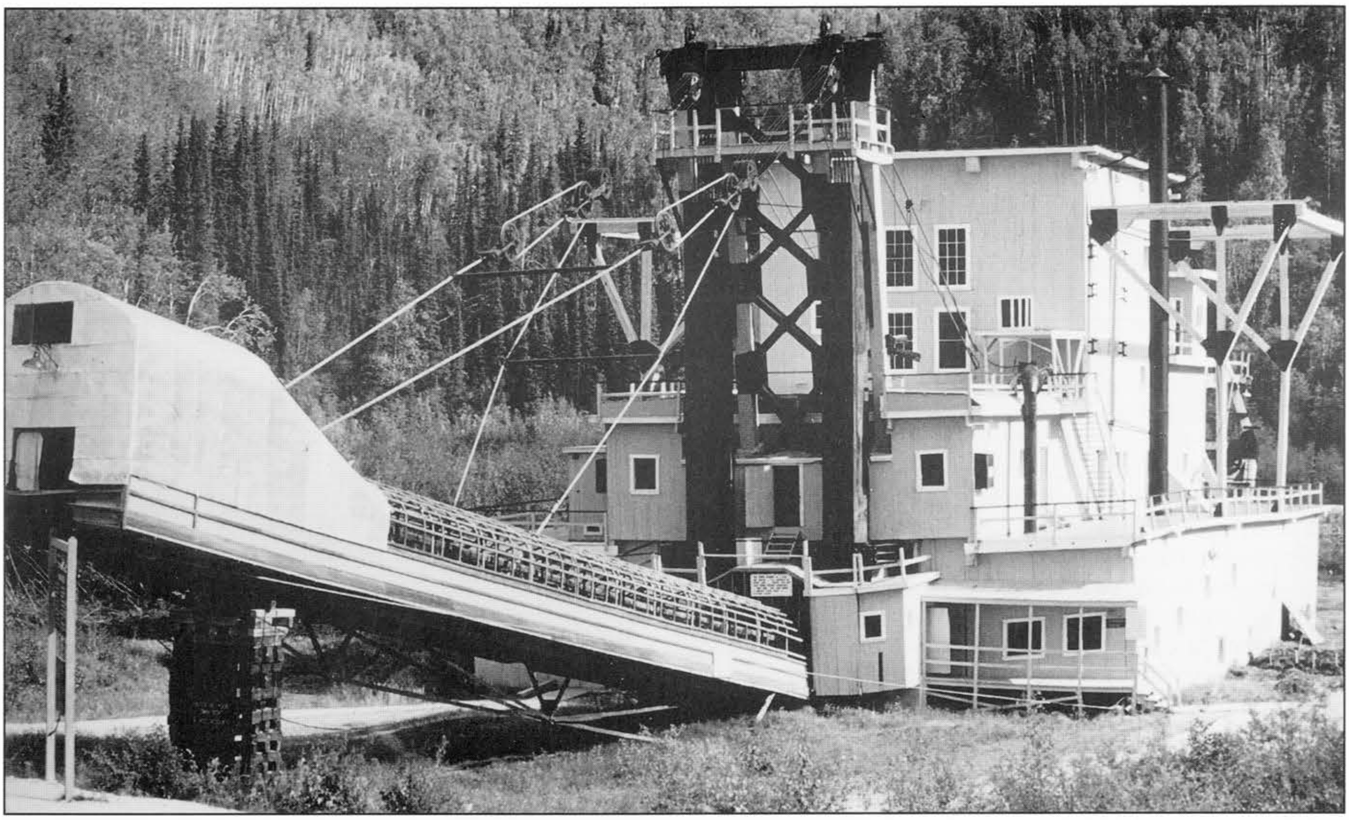


Fig. 10. Dredge Number 4, preserved on Bonanza Creek where it ceased mining in 1959. The long arm houses the tailings conveyor belt, and the bucket chain is out of sight at the far end. The photograph was taken in 1990, before the dredge was completely dug out of the gravel and turned around (photo by the author).

Fig. 11. Characteristic ribbed ridges of dredge tailings on the floor of the Klondike Valley, just upstream of the Bonanza Creek confluence. Some tailings ridges in the background have been regraded to allow re-use of the land as industrial units (photo by the author).

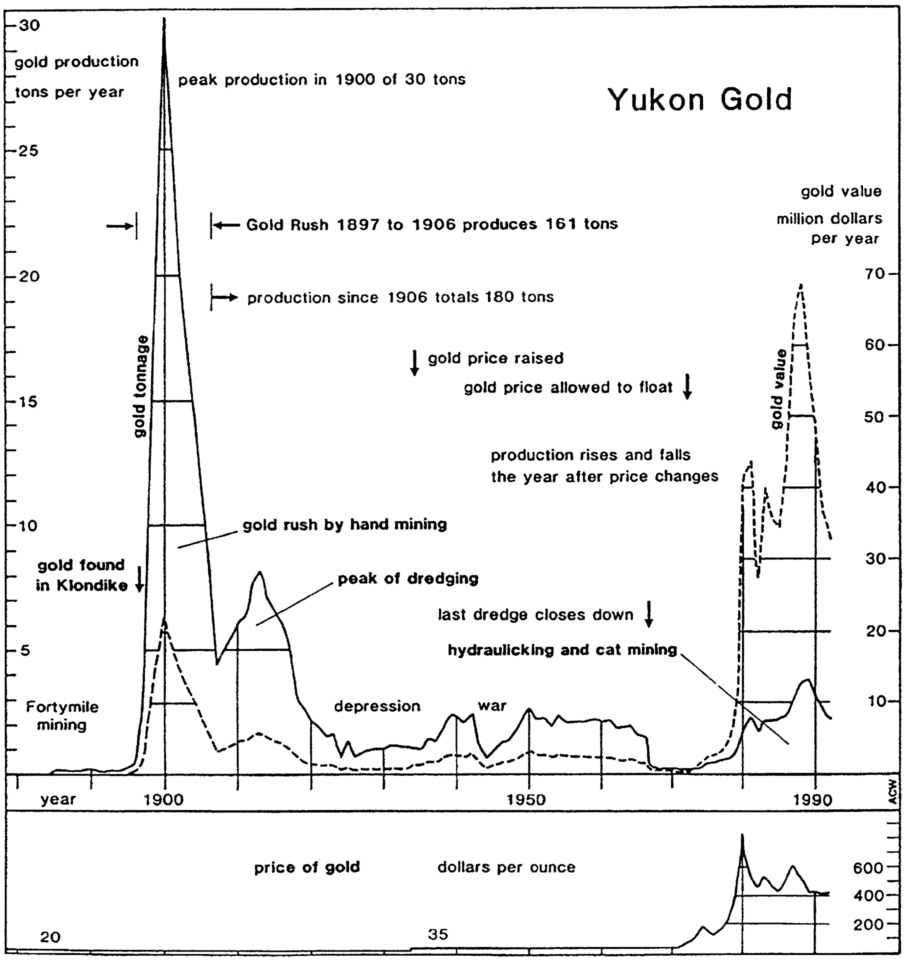


Fig. 12. Gold production statistics from 1885 to 1993. Though the data applies to the entire Yukon Territory, nearly all the mining has been on the Klondike and the changes almost entirely reflect the operations on the Klondike creeks.

revolving trommel inside the dredge housing, and the coarse debris went straight through onto the tailings disposal conveyor belt (Fig. 10). The fines dropped out of the perforated trommel onto the vibrating sluice tables, which trapped the gold with impressive efficiency. One dredge could gather up to 800 ounces (11kg) of gold in a day; but dredging had to stop when the sluices froze each winter.

Before the dredge could advance, the ground was prepared by washing off the vegetation and organic muck using the powerful monitor pumps. Then the permafrost was thawed by pumping cold water into holes bored into the alluvium; it was slower than steam, but was far more economical. The dredge advanced through the cleaned and thawed alluvium by winching itself forward on cables attached to temporary ground anchors. Once in a new position, its central steel spud was sunk into its lagoon bed. The whole dredge could then rotate around the spud, so that its bucket chain could scrape up the gravel from a wide arc. This rotating motion also swung the tailings conveyor belt at the back of the dredge, so that the barren debris formed its distinctive crescentic banks. Finer tailings from the sluices were dropped directly into the lagoon, and were then covered by the coarser debris. Each dredge ploughed through the valley alluvium, leaving its own sinuous ridge of tailings and debris to mark its route. The upper coarse material was then washed through by rainfall, to leave the crenulated banks of clean cobbles that distinguish the goldfields today (Fig. 11).

Patterns of gold production

The Klondike has yielded a total of more than 300 tonnes of gold. Annual yields have fluctuated with the changes in mining methods and also with variations in the price of gold (Fig. 12). Even today the annual gold yields are maintained by a number of small hydraulicking and cat mining operations. Production has been good in recent years, but the fall in the gold price to less than $300 per ounce in late 1997 must herald a cutback; some mines will close down, but others will just mothball their plant until they can re-open when the gold price recovers.

Gold yields with the big dredges averaged about one part per million, but this was obtained from the leaner material left behind after the initial rush. It is difficult to know what yields the first miners achieved by picking off the rich pay streaks, but they were orders of magnitude better; the best claims on Bonanza and Eldorado Creeks were the richest the world has ever known. But the total amount of rock, gravel, sediment and dirt shifted and sluiced by the Klondike miners probably exceeds 100 million tonnes. Men have moved mountains for gold, and none more than on the Klondike.

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The Geology of the Laxey Lode, Isle of Man

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Abstract: An analysis of the geological relationships of the Laxey zinc-lead ore deposit derived from the literature and from unpublished reports is presented. The deposit is a single lode 2km long and up to 8m wide with a north-south trend and an easterly dip of about 10° from the vertical. It is emplaced within the Lonan Flags (Manx Group, Lower Ordovician) and is crossed by several "slide" faults, some offsetting the lode. The lode post-dates the folding and metamorphism of the Manx Group and emplacement of microgranite dykes, probably in Carboniferous times. It is suggested that Carboniferous mudrocks were the source of the metal ions. The ore was mainly sphalerite with less abundant galena and some chalcopyrite. Some of the galena was argentiferous. It is estimated that over 1 million tons of ore containing 3-8% Pb, 5-15% Zn and 2.5% Cu were extracted.

Introduction

Lying in the Irish Sea midway between England and Ireland, the Isle of Man was noted in the 19th century for its rich lead-zinc-copper mines. Of these the Great Laxey Mine was reputed to be one of the richest zinc-lead mines in Europe with over one million tons of ore extracted before mining ceased in 1919. Descriptions of the associated relics of surface installations, particularly the giant Lady Isabella water-wheel, are available (Jespersen, 1970; Cowin, 1973; Kniveton *et al.* c.1993). Jespersen discussed the mechanics of pumping in detail and included reminiscences from former miners of some of the more recent events in the mine's history. There are also several general accounts of the history of mining (Lamplugh, 1903; Skelton, 1956; Mackay and Schnellmann, 1963; Garrad *et al.* 1972; Robinson and McCarroll, 1990) but records of the geology of this important lode are minimal and misleading.

Laxey town lies at about 80m above sea level near the east coast of the Isle of Man and the mine was a few hundred metres farther inland (Fig. 1). No detailed study of the Laxey ore deposit using modern geological methods is possible at present as the mining effectively ceased with a strike in 1919 and the mine was officially closed in 1929. Most of the workings are no longer accessible owing to flooding, collapse or infilling. The few available descriptions of the geology are either incomplete or difficult to interpret. However, some idea of the lode's relationships can be gained from the old accounts and the results are presented here. They provide an illustration of the difficulties of using old records to judge whether an ore-body really has been exhausted. Little has been said on the genesis of the lode in previous literature and an attempt is made herein to rectify this omission.

Data have been assembled from mine plans coupled with observations made at the surface and in the few accessible adits. More could be learnt by a thorough study of the nature and disposition of the host rocks in the accessible shafts and adits by anyone prepared to take the risk of underground exploration of long-disused workings. Further data could also be derived from waste material in the river and from cobbles on the beach, though most of the waste heaps have been removed or are built over. Some mineralogical data could doubtless be obtained from specimens in the Manx Museum.

Previous Research. There are few geological accounts of the mineral lode. In preparing the Geological Survey Memoir, Lamplugh (1903) had the advantage of being able to see the mine whilst it was still working and the following text draws from his work. Lamplugh and Dewey's report (1925) on copper ores largely repeated the Memoir while Carruthers and Strahan (1923) and Skelton (1956) added a few details concerning the mining history. These accounts were all summarized in an unpublished report by Mackay and Schnellman (1963 — copy in the Manx Museum library) which also provided information culled from other mining archives in the Manx Museum. As most of the mine is below sea level it has been flooded since working stopped in 1919 but a main adit driven northwards is still above water level. The northern section of this was reached by expert mine explorers in 1971, 1974 and 1982. Unfortunately the explorations described by Richards and Atherton (1971) and by Warriner and Gillings (1983) were undertaken without a geologist present and added little to geological knowledge. A general geological account of the Isle of Man with an outline of the Laxey area was given by Ford (1993).

Stratigraphic and Structural Overview. According to Simpson's (1963) geological map of the subdivisions of the Manx (Slate) Group, the Laxey Lode is emplaced within the Lonan Flags (Lonan Formation of Ford's revised nomenclature, 1993) (Fig. 2). The Lonan Formation, in common with most of the Manx Group, is now known to be of Early Ordovician (Arenig) age.

The accessible levels of the mine and the few surface exposures reveal an alternation of cleaved siltstones and argillaceous host rocks which are more like Simpson's (1963) Maughold Banded Formation than the Lonan Flags. The latter vary from massive sandstones (Agneash Grits in some accounts) to pelites along the east coast of the Isle of Man and, without detailed re-mapping, Simpson's assignment of the beds around the Laxey Lode to the Lonan Flags must remain uncertain. Furthermore,

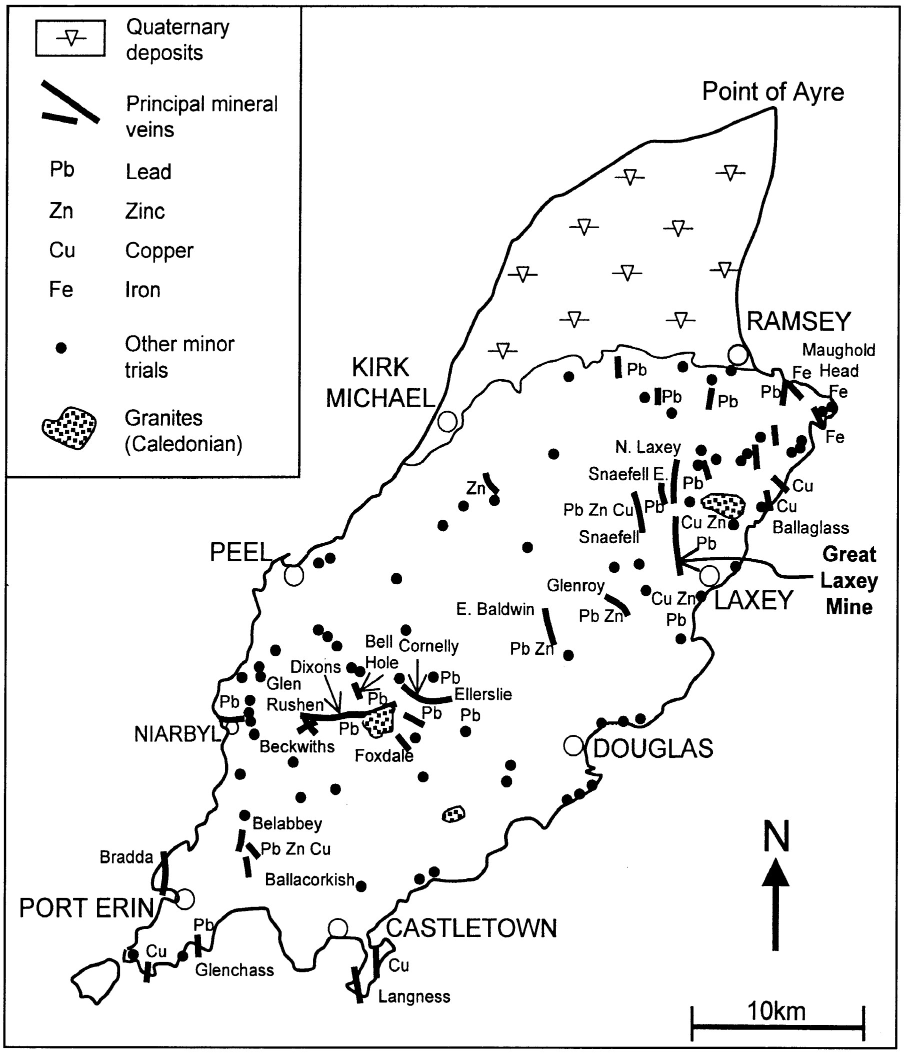

Fig. 1. Sketch map of the Isle of Man showing the location of the Laxey Lode in relation to other mineral veins, mines and trials.

