CONSERVATION, PLANNING AND OTHER ISSUES RELATING TO THE GEOLOGY OF THE CONSTRUCTION OF HIGHWAYS ACROSS AREAS UNDERLAIN BY PEBBLE BEDS OF THE SHERWOOD SANDSTONE GROUP

by

David B. Thompson

Summary

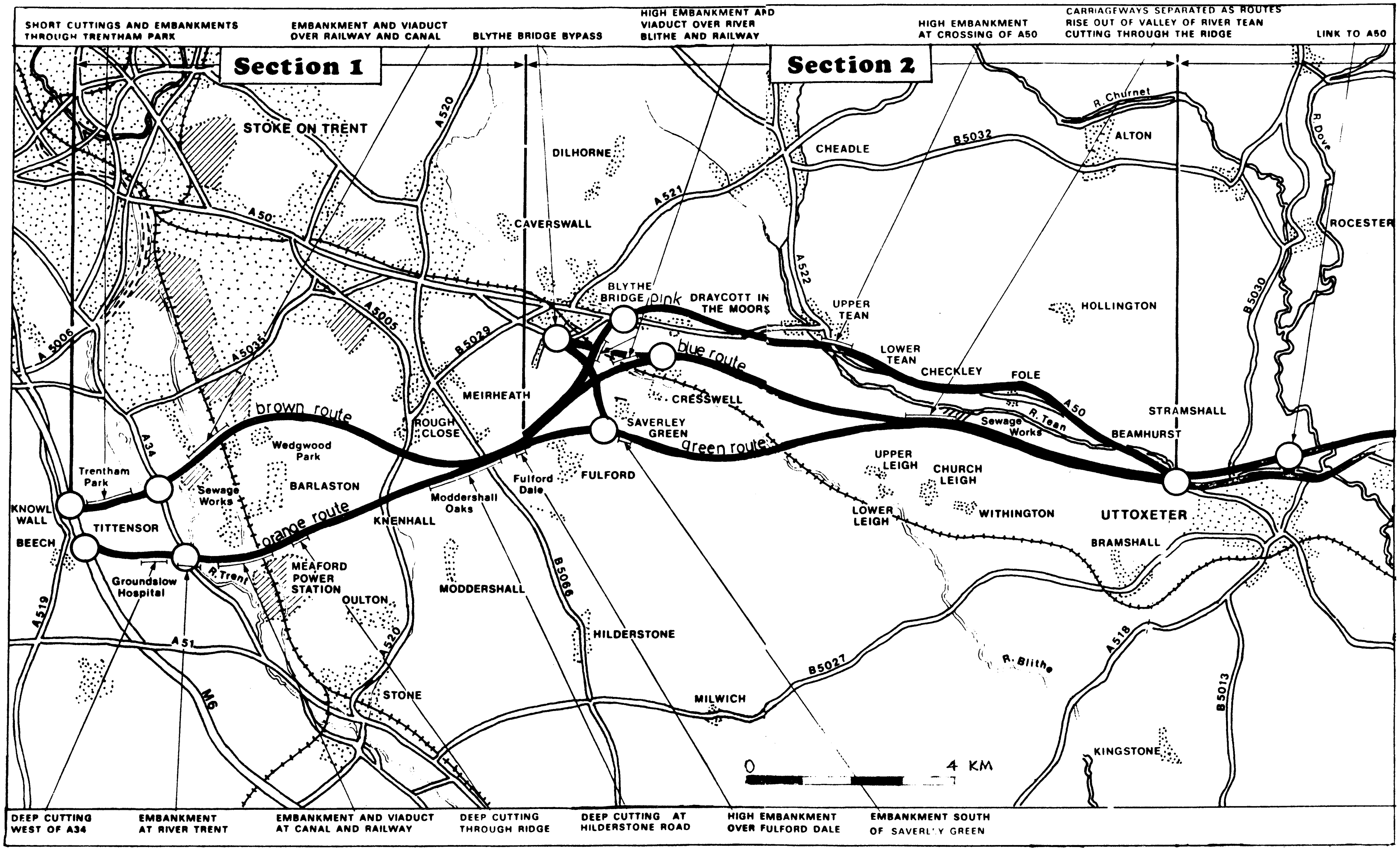
The paper describes the problems associated with the planning of the A564 Stoke-Derby road across the pebble beds of the Sherwood Sandstone Group in north Staffordshire. Planning the supply of materials to major roadworks from existing quarries may need 15 years foresight with respect to obtaining planning consent, prospecting resources, organising the working of quarries and ensuring the commitment of sufficient capital. Public consultation over the geological and other reasons for the proposed routes is nearly obligatory, and the restoration of land to agriculture or to public use is much desired. The origin of the Park Hall Country Park near Longton is described to show how the geological features of the pebble beds in an area scarred by haphazard quarrying and tipping have been utilised to construct a major public amenity in an area not hitherto well endowed. Since virtually all parts of the pebble beds are suitable for road construction an outline analysis is made of the cost benefits of supplying such materials from on-site sources along the projected highways compared with off-site sources in working, or abandoned, quarries. Whilst many of the present methods of planning and managing geological site investigations in areas of sandstone outcrops may be adequate, those in conglomerates fail to supply reliable information and are costly.