Lamplugh (1903) noted argillaceous strata in the deeper parts of the mine near Dumbell's Shaft, and "hard grits" to the north; neither was thought to have been as receptive to mineralization as the thinner flaggy beds in the main part of the mine.

The Laxey Lode trends approximately north-south at an oblique angle to the strike of the "slates" (Figs. 2 and 3). Indeed, Simpson's (1963) map indicates that the strike of the host rocks is roughly WSW-ENE, i.e. at about 60-70° to the strike of the Lode. This agrees with Lamplugh's (1903) observations and with the sections of slate visible along both the Mooar Water stream banks and in the accessible adits. The Mooar Water was diverted through a tunnel to allow space for mine installations between the Engine and Welsh Shafts (variably spelled Welsh or Welch on old plans). According to Simpson's structural analysis, the Lode crosses the Dhoon anticline but it has not been possible to define the axis in the accessible adit. Lamplugh (1903) noted that the average direction of dip of the beds in the southern section of the mine was 160° whereas in the north the dip direction had changed to 340°, supporting the concept of the Lode crossing an anticline. Later, Lamplugh and Dewey (1925) made the apparently inaccurate comment that the strike of the highly folded "slates" was at right angles to the lode, though the comment might be taken to hint that subsidiary folds have been superimposed on the Dhoon anticline.

The Laxey Lode and Mine

The Laxey Lode has generally been reported as a single vein or fracture-fill about 2 kilometres long (Mackay and Schnellmann, 1963). It lies almost beneath the Mooar Water stream, close to the village of Agneash (Fig. 3). It was eventually worked to a depth of about 500m below sea level. The Lode trends almost due north in its southern section swinging to nearer 350° near Dumbell's Shaft. It is steeply inclined to the east at an angle slightly greater than 10° from the vertical (Lamplugh, 1903; Garrad *et al.*, 1972). Lamplugh noted that the Lode filling was lenticular from a few centimetres to about 8 metres wide. No record has been found concerning slickensides on the vein walls or of the direction of movement — was it a normal fault or a wrench fault? Mackay and Schnellmann's Figure 10 (amended and redrawn here as Fig. 4) is a profile along the Lode based on the mining company's section dated 1887, housed in the Manx Museum's archives. The profile contains several inaccuracies though it is not clear to what extent these reflect mistakes in the mining company's plans or in Mackay and Schnellman's interpretation of them. Firstly, sea level is shown much lower than it really is (Fig. 4 has been revised to give a correct position). Secondly, it shows Dumbell's Shaft as having been sunk from adit level only, though it had been raised to the surface by 1877, at least 10 years earlier than the date of the plan. Finally, there are large blank areas between those shaded as having been stoped out — whether these represent barren or unworkable parts of the Lode or whether there were earlier unrecorded workings is unknown. Although levels in the deeper parts of the mine (driven up to 1919) have been added to the plan, no stoped areas are shown though surely some were worked. However, the profile does suggest that the mine was richest in ore adjacent to a series of slide faults (see below).

The mine plan used by Jesperson (1970) is that preserved in the Manx Museum. He found that it did not fit the surface features accurately and deduced that the mine surveyors had failed to make adequate allowances for changes in magnetic declination from 1858 until the mine closed in 1919. Accordingly, Jespersen "rewarped" the plan to allow for these changes. However, he only corrected that part of the plan extending a little to the north of Agneash where the 1:2500 Ordnance Survey map ended. A reduced version of Jespersen's plan is given in Fig. 5. Furthermore, Warriner and Gillings (1983) also found that Jespersen had made an incorrect assumption about the gradient of the adit, which in turn had an effect on the assumed depths and inclinations of the shafts. In spite of a recommendation by Warriner and Gillings (1983) that the Agneash Shaft should be surveyed in detail down to the adit, it was not practicable to do so at the time and the shaft has now been filled and capped, precluding any future survey. Jespersen's plan suggested that Agneash Shaft had an average inclination of about 9.8° from the vertical, but Gillings (personal communication) has suggested that the inclination was nearer to 8° down as far as the adit. In contrast, Welsh Shaft appears from Jespersen's plan to have an inclination of about 15° down to the adit. These variations in inclination are less obvious in Jespersen's shaft sections (Fig. 6).

In spite of the above variations of inclination the plan indicates a general angle somewhat greater than 10° from the vertical, as the lower levels are displaced horizontally to the east by about 100

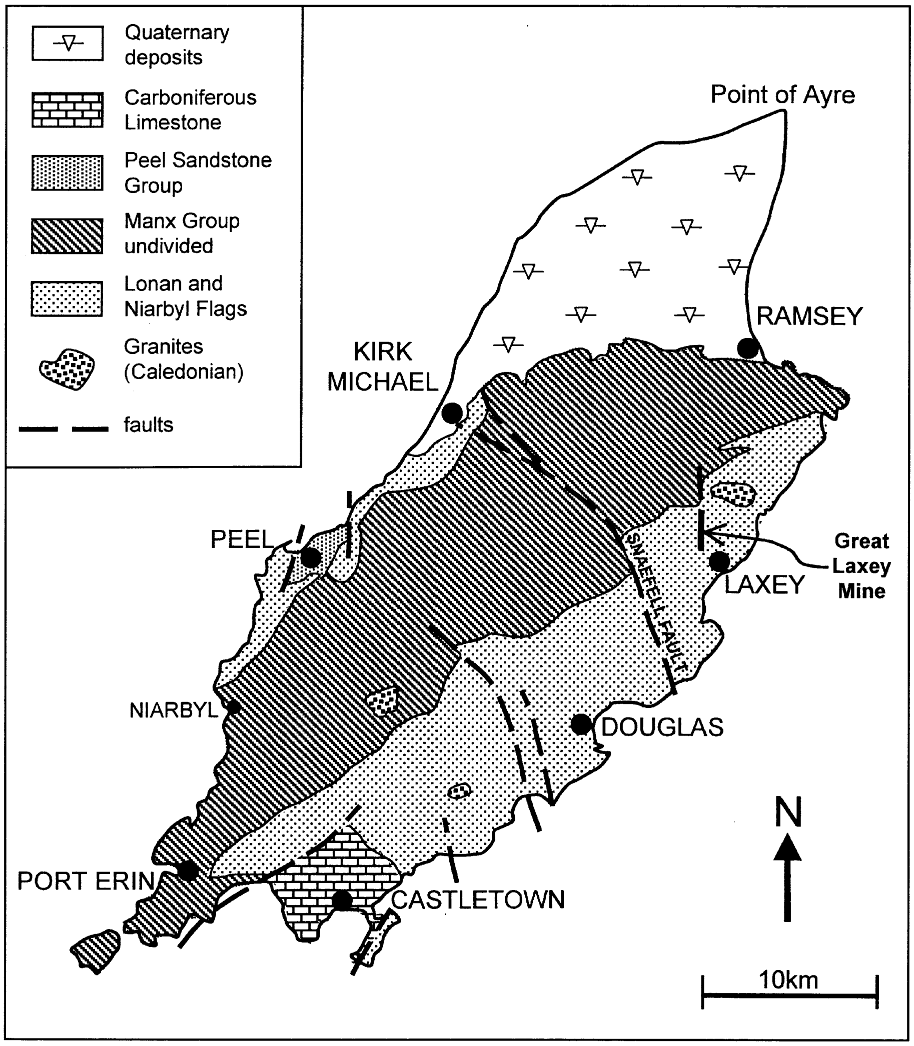

Fig. 2. Sketch geological map of the Isle of Man, based on Simpson (1963), showing the location of the Great Laxey Mine.

metres at a depth of 220 fathoms (approximately 400m) below the adit. The main shafts followed this slope and are inclined with the vein, as indicated on Fig. 6 which is adapted from Jespersen's (1970) Figure 193. The inclination of the shafts is variable as shown by the irregularities in Fig. 6. Dumbell's Shaft was said to be nearly vertical by Garrad *et al.* (1972) but in fact it has an inclination similar to the other shafts, i.e. about 10° from the vertical throughout its 660 metre depth. However, below the 230 fathom level (420m below the adit; about 500m from the surface) the working levels are almost superimposed on one another in plan view, implying that the vein, not the shaft, becomes almost vertical at this depth.

Branches splitting off the main Lode in the Laxey Mine were noted by Lamplugh (1903) and both an East Branch and an East Lode appear towards the northern end of Jespersen's (1970) plan. They were apparently found by cross-cuts driven east from the Main Lode. If these are parallel to the inclination of the Lode they may be the same vein. Some 500m of drivage suggests that some ore was found. By analogy with the Derbyshire scrins that diverge from rakes, the branch veins may represent Reidel shears, with the corollary implication that the main Laxey fracture is a wrench fault. Lamplugh commented that the branches were said to carry little ore. He also noted a few closely parallel quartz veins with little or no ore. The positions and directions of any other branch veins were not recorded.

The richness of the ore, i.e. the ratio of ore to gangue, is hard to judge though values were said to be poor in the northern extremes of the mine where the yield was "one ton lead and two tons zinc per fathom" (Carruthers and Strahan, 1923). Exactly what this means is uncertain. The metal content is likely to have been assessed from concentrates after preliminary processing; "per fathom" may have meant "per square fathom", though how this was estimated is again uncertain. It is more likely that it referred to a section of vein one fathom high and one fathom forwards, with the bargains being struck according to the width of the vein. As far as is known only the vein itself was extracted avoiding unnecessary removal of country rock. Based on the above figures, Skelton (1956) estimated that the ore carried 5.8% lead metal and 7.7% zinc metal, and he judged these figures to be barely enough to make working viable. Therefore the better parts of the vein must have had higher ore values. Mackay and Schnellmann (1963) deduced ore grades as 3-8% Pb, 5-15% Zn and 2-5% Cu, based on estimates derived from annual production figures. They estimated that 1.2 million tons of ore yielded 232,981 tons of zinc concentrates, 12,276 tons of copper concentrates and 70,138 tons of lead concentrates (elsewhere in their report Mackay and Schnellmann gave different figures — 282,891 tons Zn; 8,864 tons Cu). The lead ore was said to have yielded an average of 40 ounces of silver per ton though production figures do not confirm this. The southern sections of the mine, particularly between the Big and Welsh Slides, (the nature of the slides is discussed later) apparently carried a higher proportion of copper ore, mainly chalcopyrite (Lamplugh and Dewey, 1925). If it were possible to relate annual production figures to an annual record of stoping, then an alternative method of estimating the richness of the ore in different sections of the mine might be available.

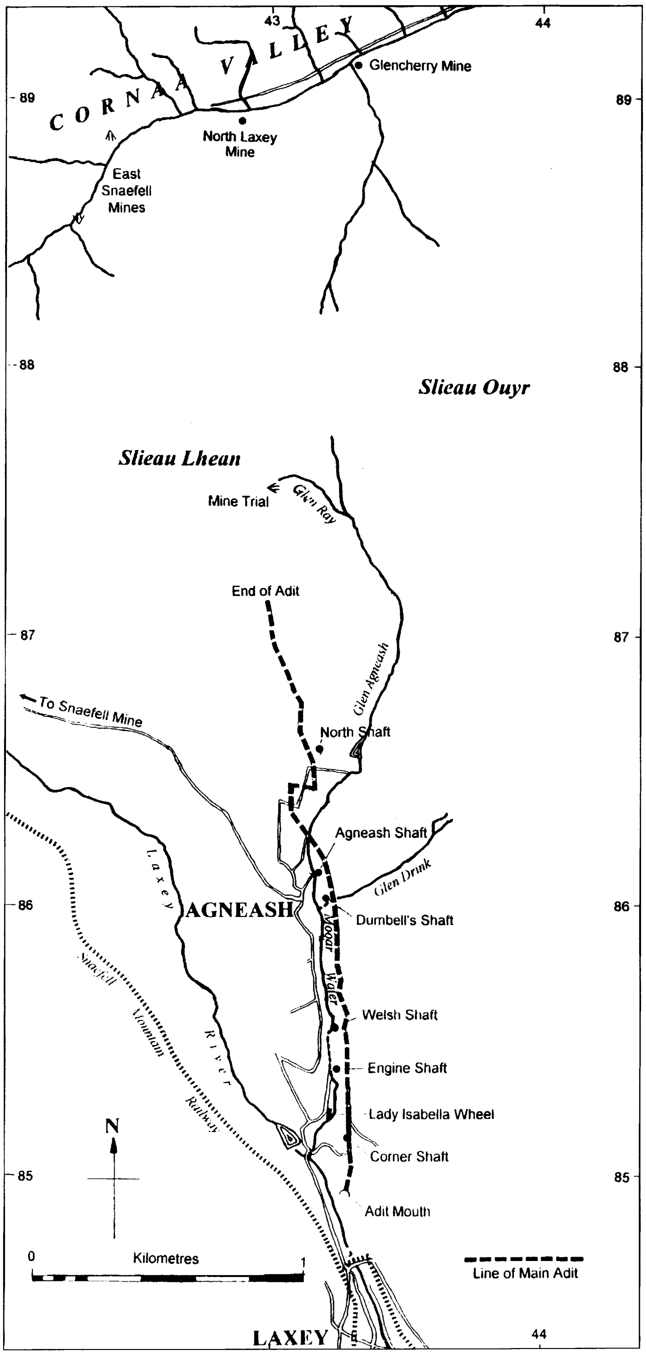

Fig. 3. Key map of Great Laxey Mine and the Cornaa Valley.

The Minerals. The ore minerals present are sphalerite, galena, pyrite and chalcopyrite whilst the gangue minerals are mainly quartz, calcite, dolomite and siderite. Minor amounts of baryte were also raised. Limited quantities of pyrite, marcasite, pyrrhotite and pyromorphite were present; oxidation

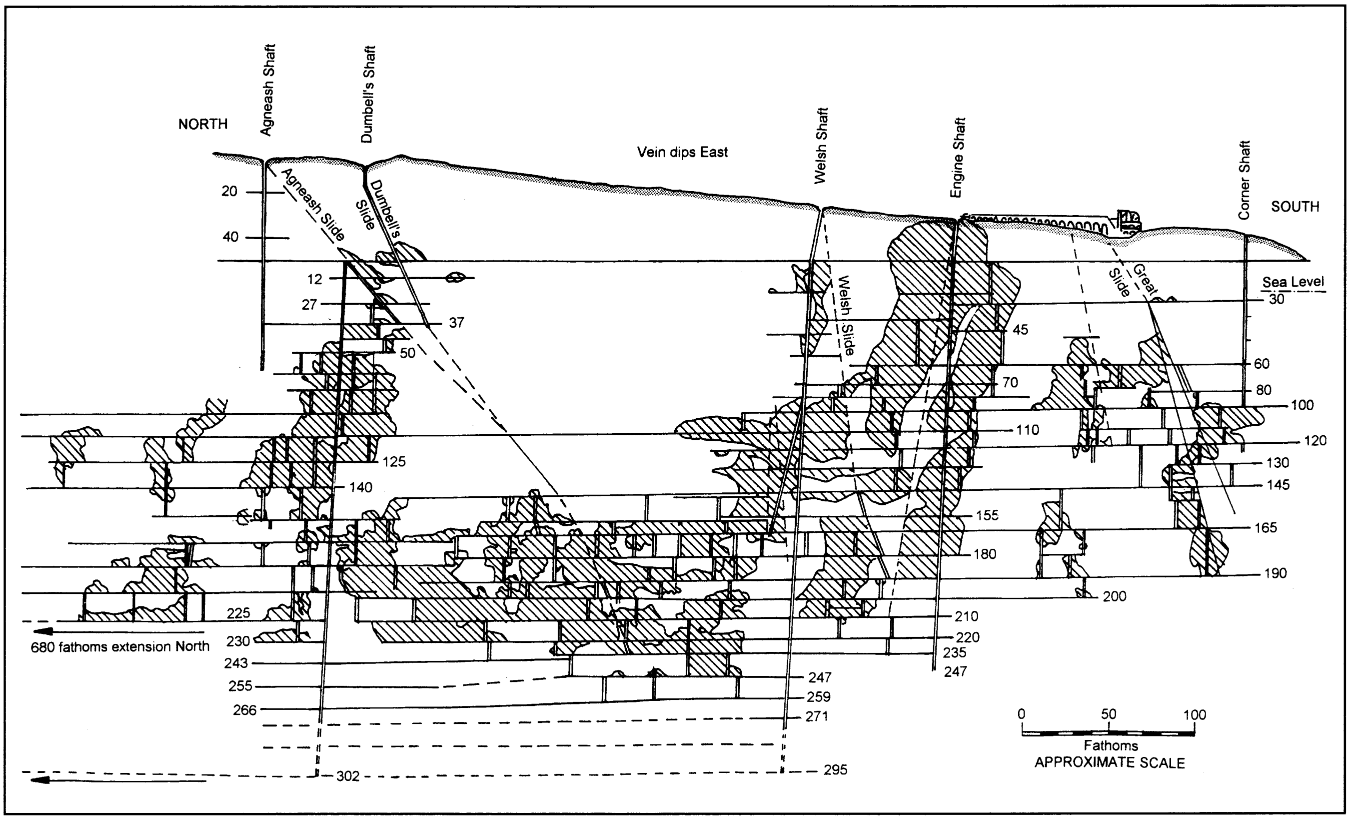

Fig. 4. Profile along the Laxey Lode showing shafts, levels and worked out stopes as they were in 1887, with broken lines showing lower levels worked up to 1919. Amended and redrawn after Mackay and Schnellmann's (1963) Fig. 10, which is based on a section in the Manx Museum. The numbered levels are only approximate depths as no allowance was made on the original for the gradient needed for drainage.

products include malachite, chalcanthite, cerussite, melaconite, melanterite, smithsonite (calamine in old literature), steatite and umber, mainly in the upper levels (Smyth, 1888, quoted in Lamplugh, 1903, pp. 572-574). Most of the galena was argentiferous but no silver minerals have been recorded. No description of the mineral textures seen across the Lode has been traced, but the sulphides were said to be in ribs apparently parallel to the walls and interlayered with the gangue minerals. Freely grown crystals of both sulphides and gangue minerals occurred in vughs, the source of specimens in the Manx Museum and other old collections. The mine was noted for its fine crystals of chalcopyrite and dolomite. The southern section of the Lode, i.e. that with copper ores, had rather more dolomite than calcite. Some records of dolomite apparently included siderite as the two minerals are not always easily distinguishable.

A thin vein of "anthracite" found on the hanging wall was subsequently identified as thucholite, a uranium-bearing hydrocarbon rather like anthracite in appearance (Davidson and Bowie, 1951, pp. 4-5). Under the microscope the thucholite was found to consist of a hydrocarbon enclosing micron-sized spherules of uraninite and pitchblende. Davidson and Bowie proposed that the uraninite and pitchblende originated from a hydrothermal mineralizing phase, that the hydrocarbon was introduced as a fluid or even gas, and that polymerization, coagulation and syneresis followed. The uraniferous hydrocarbons led Parnell (1988) to imply that mineralization took place when there was a cover of Carboniferous strata. He also found traces of other metals in the inclusions, notably Ni, Co, Bi, Sb and W.

In the early 1950s the UK Atomic Energy Authority investigated alleged uranium resources at Laxey and elsewhere on the Isle of Man and it seems that some dump material from Laxey and the Snaefell Mine was taken away for testing with negative results (Hollis, 1987).

In summary, the Lode is composed largely of a gangue of quartz with subsidiary calcite and dolomite enclosing brecciated slate clasts, with the metal sulphides tending to be concentrated near the walls but sometimes scattered through the whole vein or lining vughs.

The 'Slides'. The Lode was affected by several so-called slides, which appear to be faults offsetting the vein from its regular trend. As no geological description of any of these dislocations is available, the exact type of faulting must remain uncertain. Both Lamplugh and Dewey (1925) and Mackay and Schnellmann (1963) regarded the slides as normal faults crossing and offsetting the vein. The latters' report included a profile along the lode showing the slides, most of which are shown to come to surface close to where the shafts were sunk (Fig. 4). Lamplugh (1903) noted that the slides were not mineralised and ranged in orientation from east-west to about WSW-ENE, offsetting the vein by between 10 and 70 feet (3-20m). The Big Slide was noted to be about 160 yards (c.150m) south of Engine Shaft and "carrying the vein 10-20 feet westwards on the south side", i.e. a dextral displacement, which "dipped south at 70° from the horizontal splitting into two branches below 30 fathoms". Lamplugh's (1903) brief comments make the slide dislocations appear more complex than simple normal faults. Welsh Slide, coming to the surface near Welsh Shaft, affected the Lode in a similar manner but was a little steeper. It is interesting that neither of these slide offsets has any substantial effect on the position of the adit or levels on the mine plans (Fig. 5), as might have been expected. This suggests that they were of minor structural importance only. Dumbell's Slide dipped south and was intersected by Dumbell's Shaft at about 20m depth. Deeper still, it was joined by a steeper slide. In the northern limits of the mine, slides apparently dipped northwards and shifted the lode in the opposite direction to those noted above. The positions of other slides are not shown on the mine plan though there were known to be several south of Corner Shaft. Lamplugh (1903) thought the latter were responsible for terminating the lode to the south, as exploratory adits failed to find any continuation of the Lode to the south.

The 1982 re-survey of the northern section of the Main Adit located a dextral cross-fault about 330m north of Agneash Shaft (Figs. 2 and 5); this displaced the Lode at adit level by 59m to the east (Warriner and Gillings, 1983) but curiously the deep

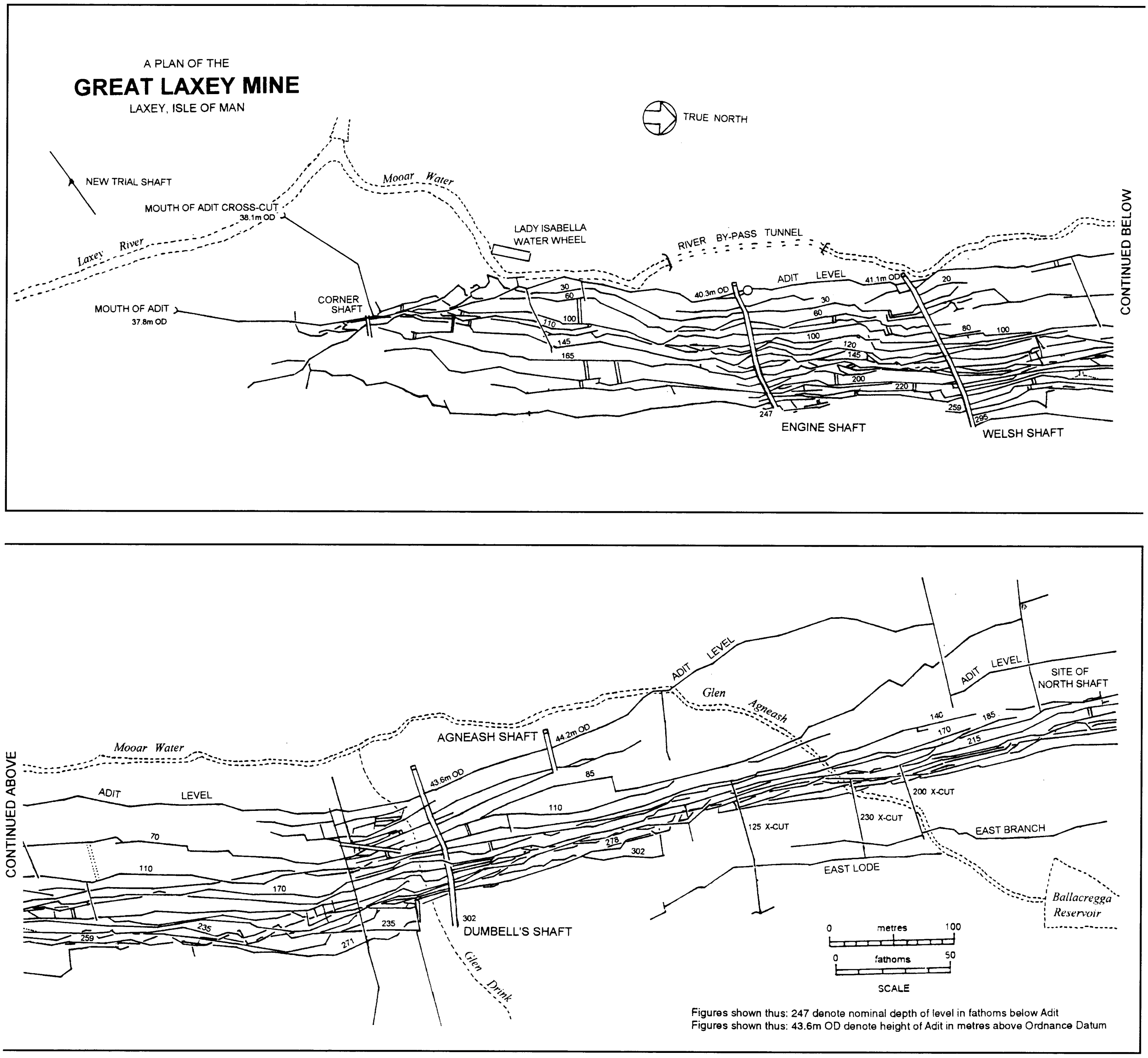

Fig. 5. Plan of levels in Great Laxey Mine, after Jespersen's "rewarped" plan of 1970 (simplified by Andy Gillings from Warriner and Gillings, 1983, Figure 3). Depth of shaft bottoms are given in fathoms (1 fathom = 1.83m). Altitudes of the Main Adit portal and of the adit at shaft intersections given in metres.

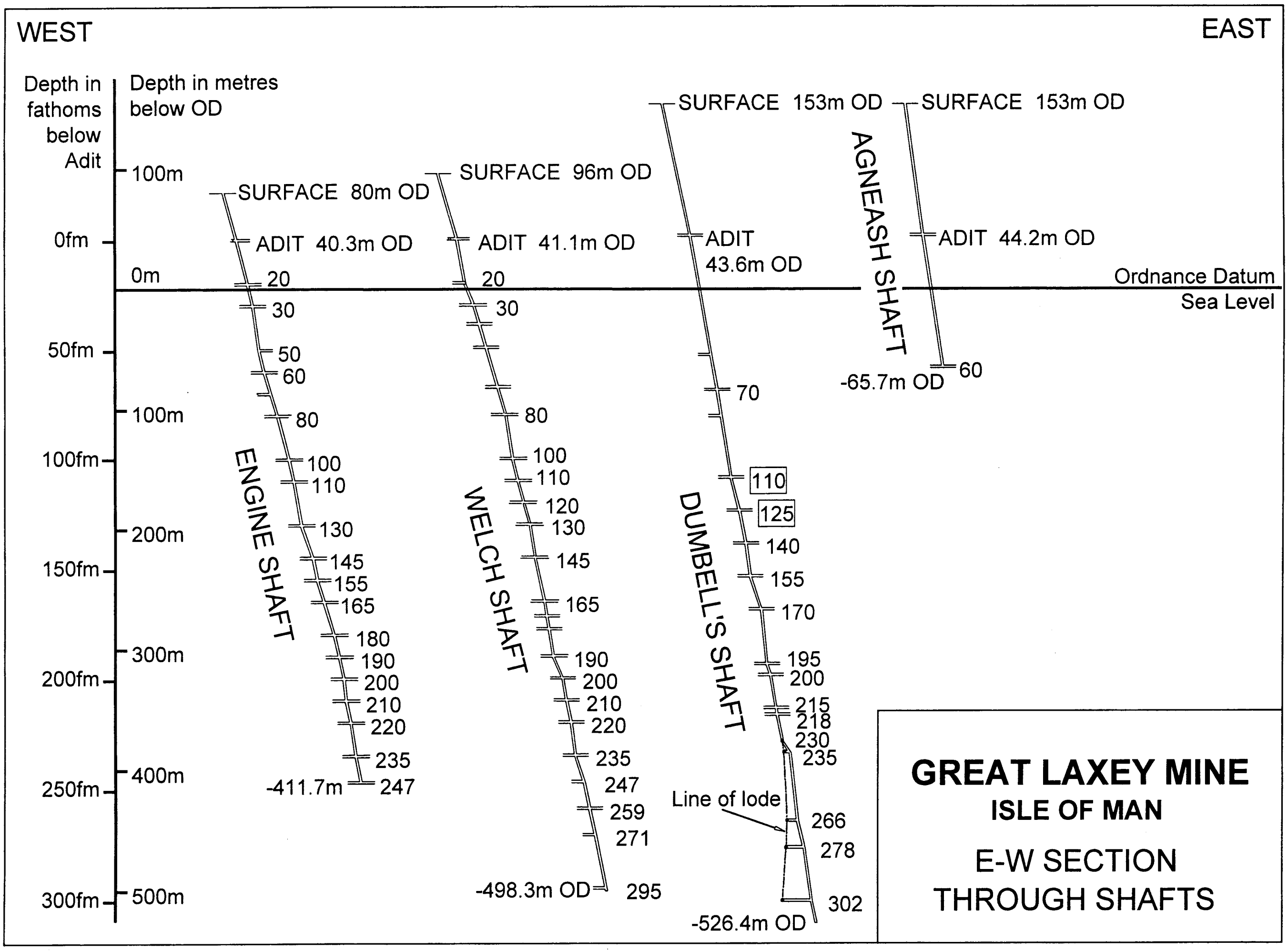

Fig. 6. Profiles of the inclined shafts, with levels indicated (simplified diagram after Jespersen's, 1970, Figure 193). The levels off the shafts are shown as though they were in an E-W plane whereas they are in fact along the N-S trend of the lode. The 1986 survey gave altitudes for some locations which differ from Jespersen's: Engine Shaft surface 81.53m O.D.; Engine Shaft at adit 39.97m O.D.; Welsh Shaft Surface 101.30m O.D.; Welsh Shaft at adit 42.61m O.D. Depths shown in fathoms (1 fathom = 1.83m).

levels seem to show no such displacement. Without further details it is not possible to say if this was a slide in the traditional sense. In spite of old miners' rumours of a slide terminating the vein at the northern limits of the mine, the 1971 exploration party found only a forefield where work was abandoned (Richards and Atherton, 1971). The 1982 exploration was stopped short of this by a roof fall. Before the modern practice of drilling inclined boreholes out from the forefield when the vein is lost, the miners' usual method of finding displaced veins was to drive cross-cuts out along faults but this was apparently not tried at the northern limit of the mine.

Microgranite Dykes. At least two porphyritic microgranite dykes are known to have crossed the lode without apparently affecting its ore content (Lamplugh, 1903). Neither the position nor the orientation of these dykes was recorded on the mine plan. However, at the surface a dyke in Glen Agneash was said to be up to 6m wide (Lamplugh, 1903) though it has not been located in the present study. The dykes were almost certainly offshoots from the Dhoon granite which lies more than a kilometre to the east. Both dykes and granite were emplaced before the Lode, demonstrating its late or post-Caledonian age. Lamplugh (1903) also noted that the Lode cuts across some "older greenstone" dykes (of probable Ordovician age) in its southern section, though again the position was not recorded on the plans.

The Search for Extensions of the Lode. It was logical for the miners to project the line of the Laxey Lode both to north and south to find extensions of ore-bearing ground. The south side of the Laxey valley failed to reveal anything of note. Nothing is known of the New Trial Shaft shown on Jespersen's plan (Fig. 5). To the north, the Lode trends beneath the Slieau Lhean ridge but a high level trial in Glen Ray failed to find anything of significance (Fig. 3).

In the Cornaa Valley, 3km north of Agneash, the North Laxey and Glencherry Mines provide some possible evidence of extensions of the Laxey Lode (Mackay and Schnellmann, 1963). These mines were some 2km north of the end of the main adit. The North Laxey Mine (SC 428 889) worked an almost north-south lode to the east of the projected line of the Laxey Lode, though they may have been linked if some curvature or offset by faulting is taken into account. In contrast to the high sphalerite content of the Laxey Lode, the North Laxey Mine yielded almost exclusively galena with baryte and pyrite becoming more common in the deeper levels. Also contrasting with the Laxey Lode, the vein at North Laxey dipped westwards. The North Laxey Mine was worked to a depth of about 300m though it was never profitable.

Some 500m to the east of the North Laxey Mine, lower down the Cornaa Valley, the Glencherry Mine (SC 433 892) could have been linked with the Laxey Lode provided that substantial allowances for undetected offsets are made. It produced only minor quantities of galena. The East Snaefell Mines (SC 424 888) were located farther west up the Cornaa Valley, lying to the west of the projected line of the Laxey Lode; they were little more than trials as they yielded no significant ore. Lamplugh (1903) made only brief comments on the ore deposits of the Cornaa Valley, but Mackay and Schnellmann (1963) gave details of shaft depths and levels taken from archives in the Manx Museum. The limited accessible levels and other mining relics were described by Pearce and Rose (1979).

Any serious attempt in future to find an extension of the Laxey Lode or parallel veins should involve a programme of diamond drilling of inclined boreholes following re-mapping and structural analysis.

Comparisons with Foxdale. Whilst the Laxey Lode has some similarities to the other large ore body on the Isle of Man at Foxdale, there are also some marked contrasts. The vein at Laxey trends almost north-south whilst that at Foxdale trends east-west. The Foxdale Lode is almost vertical and has been followed deep into the granite whereas the Laxey Lode is steeply inclined and no evidence has been found that the vein penetrated the nearby Dhoon granite at depth. The dominant sulphide at Laxey was sphalerite whereas at Foxdale it was galena. Further research on the Foxdale Lode is required to determine a better comparison with the Laxey Lode.