Introduction

The present article, although self-contained, is best read in conjunction with the previous one by Buist & Thompson (1982, this volume, pp. 241-268) which discussed the sedimentology, engineering properties and exploitation of the pebble beds of the Sherwood Sandstone Group in relation to the experience of constructing the M6 motorway and preparing for the M64 (now abandoned) and the A564 Derby-Stoke link road.

In north Staffordshire there has been considerable discussion of the provision of new roads to relieve traffic congestion which arises at many points on the A50 between Stoke and Derby, for example at Blythe Bridge and Tean (text-fig. 1). Preliminary geological investigations by the Midland Road Construction Unit (MRCU) were started in 1971 and the announcement of the preferred

Mercian Geologist, vol. 8, no. 4, 1982
pp. 271-284, 4 text-figs., 1 table



Text-fig. 1: Possible routes for the M64 (Stoke-Derby) motorway in its western part (section 1, M6 at Beech to Fulford; section 2, Fulford to Uttoxeter, to illustrate problems associated with the planning of embankments and cuttings largely in pebble bed rocks, and environmental problems (Ministry of Transport, 1976). The construction of the M64 has been abandoned but its relative costs at 1976 prices were: Brown Route, 140 acres, 10.1 km, £18.5 million; Orange Route, 130 acres, 9.15 km, £18.5 million. The A564 trunk road is to be built and will largely follow the Brown and Blue Routes.

routes was made in November 1979 (brown and blue sections, text-fig. 1). Both the previous paper (Buist & Thompson, 1982) and this note describe methods which will contribute significantly to the cost-benefit analysis of the problems which have arisen in connection with these projects. The particular parts of the M64, M6 and A564 which cross pebble beds in north Staffordshire lie between Blythe Bridge and the M6 near Beech (text-fig. 1), but the supply of materials for the new roads may involve quarries within a much wider area. Of the many possible routeways of the M64 and A564 through this area put forward by the MRCU, only two, the Orange and Brown Routes (text-figs. 1 & 2), were seriously considered. In addition to the three problems identified by Buist & Thompson (1982), four further problems are discussed here:

1. Conservation and planning issues surrounding the working of extensive quarries in the pebble beds in the neighbourhood of motorways like the M6, or link roads like the A564.

2. The possibility of restoring land, which has been quarried for long period in a haphazard way, to public use.

3. The availability and cost of off-site construction material from pebble bed outcrops in relation to the practical use of on-site resources.

4. The extent to which present methods of site-investigation are cost effective.

It is emphasised here that the views expressed in this paper are those of the author alone and are not those necessarily of his co-author of the previous paper or of the staff of the East Midlands Geological Society.

An outline of the nature and origin of the pebble beds of the Sherwood Sandstone Group

These rocks form the lower undefined part of the Cannock Chase Formation in the east and the Chester Pebble Beds Formation in the west (Warrington *et al.*, 1980) at, or close to, the base of the Trias. The old Geological Survey Great Britain maps give a clear indication of the outcrops of the conglomerates and pebbly sandstones under their designation 'f_2'. Throughout this paper the phrase 'pebble bed(s)' refers to strata of the Sherwood Sandstone Group, for example the Chester Pebble Beds Formation. The distribution of the pebble beds is widespread in the east and west Midlands (text-fig. 3) and most of what is discussed here, although derived from experience gained from north Staffordshire, is directly applicable to the whole area. The relationship of the pebble beds to the rest of the succession is shown in text-fig. 2.