Origin and Genesis of the Lode

Isotope Studies. Ages of wall-rock and fault gouge alteration based on the K-Ar method have been determined as episodic at 310-320Ma, 285Ma and 250Ma (Ineson and Mitchell, 1979). These ages suggest mid to late Carboniferous dates for mineralization. Preliminary studies by Crowley and Bottrell (1997) show that Pb isotope ratios are compatible with a Carboniferous mudstone source, with two episodes of fluid migration at 300-280Ma and 210-190Ma (i.e. late Carboniferous and late Triassic/early Jurassic). Sulphur and oxygen isotope data suggest a rather wide spread of temperatures of mineralization from 200°C down to 80°C, though the latter may be due to bacterial sulphate reduction associated with the introduction of sulphate-rich fluids derived from sea water (Crowley and Bottrell, 1997). Indeed the presence of baryte late in the mineralization sequence suggests the occurrence of oxygenated fluids at shallow depths.

Metallogenesis. The geochemical processes by which the metalliferous ores of the Laxey Lode were derived, transported and emplaced have not been mentioned in previous literature other than brief comments by Davidson and Bowie (1951) relating to the uraniferous thucholite and in the preliminary isotope studies by Crowley and Bottrell (1997). The general process may, however, be expected to be comparable to that which operated in the Pennines (Ixer and Vaughan, 1993). On geochemical grounds, these ores appear not to have been derived from granites; instead a process of metal release from the clay minerals of mudrocks during lithification is regarded as more likely. As the host rocks for the Laxey lode are "slates" of the Manx Group it might seem logical to regard these as the source, but the emplacement of the lode is considerably later than the folding, metamorphism and the intrusion of the microgranites, so another group of source rocks must be sought. Carboniferous mudrocks provide a possible solution to the problem. These presently lie beneath Permo-Triassic formations on the floor of the Irish Sea, but may well have extended high on to the Manx massif in Carboniferous and early Mesozoic times (Jackson *et al.* 1994; Chadwick *et al.* 1994). The sporadic occurrence of uraniferous hydrocarbons hints at a former cover of Carboniferous rocks (Parnell, 1988). The Eubonia-Lagman fault system which forms the western boundary to the East Irish Sea basin, roughly parallel to the east coast of the Isle of Man (Jackson *et al.* 1994), throws the Triassic down to the east by hundreds of metres, so that in pre-faulting times the strata now forming the floor of the basin would have been much higher in relation to the Manx massif than they are now. The Laxey fracture could thus be a pre-cursor, sub-parallel step fault related to the Eubonia-Lagman fault system. Though the Laxey fracture probably originated from extensional movements in late Carboniferous times, subsequent compression of Carboniferous mudrocks during later Hercynian movements would have expelled formation water containing dissolved metal ions derived from the recrystallization of the clay minerals. On reaching a favourable site, such as the Laxey fracture, where temperatures were lower or where suitable reactions could take place, the ions could come out of solution and combine to form the ore and gangue minerals. Catalysts such as hydrocarbons might have facilitated solution in the source rocks, and a change in physico-chemical conditions would assist precipitation at the depositional stage.

If the source of the metal ions was an argillaceous facies of Carboniferous age offshore beneath the Irish Sea, it raises problems concerning the hydraulics of the route by which the ore fluid moved from the Carboniferous beneath the Irish Sea floor into a fissure system in the Manx slate massif. Recent apatite fission track studies (Chadwick *et al.* 1994; Crowley and Bottrell, 1997) suggest that some 2000-3000m of Mesozoic cover was eroded from northwest England in Cenozoic times, so that a considerable part of this cover may have lain across the Manx massif. Post-Triassic uplift of the Manx massif is indicated by the Eubonia-Lagman fault system bounding the East Irish Sea Triassic basin, so a former extension of Carboniferous strata onto the massif is a distinct possibility and fluid migration into rocks formerly covering the massif becomes feasible. Such migration could be due to a combination of dewatering of the mudrocks, tectonic stresses and thermal gradients. However, until more is known of the Carboniferous rocks beneath the Permo-Trias in the Irish Sea, this can be no more than an attractive hypothesis.

With a mid to late Carboniferous date inferred for mineralization, it is perhaps surprising that no mineral veins of any consequence are known to be hosted in the Carboniferous Limestone of the south of the Isle of Man. Only minor veinlets of galena, sphalerite and dolomite a few millimetres wide have been found. Too little is known of the concealed Carboniferous Limestone beneath the Pleistocene deposits of the north of the Isle of Man for any comment to be made.

Conclusions

The Laxey Lode trends roughly north-south and cuts obliquely across the strike of the Manx Group. The Lode is inclined steeply to the east. Its position hints that it originated as a sub-parallel splay from the Eubonia-Lagman fault system bounding the East Irish Sea Basin. Mackay and Schnellmann's (1963) suggestion that the anticline crossed by the Laxey Lode may have controlled the site of ore deposition is as yet unproven.

Mineralization was later than the folding and metamorphism of the Manx Group and later than the emplacement of the Caledonian granites in early Devonian times (374±4 million years; Brown *et al.* 1968). Isotopic data suggest episodic mineralization in mid to late Carboniferous times, whilst structural considerations imply late Carboniferous rather than middle. These dates agree broadly with mineralization events in the North Pennines. There was a possible later phase of mineralization in late Triassic/early Jurassic times.

A source for the mineralizing fluids in argillaceous Carboniferous rocks extending from the East Irish Sea basin onto the Manx massif is a distinct possibility.

More research is needed to determine the structural history as well as details of ore textures and paragenesis. Regrettably no fluid inclusion studies are known to have been carried out on Laxey minerals so that no estimate of the temperature of crystallization is possible. To test the above hypothesis of ore genesis requires more accurate knowledge of the date of ore deposition than is permitted by the limited isotopic data available at present. It would also be necessary to assess the temperature and stress histories of both the Manx Group and of the surrounding Carboniferous rocks.

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A possible early elasmosaurian plesiosaur from the Triassic/Jurassic boundary of Nottinghamshire

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Abstract: The partial remains of a small plesiosaur from the Nottinghamshire Lias, curated in the Natural History Museum at Wollaton Hall, Nottingham, are described. The proportions and sequence of the cervical vertebral centra suggest that it is an early elasmosaur. More detailed identification is problematic because of the limited material available.

Background

This paper describes the partial skeleton of a small plesiosaur (Wollaton Hall Natural History Museum, Nottingham NOTNH 1987.G.60). The specimen was presented to the Nottingham Museum by W. Stafford Esq. (then President of the Nottingham Natural History Society) in 1894. Its provenance is recorded as "Cropwell". Little other information is available.

Several small limestone quarries are known to have existed in the last century along the escarpment between the villages of Cotgrave (SK 64 35) and Cropwell Bishop (SK 68 35), though no exposures were visible at the date of writing. Given that these quarries were exploiting limestone, it is unlikely that excavation would have proceeded to any significant depth into vertebrate-bearing horizons within the underlying mudstones of the Penarth Group (cf. Sylvestor-Bradley and Ford, 1968). This specimen is thus most likely to originate from the lowest part of the Lias Group, in the Barnstone Member of the Scunthorpe Mudstone Group (formerly known as 'Hydraulic Limestone Series'). The good preservation of reptiles from these beds has been noted by Sylvester-Bradley and Ford (1968). The lowest 2 metres or so of the Barnstone Member (the pre-*Planorbis* Beds) are of Late Triassic (Rhaetian) age, the remainder Early Jurassic (Hettangian) (Brandon *et al.*, 1990).

Benton and Spencer (1995) record a ?pliosauroid from Cropwell Bishop, as well as '*Plesiosaurus*' from Barnstone Quarry, about 6km to the east. Other Liassic finds recorded from the general area include '?*Plesiosaurus*' from Elston (SK 76 48), and the more extensive marine reptile fauna of Barrow-on-Soar (SK 58 18) (Kent 1980). Other material from the Westbury Formation is documented mainly from south-west England, and less commonly from other regions of Britain (Storrs and Taylor, 1996; Taylor and Cruickshank, 1993).

The abbreviations used for museum names in the remainder of this paper are listed in the Appendix.

The specimen

A label stored with the specimen reads as follows:

> 'PLESIOSAURUS: 56 vertebrae, paddle and other bones. Cropwell, Notts, Presented by W. Stafford Esq.'

A search of the geological stores at Wollaton Hall has located: 26 cervical vertebrae, 15 dorsal and pectoral vertebrae, 4 sacral vertebrae and 7 caudal vertebrae (a total of 52 vertebrae); the right humerus; the right femur and the proximal end of the left femur; the left ilium and the distal end of the right ilium; a fragment of left coracoid; 3 rib fragments. No cranial material is present.

Most of the material has been stored together in trays. Some items have been on display, and these have been given accession numbers prefixed 1987 G.60. It should be noted that other non-plesiosaurid material in the collection has the same prefix, though it is easily distinguishable from that belonging to this individual.

In general the material is exceptionally well preserved and shows fine surface detail. Five cervical and all dorsal and pectoral vertebrae are badly damaged (e.g. Plate I, 2). In places, pyritic, calcareous mudstone has replaced structures such as disc and spinal chord. Pyrite decay in the mudstone has caused cracking and fragmentation.

Cervical vertebrae. Cervical vertebrae are well preserved in three dimensions with little, if any, distortion. Their correct order can easily be established in the more anterior vertebrae. Starting with the axis, nine anterior vertebrae are preserved in close articulation and show the natural shape of the neck immediately behind the head (Fig. 1). This clear upward curve has been predicted from detailed measurement and analysis of the cervical vertebrae of the Callovian plesiosaurs *Muraenosaurus* and *Cryptoclidus* (Evans, 1993). In others the faces of centra can be matched from fragments of bone preserved on adjacent elements. The relative positions of the more posterior elements can easily be judged from relative sizes, fragments from adjacent vertebrae and to some degree by matching articular faces.

The centra are spool-shaped, slightly waisted and generally rather broader than high. Anterior centra are heavily ornamented, with rugosities around the rims of articular faces, and a well-defined ventral keel. In more posterior vertebrae, the rugosity decreases and the keel becomes less sharp and well defined, disappearing more or less from the 17th backwards.

The articular faces of the centra are usually concealed by hard matrix, but can be seen on nos. 2, 3, 8 and 12-20. They are typical of those of

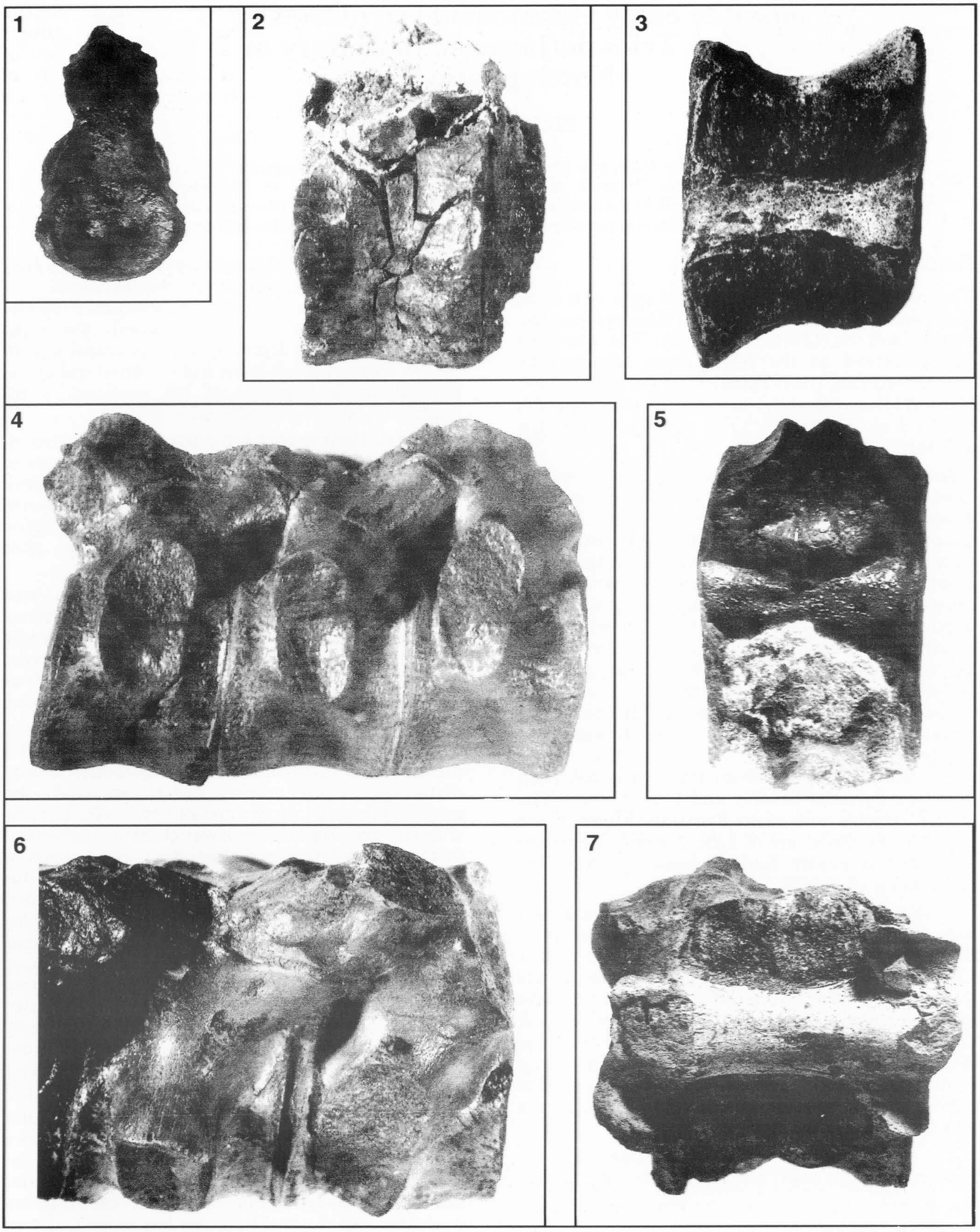

Plate I. NOTNH 1987.G.60. All photographs are natural size. 1. Articular face of cervical centrum (NOTNH 1987.G.60.8) showing paired pits (width 22mm). 2. Dorsal vertebra (NOTNH 1987.G.60.57) showing damage (height 64mm). 3. Base of neural canal (dorsal vertebra NOTNH 1987.G.60.57) (length 48mm). 4. Sacral vertebrae (NOTNH 1987.G.60.24, 25, 42) (length of block 100mm). 5. Base of neural canal (caudal vertebra NOTNH 1987.G.60.28) (length 43mm). 6. Interlocking zygapophyses on sacral vertebrae. 7. Internal cast of neural canal (dorsal vertebra NOTNH 1987.G.60.52) (length 70mm).

elasmosaurs, showing a shallow V-shaped section as opposed to the double sigmoid curve characteristic of cryptoclidids (Brown, 1981; 1994). The faces to the anterior vertebrae are oval or slightly heart-shaped, slightly flattened under the neural canal. There is a shallow depression in the middle of the face in which can be seen a pair of small pits (Plate I, 1). In vertebrae towards the posterior end of the neck, the rims of the articular faces become more rounded and the faces have deep depressions in the middle; these depressions change in shape from oval at vertebra 16 to heart-shaped at no. 24. The five most posterior cervical vertebrae are poorly preserved, having suffered pyrite decay as described above. Two of these appear to be fused, and bear a rib to each centrum on the right side and a single rib to the pair on the left.

Paired rib facets are placed low on the sides of the centrum (Fig. 2). The lower facets are flattened ovals, curved below, flattened above. The upper facets are in the form of a broad-based triangle, the wide base below. All neural arches are fused. The base of each arch runs the full length of the centrum, and extends downwards on the outside to a point extending towards the pointed top of the upper rib facet. In more posterior cervical vertebrae, from no. 16 onwards, the points are joined by a well-defined notch. A similar structure has been noted by Storrs (1997) in a juvenile specimen of *Plesiosaurus dolichodeirus* (YPM-PU 3352).

All cervical vertebrae have paired nutritive foramina on the ventral surface on both sides of, and close to, the keel. A third ventral foramen is present (Fig. 3) on vertebrae 14-18, most prominently on no. 17.

Pre- and post-zygapophyses are large, and extend well beyond the articular faces. Several vertebrae are preserved with fragments of zygapophyses from adjacent vertebrae in articulation. The close match of the articular surfaces of the zygapophyses shows that there was a tight fit up to the 10th vertebra, including a rigid neck. Posterior to this, preservation is less good, and no articulation is preserved until the sacral vertebrae.

Analysis of dimensions of cervical vertebrae. The good three-dimensional preservation of the cervical vertebrae of this specimen gives the opportunity for detailed analysis of the dimensions of the neck. Most Liassic vertebrate specimens are mounted for display within their original matrix, making it impossible to obtain accurate measurements.

Brown (1994) has redefined the two long-necked plesiosaur families, Elasmosauridae and Cryptoclididae. Diagnostic features differentiating the two families relate in the main to skull anatomy, but include the shape of the articular faces as mentioned above. In addition, the elasmosaurs are distinguished by having more elongated anterior cervical vertebrae. In his earlier publication, Brown (1981) plots the vertebral length index (VLI = the ratio of ventral length to the average of posterior width and height) for three individuals of *Cryptoclidus*. Figure 4 plots these data, and adds data from several specimens of the elasmosaur *Muraenosaurus* as well as other individuals of *Cryptoclidus* (sources of measurements are given in Table 1). This shows a clear differentiation between the two families not only in the proportions of the centra, but more significantly in the variation of VLI along the length of the neck. In elasmosaurs the ratio increases sharply from the most anterior vertebra, reaching a peak around the 12th, then decreasing steadily towards the body. In cryptoclidids, the VLI is more or less constant until about the 20th vertebra, after which it decreases gradually then rises again just before the neck meets the body.

Figure 5 plots cervical VLI for NOTNH 1987.G.60 against curves showing the averages for each family computed from the measurements in Figure 4. This shows clearly that the VLI sequence matches closely that for elasmosaurs. However, the limited size of the dataset for these charts limits the statistical significance of these results and a more detailed investigation into the vertebral columns of the Plesiosauroidea would be required for a rigorous validation.

Dorsal and pectoral vertebrae. Parts or all of at least 19 dorsal and pectoral vertebrae are present, though their poor preservation has obliterated most morphological features. Where transverse processes are preserved they are very low, hardly separated from the centra. The neural canal is preserved as an internal cast on some vertebrae, giving rise to a surface texture (Plate I, 3). In other cases, an internal cast of the channel is preserved (Plate I, 7).

Sacral vertebrae. Three sacral vertebrae are preserved (Plate I, 4) as a sequence of three perfectly preserved centra, welded together by a thin layer of matrix which has replaced intervertebral discs. The close interlocking of the zygapophyses (Plate I, 6) and the very thin discs suggests that this part of the vertebral column was rigid, though the possibility that this is the result of taphonomic processes cannot be discounted.

Caudal vertebrae. Caudal vertebrae are shorter and broader than the cervicals, and generally more rounded and smoother in appearance. Their preservation is good, and fine surface detail can be seen. The shape of the centra tends to pentagonal, with a horizontal ventral surface forming one side of the pentagon. The rib facets are oval, and located high on the centra in contact with the neural arch facets. Most neural arches are fused. The stippled texture of the internal surface of the neural canal can be seen where neural arches are missing (Plate I, 5). Haemapophyses are only discernible as pairs of slight ridges on the underside of anterior caudal centra. On more posterior centra, they form facets on both anterior and posterior rims of the articular faces.

Limb bones. The right humerus is complete and exceptionally well-preserved. The left humerus is missing. The humerus is distinguished from the femur by the curvature of its axis, which is more

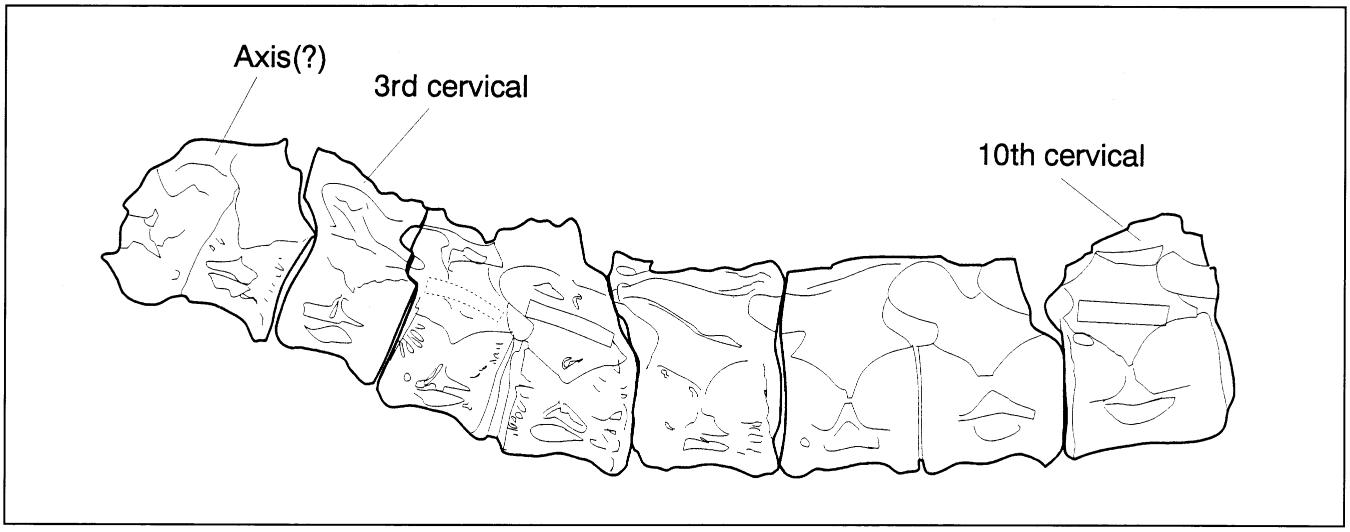

Fig. 1. Cervical vertebrae nos. 2 to 10 of plesiosaur NOTNH 1987.G.60 in left lateral view showing natural curve of neck. Overall length 174mm.

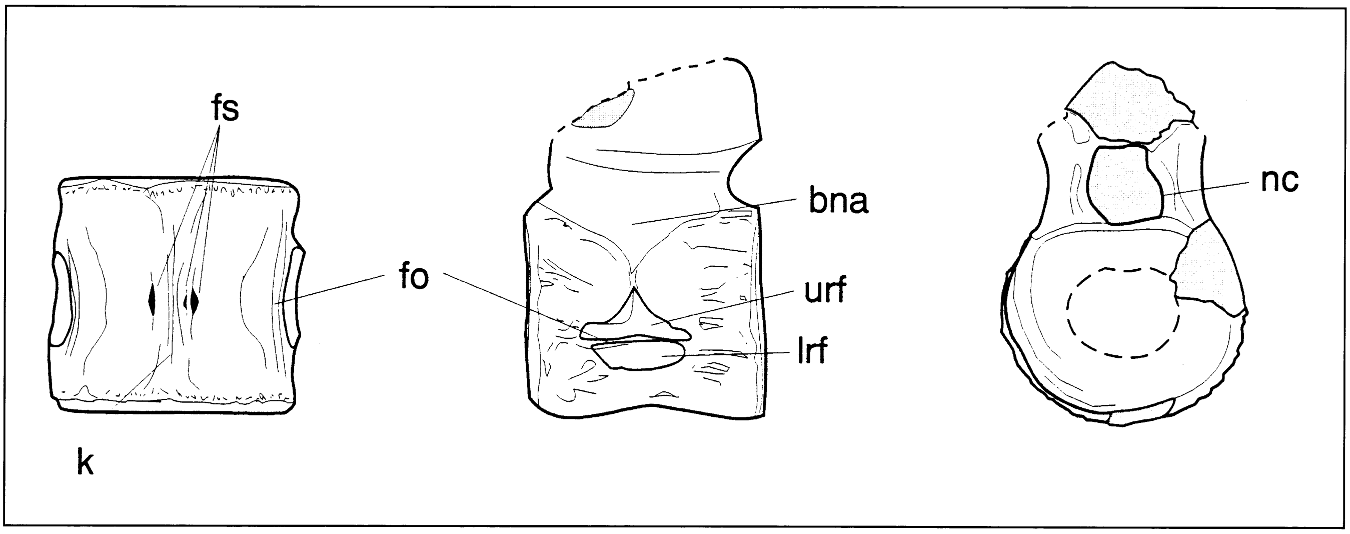

Fig. 2. 13th cervical vertebra (NOTNH 1987.G.60.18) in ventral, left lateral and anterior views. Length 27mm. Abbreviations: bna — base of neural arch; fo — foramen dividing rib-head; fs — subcentral foramen; k — keel; lrf — lower rib facet; nc — neural canal; urf — upper rib facet.

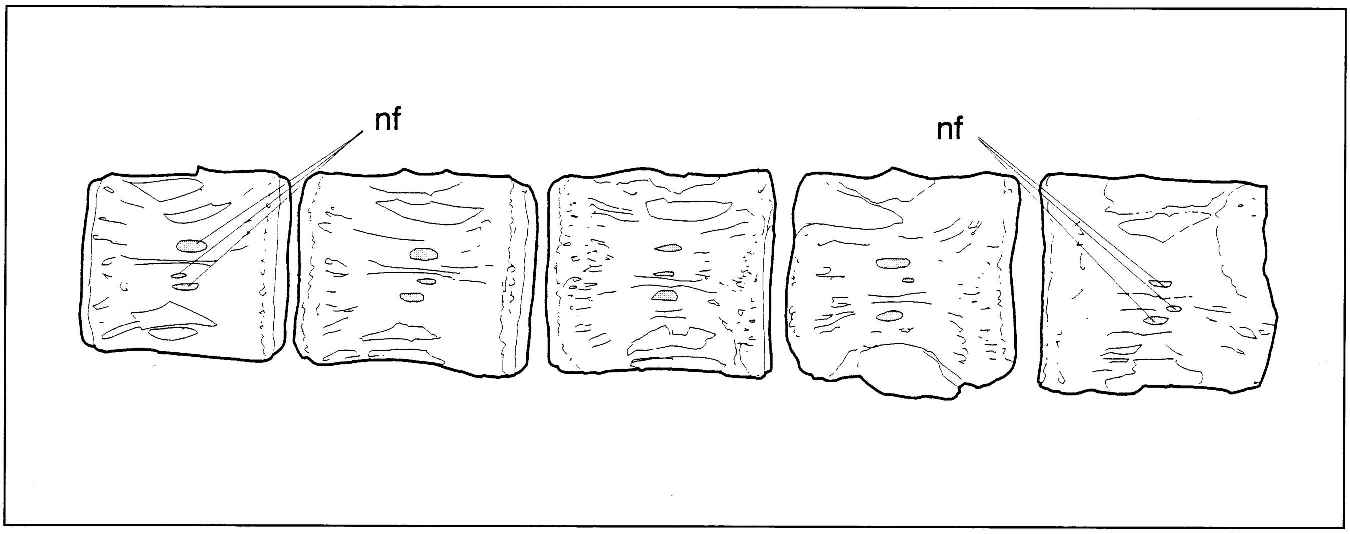

Fig. 3. Cervical vertebrae nos. 14 to 18 of plesiosaur NOTNH 1987.G.60 in ventral view showing third nutritive foramina. Overall length 180mm.

Ref	*Designation*	*Species*	*Location*	*Source*
G.60	NOTNH 1987 G.60		Wollaton Hall Natural History Museum, Nottingham	measurements by author
E1	BMNH R 3698	*Muraenosaurus beloclis*	British Museum (Natural History)	measurements by Mark Evans (Leicester)
E2	LEICS G18.1996	*Muraenosaurus* *? M.leedsi*	New Walk Museum Leicester	measurements by author
E3	BMNH R2863	*Muraenosaurus leedsi*	British Museum (Natural History)	Evans 1993
C1	BMNH R2860	*Cryptoclidus eurymerus*	British Museum (Natural History)	Evans 1993
C2	HMG V1104	*Cryptoclidus eurymerus*	Hunterian Museum, Glasgow	Brown 1981
C3	BMNH R2417	*Cryptoclidus eurymerus*	British Museum (Natural History)	Brown 1981
C4	BMNH R2860	*Cryptoclidus eurymerus*	British Museum (Natural History)	Evans 1993

Table 1. Sources of specimens used for VLI determinations in Figures 4 and 5. See Appendix for abbreviations.

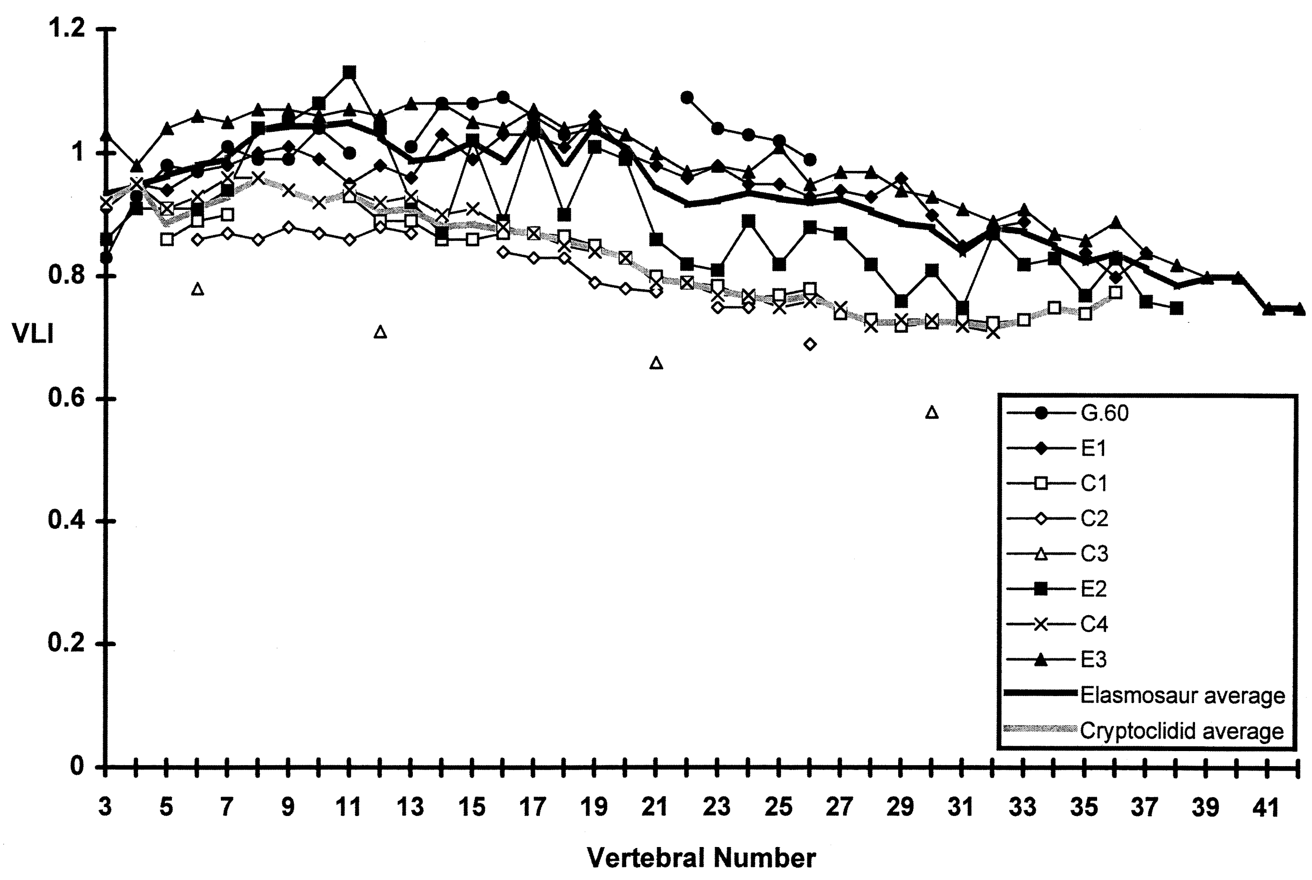

Fig. 4. Comparative chart of vertebral length index (VLI) for Jurassic long-necked plesiosaurs. See Appendix for sources.

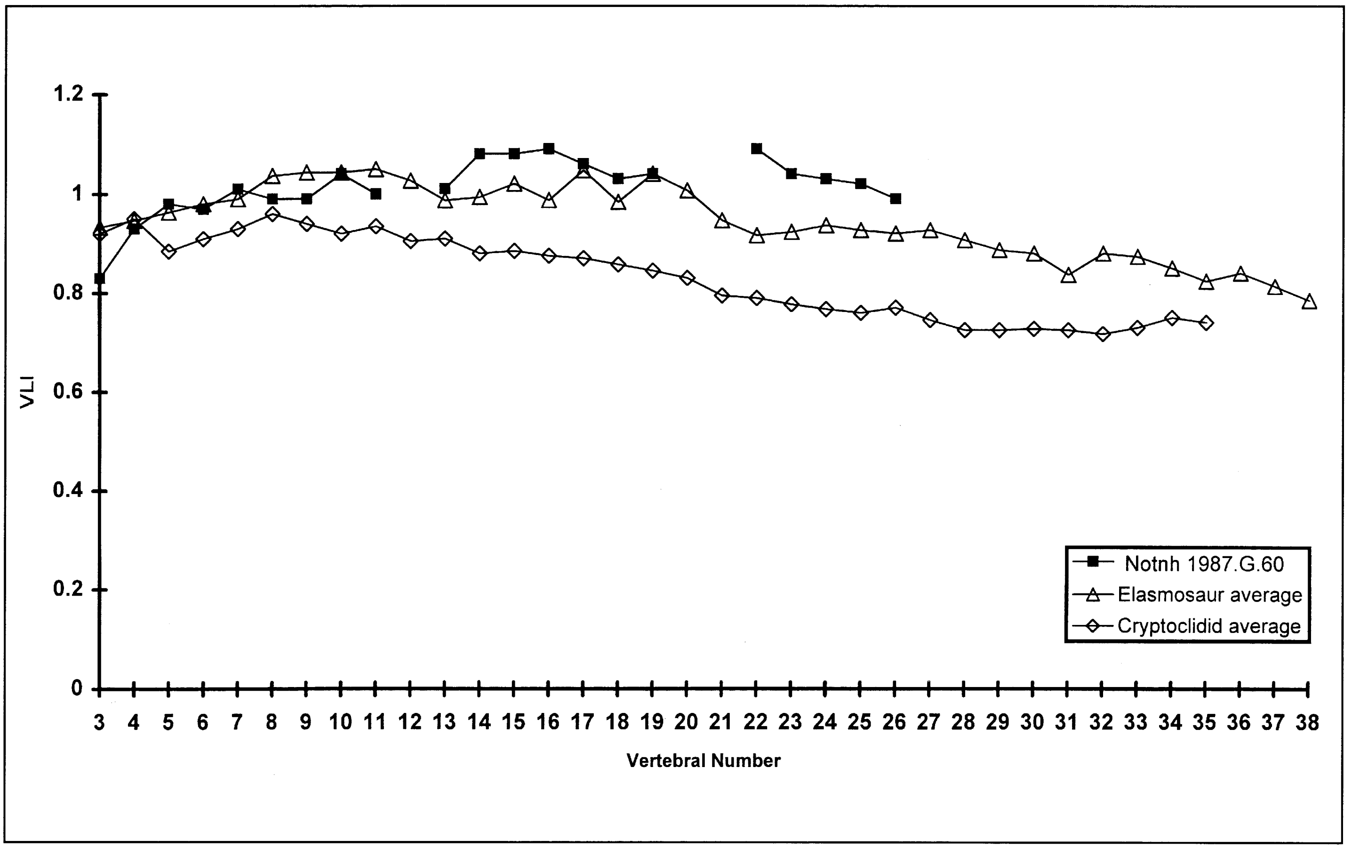

Fig. 5. Vertebral length index for NOTNH 1987.G.60 plotted against elasmosaur and cryptoclidid averages, based on data in Figure 4.

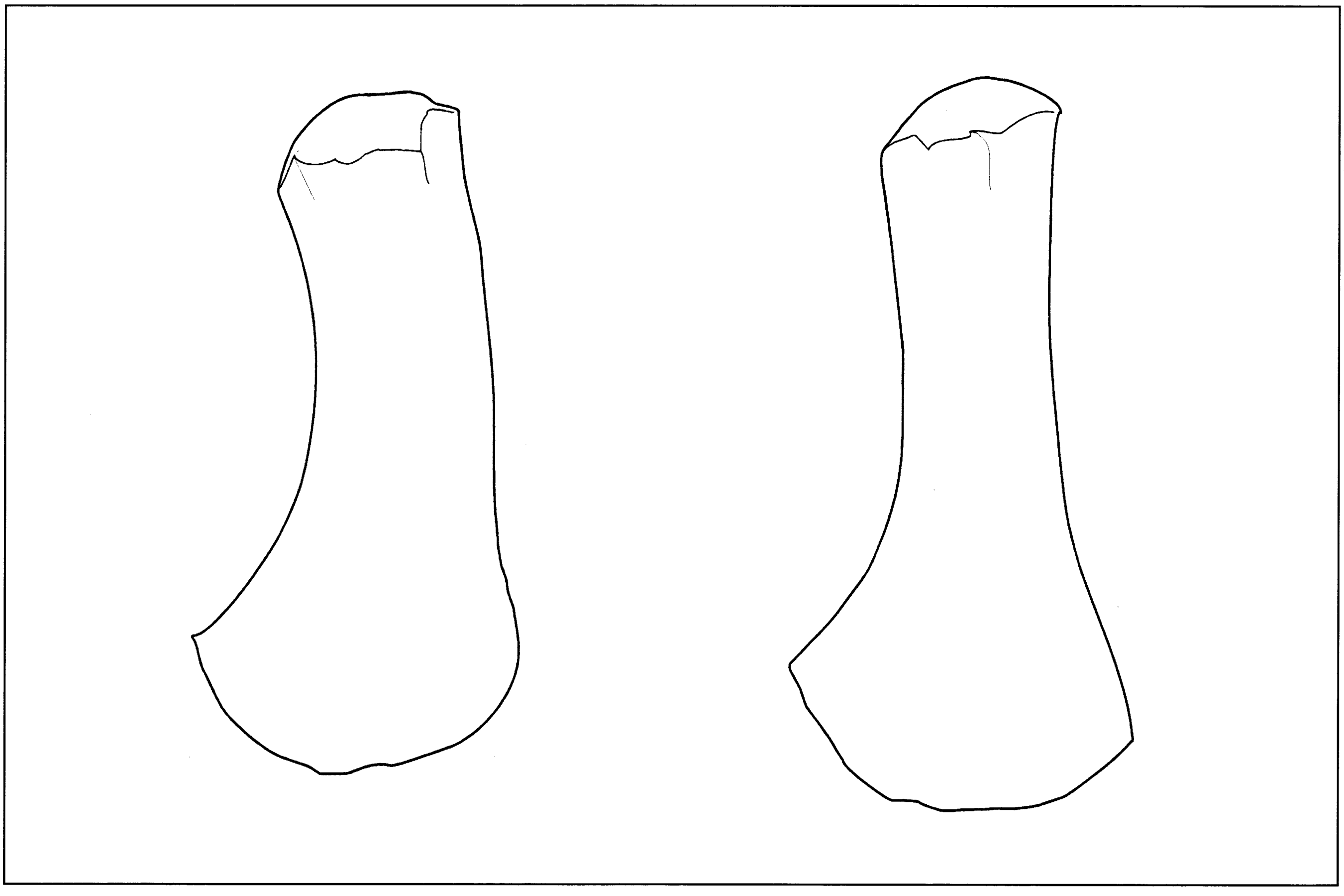

Fig. 6. Right humerus and right femur, dorsal view. Length of humerus 200mm, length of femur 190mm.

or less straight on its anterior edge and strongly curved on its posterior edge (Fig. 6). Cruickshank (1996) records the humerus of a *Pistosaurus*-like sauropterygian from the Rhaeto-Hettangian of Barrow-on-Soar, showing a similar morphology. The humerus of NOTMH 1987.G.60 is broad and robust. The head is large, and the articular facet is in the form of a rounded, narrow-based triangle, the base being at the anterior end. It is marked by the rugosity evident of a substantial cartilaginous covering. In section, the shaft is a flattened oval, the same width as the head and approximately one third of its thickness. The distal end is flattened, and flares posteriorly to twice the breadth of the shaft. The articular face is smoothly curved. There are no facets in the bone for radius and ulna, though here again rugosity is evidence of a cartilaginous extension. The lack of pre-axial expansion can be interpreted as a primitive or juvenile characteristic. It shows some surface ornament at distal and proximal ends in the form of shallow, parallel ridges that follow the axial curvature of the bone. The dorsal surface is smooth, and the ventral surface is generally smooth though with some light rugosity near the proximal end, most markedly on the posterior portion.

The complete right, and the proximal end of the left femur are exceptionally well-preserved. The femur is straight and robust, flaring out at the distal end to about twice the breadth of the mid-shaft. The flare extends posteriorly rather more than anteriorly. The head is round in section. The articular facet is rugose. The section of the shaft is oval, rather deeper than the humerus. The distal end is rounded and rugose, with a slight prominence on the curve which may mark the beginning of the ontogenetic development of the sub-division into tibial and fibular facets. The ventral surface is smooth. There are strongly marked rugosities indicating muscle insertions close to the proximal end. These are centred especially on two areas, one slightly in front of the axis, the other in the posterior third.

Analysis of dimensions of limb bones. Table 2 uses the average diameter of the dorsal vertebrae as a reference against which to plot the relative sizes of limb bones for a range of genera. Typically, dorsal vertebrae do not vary very much in diameter within an individual specimen and the diameter of the dorsal vertebral column is determined primarily by structural considerations and therefore related closely to the size of the animal.

The first two columns show that the limb bones are about 20% longer than those of later plesiosaurs. The relative lengths of limb elements falls into the same range as those for the Callovian specimens and show limb bones of roughly the same length. The fourth and fifth columns show the degree to which the distal ends of the bones are flared. This shows that the femur flares roughly to the same degree as the Callovian specimens, whereas the humerus is distinctly narrower. These measurements of proportion may imply an evolutionary progression whereby both limbs shorten, and the humerus becomes more flared. This would reflect the development of better adaptations to a marine environment, and the unique underwater locomotory method of plesiosaurs (Taylor, 1986). In the absence of a rigorous phylogeny, such conclusions must remain speculative.

Other material. The left ilium is complete and well-preserved. The right ilium is represented by a fragment from the distal end. The ilium is notably slender and curved. The articular face of the head is divided into two well-defined triangular facets, one forming the junction with the ischium, the other forming part of the acetabulum. The head tapers to a narrow shaft, which twists markedly, flares and curves inwards proximally. The anterior quarter of the articular facet is set at an angle of about 45° to the remainder, which is in turn angled at about 80° to the main axis of the bones.

Girdles are represented by a single, poorly preserved fragment of coracoid. Three fragments of rib show that these were thick and apparently pachyostotic, circular or sub-triangular in section. The single preserved rib head is that of a dorsal rib. The head face is oval.

Discussion

The proportion and sequence of the cervical vertebral centra suggest that it is an early elasmosaur, but the limitations of the material available do not allow for identification at the generic level. The triangular form of the bases of the neural arches in NOTMH 1987.G.60 resembles that described on two immature cervical vertebrae of uncertain taxonomy (BMNH 2055, Lydekker 1889) and also from a series of vertebrae from the Linksfield erratic (Rhaeto-Hettangian), Morayshire, Scotland (Taylor and Cruickshank, 1993). In the latter, the upper part of the upper rib facet is generally irregular in form, though with a slight tendency towards the triangular. Taylor and Cruickshank (1993) also refer to other similar material recorded from the Rhaetian of Aust Cliff, Avon. Reference to the V-shaped neurocentral suture on a juvenile specimen of *Plesiosaurus dolichodeirus* has been made above (Storrs, 1997). This is regarded as an ontogenetic feature, and may be equally applicable to unrelated genera.

Taking into account missing vertebrae and cranial material, the overall length of the animal represented by the Cropwell remains is estimated at between 1.4 and 1.6m. This is small, but not uniquely so. The fused neural arches and unfused rib heads of this individual suggests that it was not fully grown. In comparison, Storrs (1995) describes a juvenile '?*Plesiosaurus*' estimated at between 1.25 and 1.5m in length, though with cervical vertebrae that are much shorter in proportion to their breadth.

Hawkins (1834) figures the complete articulated skeleton of *Thalassiodracon hawkinsi* (as *Plesiosaurus triatarsostinus*) giving an overall length of 5′6″ (1.7m). The general form of the limb bones is

		H/av.Ø	*F/av.Ø*	*H/F*	*F L/W*	*H L/W*
NOTNH 1987.G.60		615%	602%	102%	52%	47%
LEICS G18.1996	*Muraenosaurus*	486%	451%	108%	45%	58%
BMNH R.2421	*Muraenosaurus*	515%	478%	108%	51%	60%
BMNH R.2428	*Muraenosaurus*	470%	424%	111%	56%	62%
BMNH R.2463	*Muraenosaurus*	500%				
BMNH R.2425	*Muraenosaurus*	459%	436%	105%	56%	65%
BMNH R.2539	*Triclidus*	450%	470%	96%	55%	57%
BMNH R.2412	*Cryptoclidus*	561%	522%	107%	61%	75%
BMNH R.2417	*Cryptoclidus*	473%	486%	97%	57%	63%
BMNH R.2420	*Cryptoclidus*	563%	512%	110%	59%	74%

Key

H/av.Ø	Length of humerus/average diameter of dorsal vertebrae
F/av.Ø	Length of femur/average diameter of dorsal vertebrae
H/F	Length of humerus/length of femur
F L/W	Length of femur/maximum width of femur
H L/W	Length of humerus/maximum width of humerus

(Sources: NOTNH 1987.G.60 and LEICS G18.1996 — measurements by the author, others from Andrews (1910)

Table 2. Comparison of relative limb dimensions for long-necked plesiosaurs. See appendix for abbreviations.

similar to the Cropwell specimen, though the articular facets for the radius, ulna, tibia and fibula are more clearly defined, possibly an ontogenetic feature. As the cervical vertebrae of Hawkins (1834) specimen are deeply embedded in matrix, there is no way of determining the VLI. Storrs and Taylor (1996) illustrate the 5th cervical vertebra of *T. hawkinsi*. This differs in form and proportion from those for the Cropwell specimen, though this might again be explained as an ontogenetic feature. The cervical centra of NOTNH 1987.G.60 are significantly more elongated than those of the specimen of *Plesiosaurus dolichodeirus* described by Owen (1865).

Summary

The specimen described in this paper exhibits a range of characteristics that seem to rule out its inclusion in any currently described genera of Lower Jurassic plesiosaur other than '*Plesiosaurus*'. However, this genus has tended to become a 'catch-all' for any specimen which cannot be included in other genera. Storrs and Taylor (1996) and Storrs (1997) have started the process of breaking '*Plesiosaurus*' down into a range of genera, which should lead to a better understanding of the evolutionary relationships of the long-necked plesiosaurs.

The concentration, especially in recent years, on skull morphology has tended to play down the importance of post-cranial anatomy as a diagnostic element in plesiosaur taxonomy. There is a tendency, especially in the long-necked plesiosaurs for heads to become detached from bodies prior to fossilisation, which can make the association of cranial to post-cranial anatomy problematic. Complete, articulated specimens exist, though these were collected mainly in the last century and are in display mounts which make impossible the detailed analysis of dimensions used in this paper. Given these constraints, plotting of VLI along the length of the neck seems to provide a potentially useful tool to distinguish elasmosaurs and cryptoclidids and may throw light on the early evolution of these families.

Acknowledgements

I should like to thank: Neil Turner of Wollaton Hall Natural History Museum for the loan of the specimen and help with research into the locality; Arthur Cruickshank for his support, guidance, teaching and the loan of numerous papers; John Martin of Leicester Museum for access to collections, advice and support; Grace Deeks for her report on the condition of the dorsal vertebrae; Mark Evans and Leslie Noe for advice and the opportunity to discuss various aspects of the specimen.

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Appendix

The following abbreviations apply to the museum specimens referred to in this paper:

BMNH — British Museum (Natural History), London;

LEICS — New Walk Museum, Leicester (formerly Leicester Museum and Art Gallery);

NOTNH — Natural History Museum, Wollaton Hall, Nottingham;

YPM-PU — Yale Peabody Museum — Princeton University.

EXCURSION

Middle Jurassic limestones in the Ketton-Wansford-King's Cliffe area

Leaders: Albert Horton and Alan Dawn

29th June, 1997

In the East Midlands, the outcrops of the various formations within the Jurassic succession form a series of belts trending north-south. The most substantial limestones occur within the Middle Jurassic succession, which is summarised in the table below.

Oxford Clay Formation
Kellaways Formation
Cornbrash Formation
Blisworth Clay Formation
Blisworth Limestone Formation
Rutland Formation
Lincolnshire Limestone Formation
Grantham Formation
Northampton Sand Formation

The succession commences at the base with the sandy ironstone of the Northampton Sand Formation, overlain by the silts and sands of the Grantham Formation (formerly Lower Estuarine Series). The dominant limestone is the Lincolnshire Limestone Formation. This forms a prominent escarpment that has been quarried for building stone from time immemorial. Lincoln, Grantham and Stamford and their adjacent villages are built largely of this stone and roofed with Collyweston Slate, which originates from the lower part of the formation. The clays of the Rutland Formation (formerly Upper Estuarine Series) are next in the succession, overlain in turn by the Bilsworth Limestone Formation. The alternation of limestone and clay continues upwards with the Bilsworth Clay Formation and the Cornbrash Formation. The latter is the uppermost of the limestone beds within the succession and is overlain by the sands and mudstones of the Kellaways Formation and the clays and mudstones of the Oxford Clay. In the area visited there is a patchy cover of Pleistocene boulder clay.

In addition to building stone, other uses have been found for the limestones and clay. At Ketton, the Lincolnshire Limestone is made into cement. Huge quantities of the Northampton Sand ironstones were formerly mined for iron ore. Today many quarries produce road aggregate. All this mining activity has left a legacy of numerous disused and working quarries which allow the geologist to study all the various formations within the Middle Jurassic succession.

Locality 1. Ketton Quarry (Castle Cement)

Ketton Quarry currently displays almost the whole succession due to the presence of faulting. The trip commenced with an examination of the Lincolnshire Limestone. The lower beds are rather fine-grained, with a micritic cement. The topmost beds form the famous Ketton Freestone, a high quality building stone. It is an ooidal limestone, formed of small round grains cemented with a sparry calcite. The Freestone is 'unbedded' and cuts freely in any direction. Often blue-hearted, it derives the blue-grey colour from finely disseminated iron pyrites.

The upper surface of the Linconshire Limestone represents a disconformity, an erosion surface estimated to represent a time gap of about five million years. The transgression of the sea at the end of this period resulted in the deposition of the clays of the Rutland Formation. These comprise some seven distinct cycles of deposition, each containing abundant gastropod and bivalve fossils at the base, which gradually reduce in number upwards; the top of each cycle is marked by a rootlet bed. The Rutland Formation gradually passes upwards into the Blisworth Limestone, a fossiliferous limestone quite distinct from the Lincolnshire Limestone. The bivalves *Pholadomya*, *Pleuromya*, *Modiolus*, *Protocardia* and others are common, as are epithyrid brachiopods and gastropods.

About four years previously, quarrying operations revealed a hitherto unsuspected fault system, resulting in the preservation of much higher formations not previously known to be present. In ascending order these are the Blisworth Clay, a blue and green clay with microscopic ostracods. This is followed by the Cornbrash Limestone, a rich brown limestone bearing the ammonite *Macrocephalites* and many bivalves, gastropods and brachiopods. Its upper surface is paved with the giant clam *Lopha marshii*. Recently this formation has yielded the atlas bone and first cervical vertebra of a crocodile. The overlying Kellaways Formation also contains an abundant marine fauna of belemnites, *Gryphea* and ammonites.

Locality 2. Ring Haw Quarry

This is a disused ironstone strip mine in the Northampton Sand Formation. It yielded iron ore that was formerly smelted in the furnaces at Corby iron and steel works. Closed about 25 years ago, the quarry is somewhat overgrown, but it is still possible to see the boundary with the underlying Whitby Formation (formerly Upper Lias Clays). The impermeability of the Whitby Mudstone has resulted in shallow flooding of the quarry, enabling plants and wildlife — including newts — to flourish. Above the ironstone are the sands of the Grantham Formation, containing numerous rootlet horizons. The overlying lower Lincolnshire Limestone was better seen in the Cross Leys Quarry (see below).

Locality 3. Framples Field Quarry

Here the Rutland Formation has been extracted for the manufacture of refractory products. It is overlain by the Blisworth Limestone as at Ketton. The method of working the quarry enables the visitor to study the Rutland Formation at close quarters and the shelly horizons and the root beds can be examined in great detail. As at Ketton, the Blisworth Formation is fossiliferous.

Locality 4. Cross Leys Quarry

Although it only shows the lower beds of the Lincolnshire Limestone, this quarry is of great interest because it shows unusual decalcification features. An intriguing pattern of alternate bands of calcite and sand appear as a series of undulating or horizontal layers. Elsewhere the harder rock shows concentric curving weathering patterns and in places large globular masses (the quarrymen's 'doffers').

A total of 28 EMGS members participated in the excursion, and were rewarded with a great variety of Jurassic sedimentary rocks, presenting a fascinating record of our geological past.

Alan Dawn

EXCURSION

Excursion to Breedon on the Hill Quarry

Leaders: K. Ambrose and A. Horton

Wednesday, 16th July, 1997

The purpose of this excursion was to examine the Carboniferous Limestone exposed in the quarry at Breedon on the Hill, South Derbyshire [SK 40 23]. Three main limestone types or 'facies' are present, the base of the upper one being defined by an unconformity. The entire sequence is heavily dolomitised and as a result, precise environmental interpretation remains speculative. Mineralisation was also examined together with several caves with a variety of fills, including one choked with sediments of Triassic age.

Breedon Hill forms the most northerly of 5 inliers of Carboniferous Limestone aligned NNW-SSE, lying between Grace Dieu (west of Shepshed) and Melbourne. The quarry has a maximum depth of about 90m and exploits the limestone for roadstone. It is excavated almost entirely into the Milldale Limestone Formation (Aitkenhead and Chisholm, 1982) of Early Chadian age. The younger Cloud Hill Dolostone Formation, of ?Holkerian-Asbian age, is exposed only in the upper part of the north-west face. A major fault crosses the quarry, trending approximately north-south.

The inliers of Carboniferous Limestone in South Derbyshire have received little attention over the years. Table 1 shows the lithostratigraphy of the Carboniferous Limestone in Breedon and the neighbouring Cloud Hill quarry, situated about 1km to the south (based on Ambrose and Carney, 1997). The first detailed accounts were by Parsons (1918) and Mitchell and Stubblefield (1941), who both erected a stratigraphy for the beds. The quarries also received brief mention by Ford (1968). Monteleone (1973) produced the first detailed work on the Carboniferous Limestone of Leicestershire and South Derbyshire in an unpublished PhD thesis. King (1968, 1980, 1982, 1983) has published various papers relating to the mineralisation seen in the quarries. The caves at Breedon Hill have been described by Ford and King (1966) and Simms (1990).

In 1993, the British Geological Survey commenced a full resurvey of the 1:50 000 sheet 141 (Loughborough), which includes all of the Carboniferous Limestone outcrops. The results of the mapping and detailed logging of the quarries have enabled the stratigraphy to be revised, a more accurate assessment of the age of the rocks to be determined and environmental interpretations to be made.

Throughout the early Carboniferous, the area south of Breedon (the Hathern Shelf) was submerged below a shallow shelf sea, lapping onto the emergent Charnwood block. To the north lay a fault-bounded deep sea trough, the Widmerpool Half Graben or Gulf, in which a thick turbidite sequence accumulated as a result of fault-controlled subsidence. The Breedon inlier formed as a result of intense Late Carboniferous deformation. It stood out as an inselberg in the Permo-Triassic desert and gradually became buried by sediment deposited by fluvial and aeolian processes. The inselberg was probably completely buried in Mid to Late Triassic times. The cave system at Breedon probably formed in response to a number of processes, attaining much of its visible extent by Early Triassic times. The inselberg may have remained buried until at least the Palaeogene, and was doubtless further exhumed by the various ice advances and accompanying periglacial erosion during the Pleistocene.

LITHOSTRAT.	AGE
Mercia Mudstone Group	Mid-Triassic
Major unconformity	
Cloud Hill Dolostone Formation	Early Carboniferous (Asbian-Holkerian)
Main Breedon Discontinuity	
Milldale Limestone Formation	Early Carboniferous (early Chadian)

Table 1. Stratigraphy of the rocks exposed in Breedon on the Hill Quarry.

The Milldale Limestone is about 400m thick at Breedon and was examined at the **first locality** along the entrance roadway at the south end of the quarry. These are the oldest strata in the quarry. They comprise at least 170m of grey to buff, locally red, purple or ochreous-stained, thin to thickly bedded, fine to coarsely crystalline dolostone. The individual beds of dolostone are generally massive, although some show evidence of internal lamination. The beds are commonly separated by thin, undulating, grey or red shaly mudstone or silty mudstone partings, some of which have been emphasised by stylolitisation, a process of rock dissolution by pressure solution. These strata are very poorly fossiliferous, with only crinoids noted in both the limestones and the shaly partings. Chert nodules occur at some levels in this part of the sequence and were seen in fallen blocks. The cherts formed penecontemporaneously with deposition and were unaffected by dolomitisation. They usually contain well-preserved foraminifera, which may provide one of the very few indications of age in these heavily dolomitised rocks, though no foraminiferal analyses of the cherts from Breedon Quarry have been carried out. At the bottom of the roadway, the dolostones are thinly bedded and dark grey patches are visible on the rock face, caused by increased carbonaceous debris and bitumen staining. Bitumen spots also occur along some of the bedding and joint surfaces. Finely comminuted crinoid debris is locally common. These bedded dolostones are thought to represent distal storm deposits, gravity flows and turbidites, deposited on the ramp between the Hathern Shelf to the south and Widmerpool Half Graben (Gulf) to the north. The muds and silts settled out from suspension during quieter periods.

The major fault running north-south through the quarry is most clearly observed on the western face, where it produces a broad shatter zone. Neither the direction nor the amount of throw of this fault can be determined, but it can be traced away from the quarry in the overlying Triassic rocks where it downthrows to the east. The Carboniferous Limestone beds on either side of the fault are steeply dipping, locally folded and overturned in places.

The **second locality** was at a large cave which is completely filled with sediments of Triassic age. The present exposure on the quarry floor is about 60m wide with a vertical face of about 11m. Both the cave roof and the infilling sediments dip at about 40°, giving a true thickness of at least 9m. The infill deposits comprise red and green breccias, massive siltstones and mudstones. A laminated bed is visible near the top of the sequence and was examined from fallen blocks. It consists of clay-silt/sand couplets and clay/silt couplets, the latter locally showing microfaulting and slumping. The breccias are matrix supported and contain a very high proportion of intraformational sandstone, siltstone and mudstone clasts, some showing very thin lamination. There are also a few Carboniferous Limestone clasts, which occur mainly near the margin of the cave deposits and are more common at the northern end. The breccias probably represent debris flows, and the massive silts were probably deposited rapidly from sediment-laden water. In contrast, the laminated bed suggests more quiescent deposition from suspension; the couplets may represent seasonal variations in sediment discharge. The projected topographical level of the cave, where it intersects the outer edge of the inlier, occurs close to the boundary of the Sneinton, Radcliffe and Gunthorpe formations, suggesting a latest infill of early Middle Triassic (Anisian-Ladinian) age. Alternatively, Simms (1990) suggested a Late Triassic (Late Carnian) age for the formation of the Breedon Hill caves.

Other caves and voids were observed at various points in the quarry. They are mainly open, but at least two types of partial infill were observed: dolostone debris which has probably collapsed from the cave walls and roof; and large dog-tooth spar calcite crystals lining the walls. Many of these calcite linings are stained by iron oxides and other minerals; some copper minerals were noted, including malachite and chalcopyrite.

The **third locality**, at the northern end of the lower level of the quarry, showed the second main facies type present in the quarry and provided an opportunity for fossil hunting. The beds here are assumed to overlie the bedded dolostones seen at the first stop and comprise at least 100m of massive, unbedded, pale grey to buff, generally fine to very finely crystalline dolostone. These strata are richly fossiliferous and contain a diverse fauna of brachiopods, crinoids, corals (including the solitary coral *Amplexus coraloides*), nautiloids and ammonoids (goniatites). The structureless dolostone is thought to represent a deep-water, mud-mound 'reef', an accretion of calcite mud produced by micro-organisms. The dolostone contains many small cavities, which usually show a distinct alignment. These are thought to be primary cavities that formed just below the sediment surface during accretion of the mound. Other cavities represent the casts of bioclasts. Some contain concentric fills.

The Breedon mud mound is assumed to be of the same composition as the Chadian 'reefs' of Derbyshire. These 'reefs' are skeletal mounds (Waulsortian reefs), composed of fenestrate bryozoa and sponge spicules, with common crinoids (e.g. Bridges and Chapman, 1988; Bridges *et al.*, 1995). Such Waulsortian mounds were deposited in water of between 200-300m depth, deeper than the underlying ramp carbonates seen at the first stop. The massive dolostone beds form the core of the mound; overlying bedded dolostones, visible in the north-west face of the quarry, probably represent accumulation of debris on the flanks of the mound.

The **final locality** was on the upper level at the northern end of the quarry. The face exposes a near vertical dipping, strike section of pale grey to buff, bedded mud-mound dolostones which have yielded the Early Chadian goniatite *Fascipericyclus fasiculatus*. At one point, quarrying and rock falls have revealed the unconformity (the Main Breedon Discontinuity of Figure 1) at the base of the overlying Cloud Hill Dolostone Formation. The unconformity consists of a red-stained bedding plane with common *Thalassinoides* burrows. Also seen in a fallen block was the colonial coral *Lithostrotion*, of Viséan, ?Holkerian age.

The basal Triassic unconformity occurs about 5m higher up the face and is overlain by a bed of coarse, matrix-supported breccia infilling a shallow wadi-like structure with an irregular, undulating base. A bed of sandstone overlies the breccia and can be seen to overlap it and rest on the Carboniferous Limestone at either end of the face. Fallen blocks of the breccia and overlying sandstone were examined on the quarry floor. The breccia is composed exclusively of angular clasts of Carboniferous Limestone set in a matrix of sand, silt and clay. Many of the coarser sand grains are well rounded and wind-etched, suggesting an aeolian origin. The matrix-support fabric of the breccia indicates deposition as a debris flow, but the limestone clasts may originally have formed a scree on the flanks of the inlier. The overlying sandstone is predominantly red-brown, with pale red, greenish grey and ochreous mottling, and is fine-grained with some coarser, well-rounded aeolian grains. Some laminae are coarser, with reworked grains of granular dolomite derived from the Carboniferous Limestone. It is well laminated and there is evidence of disruption and soft sediment deformation.

The excursion ended with a visit to the Church at Breedon on the Hill. The party was given an account of the history of the church, which is built of sandstone originating from both the Triassic and the Millstone Grit, with later repair work using Lincolnshire Limestone. The latter was also used for the Saxon carvings displayed in the church, which also contains some superbly preserved alabaster monuments.

Acknowledgements

The organisers of this excursion gratefully acknowledge the co-operation and assistance of the management and staff of Breedon Quarry (Breedon PLC) and the Parochial Council of Breedon Church. This article is published with the permission of the Director, British Geological Survey.

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Keith Ambrose and Albert Horton

EXCURSION

The Marlstone Formation of north-east Leicestershire

Leader: Albert Horton

1st July, 1998

Nearly 40 members met at the Old Dalby Ministry of Defence carpark on a cold and overcast 'summer' evening. The excursion had two objectives; the first was to study the stratigraphy and sedimentology of the Marlstone Formation and its enclosing sediments, the second to discuss the development of the Marlstone escarpment. The geological succession studied is summarised in Table 1.

Brownhill's and North Quarry form part of an important Nature Reserve. The sites must not be hammered or disturbed in any way. Access is by permit only from the Leicester and Rutland Wildlife Trust, 1 West Street, Leicester LE1 6UU.

Green Hill, Nether Broughton (SO 695 235)

This embayment at the south-western extremity of the Vale of Belvoir offers fine views northwards across the Vale to the distant escarpment of the Penarth Group (formerly Rhaetic). The Vale has a gently undulating topography formed by a series of small escarpments ranging from 1 to 10 metres in height, each representing a thin but resistant bed of limestone, sandstone, or nodular ironstone within the Charmouth Mudstone Formation. Green Hill lies on the main escarpment that bounds the Vale of Belvoir to the south-east. The escarpment is capped by the Marlstone Formation, which comprises up to

4.2m of oolitic ironstone overlying about 5 metres of sandstone ('Sandrock'). The underlying Dyrham Foundation consists of siltstones and silty mudstones and crops out the steep slopes below the Marlstone, where it gives rise to sharp hollows and a distinctive, gorse scrub vegetation. The downward passage from the Dyrham Formation into the mudstones of the Charmouth Formation lies about halfway down the scarp slope and, though ill-defined lithologically, is well marked by a line of springs. 'Cutting back' by these springs ('spring sapping') excavated the sharp hollows.

Mudflows and landslips occur in numerous places along the scarp and most probably formed during periglacial periods. To the west of Green Hill, the escarpment is capped by till ('chalky boulder clay'). To the east, near Stathern, till infills two valley-like depressions that cut the escarpment. Glacial deposits are absent from the Vale, perhaps reflecting the efficiency of stream erosion and transportation in sculpting the Vale's landscape. There is little doubt that the Marlstone escarpment lay some distance to the north of its present position at the time of the last (Anglian) glaciation to affect this area (500,000 years ago), but its former location is conjectural.

Formation	*Member*	*Former Name*
Whitby Mudstone Formation	Cephalopod Limestones Member Fish Beds Member	Upper Lias
Marlstone Rock Formation		Marlstone Rock Bed
Dyrham Formation	Sandrock Member	Middle Lias Silts and Clays
Charnmouth Mudstone Formation		Lower Lias

Table 1. Stratigraphy of the Liassic rocks.

Church Farm, Holwell (SO 7346 2371)

The Sandrock is exposed at road level near the farm, and consists of ferruginous and locally shelly, fine-grained calcareous sandstone. The grey micaceous siltstone and silty mudstone of the underlying Dyrham Formation is exposed at the road junction 50m to the north. The garden wall of the farm is built of Sandrock blocks, capped by micritic limestones originating from the Barnstone Member (formerly known as Blue Lias or Hydraulic Limestones) at the base of the Lias. Below the house, a retaining wall above the Sandrock includes several blocks of conglomeratic limestone with pebbles of fine-grained ferruginous siltstone. This bed commonly forms the base of the Marlstone Formation in the surrounding district.

Holwell is a classic "ironstone village" built of pale to rusty brown stone. To the consternation (and possibly fear!) of the villagers, the party examined the various different types of stone in a house wall. Most consists of ferruginous siltstone with shell-rich horizons, but examples of dark rusty brown finely oolitic ironstone and a paler, crinoid-debris rich ferruginous limestone were also seen. Nests of brachiopods occur in both the Sandrock and ironstone lithologies.

Brown's Hill Quarry (SO 742 235)

Here the party was able to study the Sandrock, the Marlstone Formation and the overlying Whitby Mudstone Formation. The Sandrock exposed in the floor of the quarry consists of pale brown, fine-grained ferruginous sandstone. It is a very uniform, relatively soft 'freestone', characteristics that favoured its extensive use as a building stone. Sadly it weathers readily, and the original Ashlar construction of many principal buildings has been destroyed, albeit over a period of almost seven centuries in the case of churches. The base of the Marlstone is marked by a shell-debris rich horizon; the conglomerate seen at some localities is absent here. The Marlstone is about 4.2m thick, and originally consisted of chamositic, sideritic, shell-debris rich limestone. Weathering has resulted in decalcification and alteration of the rock to an ore-grade ironstone, with a 'dried ore' iron content averaging 25% but ranging up to 40%. Locally, the ore was quarried between 1878-81 and from 1917 to 1993, with underground mining from 1931-42 in areas of thicker overburden.

The weathering, oxidisation and redistribution of the iron have destroyed many depositional structures, but cross-lamination still persists, picked out by crinoidal shell-debris and grain-size variations. Together with the presence of a robust and varied brachiopod, bivalve and belemnite fauna, the cross-lamination indicates accumulation under high-energy conditions. Ghosts after ooliths and shells can still be recognised in places.

The top bed of the Marlstone is exposed on a bared surface close to a mine adit. It is a ferruginous limestone with abundant, broken and randomly-arranged belemnites and a few ironstone pebbles — a true 'belemnite battlefield'. Currents were too weak to orientate the belemnites.

The onset of the Toarcian times was marked by an abrupt change in lithology and the deposition of the Fish Beds Member of the Whitby Mudstone Formation. The basal bed is a hard, pale buff-grey, very finely laminated micritic limestone with layers of very small, convex-upward orientated shells of ostracods and immature molluscs ('spat'). The remainder of the Fish Beds Member consists of very thinly laminated mudstones (paper shales). The laminae are composed of couplets of green calcareous mudstone alternating with brown bituminous mudstone containing abundant molluscan spat and thin-shelled bivalves, and uncommon ammonites, fish and insect debris. The calcareous mudstone may pass laterally into nodular limestones. One such bed, now decalcified but with fish spines, occurs some 0.15m above the base. A bed of nodular pyritic limestone occurs about 0.15m higher still.

The base of the Fish Beds Member records a major world-wide marine transgression with the creation of a quiet, deep water anoxic environment. Sediment supply was limited and deposition was slow below the depth of significant current activity. There was no bottom dwelling fauna due to the anoxic conditions and hence no bioturbation to disrupt the micro-lamination within the bottom sediment. Nevertheless, organic productivity was high at shallow depths, with algal blooms resulting in mass mortality of nektonic faunas and their accumulation as death assemblages on the seabed.

North Quarry (SO 742 237)

This quarry worked from 1943 to 1963 and the worked area was restored to grassland in 1974. This can be contrasted with the original hill and vale dumps at Brown's Quarry and the ancient Sandrock workings in the grass field to the west. The party divided into two groups at this stage. The wardens of the Reserve conducted tours of the site for one group while the waiting group continued to examine the geology in the quarry. Here, the gradual upward transition from the fissile Fish Beds Member to the blocky medium grey mudstones of the Cephalopod Limestone Member was studied. The mudstones contain scattered bivalves and ammonites, with fine shell debris and '*Chondrites*' type burrows. Some ammonites are preserved as uncrushed outer whorls; large *Hildoceras* are preserved in calcite micrite nodules and small *Dactylioceras* as sideritic phosphate nodules. A weathered bed of pale buff-grey micritic limestone nodules with large ooliths and pisoliths (up to 3mm) occurs at the top of the quarry. These grains also occur scattered throughout the enclosing slightly calcareous mudstone. The Cephalopod Limestones mark a change to less anoxic bottom conditions, the "Chondrites" burrows reflecting a slightly more oxygenated environment with gently agitated bottom waters.

The excursion concluded with a discussion of the origin of the Marlstone and its ooliths. The latter are an enigma, in that they are composed of minerals that suggest precipitation in reducing conditions, contrasting with the abundant evidence of current activity and oxygenated conditions in the host sediment. In the Marlstone, the ooliths originally consisted of chamosite, a ferrous iron phyllosilicate of the glauconitic group of minerals. In the Cephalopod Limestones Member, the ooliths are of calcium phosphate. Classic calcareous ooliths accrete in high-energy open water environments where aragonite is precipitated around a nucleus, yet both of the present examples are formed of minerals that occur only as traces in sea water. They therefore must have formed by processes other than direct precipitation. The Marlstone contains very little primary detrital clay. The chamosite occurs (in fresh specimens) both as oolite cores and rinds, and the ooliths are enclosed in calcite-siderite cement. Siderite replaces chamosite in some ooliths. The party discussed how ferric iron could have been transported into the basin as colloidal particles or as films adhering to clay particles or other detrital grains. It was suggested that reduction of ferrous to ferric iron was then accomplished by biogenic action in the mildly alkaline and reducing environments at shallow depths within the bottom sediment, and that the ferrous ions then reacted with detrital clay minerals to form berthierine glauconite, a mineral found in modern sediments. Siderite alteration and cementation took place in the more strongly reducing conditions at depth within the substrate in the absence of sulphate ions (pyrite forms in reducing conditions when sulphate ions are present). Chamosite then formed by the diagenetic alteration of berthierine. In the case of the phosphatic ooliths in the Cephalopod Limestone Member, the party concluded that these must have formed during early diagenesis by replacement of primary aragonitic ooliths by authigenic phosphate. Both the chamositic and phosphatic ooliths were thought to have been reworked from their sites of formation and transported into the environment of deposition; a high-energy, current-swept environment in the case of the Marlstone, and a quiet water setting in the case of the Cephalopod Limestones Member, where bioturbation dispersed the ooliths through the mudstone.

Albert Horton

SECRETARY'S REPORTS FOR 1996/97 AND 1997/98

Reports for these two years have been amalgamated by the Secretary and Editor, in order to bring reporting up-to-date in Mercian Geologist.

Twenty new members joined in 1996 and 54 in 1997. In March 1998, membership stood at 332 ordinary/joint/student and 76 Institutional. It is with regret that the deaths of four long standing members of the Society are recorded: Mrs Madeleine Samuel, Miss Nancy Mulholland and Mrs June Elliot after illnesses; and Mr Tony Bampton, a founder member, in an accident. The Society was also saddened to learn of the death of Dr Ansell Dunham, a non-member who was well-known to the Society. The Society congratulates two members who were bestowed with Honours in the 1997 Queen's Birthday list (see *Mercian Geologist*, Volume 14, Part 2, page 51). Dr Trevor Ford, a founder member of the Society and past President was awarded an OBE for services to geology and cave science. Mr David Robinson, a member for 33 years and past Council member was awarded an OBE for services to journalism and the community in Lincolnshire.

Field meetings

The field meetings were once again organised by Dr Ian Sutton and the Society continues to benefit from his wide knowledge of interesting locations and enthusiastic leaders. Dr Sutton's office also saves us a lot of work by maintaining the Society's mailing list and receiving and collating postal bookings.

Few other geological societies can turn out sufficient members to make coach hire viable. This is greatly preferable to the marshalling of large numbers of cars, so please keep coming on the trips. We welcome guests of members on field trips where numbers are not limited. For insurance purposes, guests are assigned day membership at a cost of £2.00. Members are reminded that the Society has public liability insurance only and that it is members' responsibility to ensure that they have adequate personal insurance and are adequately equipped with appropriate clothing, footwear and a hard hat.

Trips in 1996. In May, Dr Lomax led 24 members on a trip to the Speeton Cliffs area of Yorkshire (see *Mercian Geologist* Volume 14, Part 2, page 88). The Speeton Clay Formation from the Kimmeridgian to the Barremian was followed along the beach and numerous interesting fossils were seen and some collected.

The weekend trip to the Lake District in June regrettably was cancelled due to lack of support. As a result of the cancellation, the views of a sample of the membership were sought to gauge interest in re-organising the trip. This showed substantial interest for a trip in September 1997, but in the event numbers still proved insufficient and it was cancelled again.

In June, Albert Horton and Brian Chambers led an evening 'multi-disciplinary' trip to Cresswell Crags in conjunction with Dr Pat Horton and the Institute of Biology. This included a lecture on bats, with the opportunity to handle live animals, a brief summary of the overall geology and more detailed study of the archaeology and geology of the Robin Hood Cave. Also in June, Ian Sutton led an evening walk from Robins Quarry to Ashover village to transect the Ashover inlier. The trip was well attended despite the rival attractions of Euro96. As is often the case there were additional interesting contributions from members.

In July, Neil Aitkenhead and Ian Chisholm led an interesting walk to Ecclesbourne Valley and Alport Hill. The trip was joined by local landowners who were most interested to learn about what lay below their property. The final field trip in 1996 was to the Ercall quarries and was led by Susan Beale. Nearly 40 members enjoyed a very well organised and prepared excursion.

Trips in 1997. The season began in May, when Dr Sarah Davis led 18 members on an energetic trip across Kinder Scout. In June, Albert Horton, Ian Sutton and Neil Aitkenhead led about 50 members on an evening trip to Dove Dale. They were also assisted by Dr Peter Gutteridge. Later in June, Alan Dawn and Albert Horton led 28 members on a day trip to Ketton and the surrounding area (reported in this issue). In July, Albert Horton and Keith Ambrose led an evening visit to Breedon attended by 76 members (reported in this issue). In September, Richard Ellison and Alan Smith of the BGS led a trip to the London Basin. The north Charnwood area was visited in October, led by John Carney with 30 members in attendance. The season was rounded off in November by a geomorphological excursion to south Lincolnshire led by Professor Jim Rose. As always, the extra contributions by BGS staff and other knowledgeable members have enhanced the value and interest of the trips.

Indoor meetings

The meetings for 1996/1997 and 1997/98 were organised by Dr Neil Aitkenhead for the fifth successive year. Again the Society is very fortunate to have someone with such a large number of contacts to be able to find suitable speakers.

The lecture following the 1996 AGM was by Dr Terry Fletcher on the famous Burgess Shales and its distinctive, ancient fossils. This proved to be both interesting and spectacular for members, with some graphic descriptions of the practical difficulties involved in working in inaccessible mountain terrain in high latitudes. The last meeting of the 1995/96 winter season was by Dr Jane Evans on the techniques she is using to date some plate boundary rocks in China. The talk included fascinating accounts of the local people and their culture. The traditional lecture held annually at Derby was delayed to coincide with Derby Environmental Week in the hope of a good attendance. Although very few EMGS members attended, the presence of students and local people attending as a result of DEW activities made the meeting a success. Dr John Carney covered the geological history from the Pre-Cambrian to date and its influence on development in Derby and its surroundings. This was an ideal lecture for this occasion and was well received with lots of questions.

The new 1996/97 season started with a lecture by John Rippon on Rivers in the Coal Measures. Mr Rippon's researches over a long period challenged the existing theories. This enlightening talk was very well-received by 90 members and generated a lot of interesting questions. The November lecture was by Dr Dave Roberts on the Quaternary of Norfolk, and his fresh interpretations of the cliff structures were of particular interest in view of a recent Society trip to the area (for report see this issue).

The organisers of the Yorkshire Geological Society meeting at Leicester University in November 1996 invited EMGS as joint participants together with the Leicester Literary and Philosophical Society. About 20 EMGS members attended four linked lectures on the theme of from 'mudrock to brick wall'. In December our usual 'light-hearted' lecture and "cheese and wine" were neatly combined by Dr Roger Suthern, who talked about the geology and wines of southern France and then led members in a wine tasting. Unfortunately, very bad weather on the night kept attendance low.

In January Dr Ian Hill presented his latest ideas on the puzzle of 'What moves the Plates?' A full house was enthusiastic about the talk and eventually questions had to be curtailed. For the Foundation lecture in February, the President took the plunge and shared her favourite geological locations with us to demonstrate geology viewed from afar and in close up. The address was followed by an excellent meal in the comfortable surroundings of the University Staff Club.

The meeting following the 1997 AGM was by Dr William Jones on the Geology and Scenery of Santorini. This proved to be both interesting and spectacular for members. In April 1997 a meeting held at Derby University was successful in attracting about 20 non-members. Dr Charlie Underwood's talk on small sharks and pink rocks in the Cretaceous created a great deal of interest. The last meeting of the 1996/97 season was by Dr Keith Ball who provided all the answers on the subject of Radon that had been prompted by a talk the previous year.

The 1997/98 season of lectures got under way in October with Professor Jane Plant giving a most clear overview of the radio-active processes driving the earth's geological evolution. In November, Dr Alan Wooley's talk on Carbonatites cleared up a lot of the mystery and controversy that has surrounded these rocks. In December our traditional 'cheese and wine' was preceded by Dr Ian Sutton's entertaining talk on the geological background and the human story behind the Klondike gold rush, marking its centenary. About 90 members attended.

Following numerous expressions of interest from members, a workshop afternoon was held in March 1996, organised by Les Hall and Peter Jones. Members were introduced to the techniques of preparing replica fossils and acetate peals, and several microscopes were set up to enable hands-on examination of petrological and palaeontological specimens. Unfortunately, despite the success of the 1996 event, there was insufficient support for another workshop in 1997.

Other Society proceedings

Council met formally six times in both 1996/97 and 1997/98 and has continued to promote interest in geology in the region by encouraging research, education and conservation. The Society has continued with or supported several projects.

1. In 1996, the Society was well represented at Derby Environmental Week with a lecture and displays at Derby Museum, Derby University and Elvaston Castle. Dr Carney, Mr Horton, Mr Jones, Mrs Moore and Mr Mucklow are particularly thanked for their efforts. In 1997 the Society was represented at the National Environmental Week at Elvaston Castle by Les Hall and Colin Bagshaw.

2. The EMGS field guide has progressed steadily, with all except one contribution now edited by Albert Horton with assistance from Les Hall. Several members have assisted with putting the excursions to the test by walking over the routes and feeding comments to the editors.

3. In December 1996, following the considerable success of the first edition, a revised second edition of the Nottingham Sandstone Caves book was published and is an ideal purchase for anyone with a general interest in local history. Thanks to the generosity of the author, Dr Tony Waltham, and the energetic distribution team of Andrew and Judy Rigby, Judy Small and Dr Waltham, the Society made a profit of £4,200 on the first edition with nearly 4,000 copies sold. Dr Waltham has now rewritten the book to make it even more assessible to the lay reader and thereby broaden its appeal. The new version is in a smaller format with colour illustrations and extra information; it has received excellent reviews and is selling well. The Society expresses its gratitude to the author Tony Waltham, to Andrew Rigby for the production editing and printing, to Tony Waltham, Andrew Rigby, Judy Rigby and Judy Small for distribution and to Tony Waltham and Tony Morris for the publicity in the *Evening Post* and on Radio Nottingham.

4. We have now had four meetings with representatives of Nottinghamshire County Council on the provision of geological information for interpretative notice boards as part of the Corridors

to the Countryside project. This project moves very slowly, but has the aim of erecting display boards giving wildlife and geological information on local sites of scientific, environmental and educational interest. The Society has collaborated with the Nottinghamshire Wildlife Trust to provide geological interpretations and descriptions of some sites.

Six circulars were published in both 1996 and 1997, and Ian Sutton and Tony Morris are thanked for their assistance in producing and distributing these. Andrew Swift is thanked for producing a new promotional leaflet-cum-application form, which is helping to attract new members. The Society also gratefully acknowledges the assistance of numerous members with various tasks such as preparing refreshments at meetings, providing accommodation for speakers and staffing the EMGS display at a range of events. Finally the Society wishes to thank Nottingham University for providing us with excellent accommodation for Council and indoor meetings. We are very lucky indeed to be able to use these facilities.

Alan Filmer

NOTES TO CONTRIBUTORS

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Abstract. Scientific papers should be accompanied by a brief abstract stating the essential information and conclusions presented in the text.

Text. Please present contributions on A4 (297 × 210mm portrait) paper, typed or word-processed on one side only, double-spaced, with ample margins.

References. All references cited in the text should be listed; the author is responsible for the accuracy of references. In the text, references should be given as: (Smith, 1992); use (Smith *et al.*, 1992) for more than two authors. In the References, list all authors and do not abbreviate journal titles.

Illustrations. Line drawings and photographs will all be included as text-figures, and should be presented wherever possible to cover or be in proportion to one column (width 84mm) or two columns (width 178mm) and up to 245mm depth. When full page line drawings and photographs are used an appropriate allowance should be made for the required caption. The smallest lettering on line diagrams should not be less than 1mm high. A full list of figures, with captions, should be submitted on a separate sheet. Approximate locations for text-figures should be indicated in pencil in the margin of the text. Tables will be typeset and should be designed to fit single or double column widths and up to the maximum depth.

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