The pebble beds of the Sherwood Sandstone Group have been shown to consist of the following facies (Buist & Thompson, 1982):

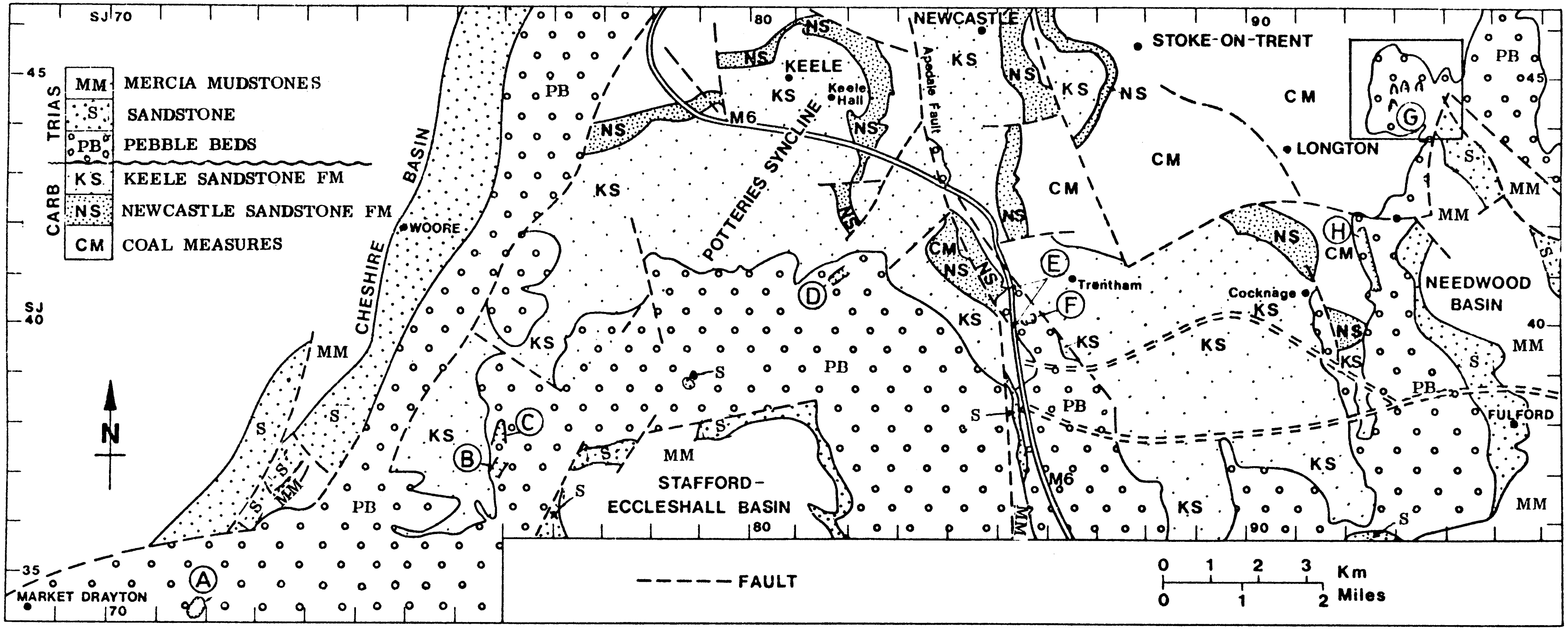
Facies A — Flat stratified pebble conglomerate or gravel representing former longitudinal or diagonal gravel bars in a braided river.

Facies B — Cross-stratified pebble conglomerate or gravel representing the downstream avalanche surfaces of such bars, or the migration of transverse gravel bars.

Facies C — A spectrum of cross-bedded sandstone, grading from medium to fine pebbly sandstones (type C_1), to medium to very fine argillaceous micaceous, usually pebbleless sandstones (type C_2), representing the migration of sandwaves and megaripples and transverse bars in a sandy braided river.

Facies D — Interbedded fine-grained argillaceous sandstone, siltstone and mudstone indicating the settling of argillaceous sediment from suspension in areas of slackwater at periods of high to moderate discharge, or overall settling of fines at low discharge, in gravelly or sandy braided rivers.

The lowest part of the pebble beds often consist of Facies C_2 and C_1, but the succession coarsens upwards by the addition of Facies A and B to C_1 until the main productive gravel horizons are reached. Thereafter the succession fines upwards by loss of Facies A and B and



Text-fig. 2: Geological map of north Staffordshire to show possible lines of the M6 motorway (now abandoned) and the A564 link road over pebble bed outcrops, and the positions of quarries which were available at the time of construction of the M6 motorway. The northerly route is the Brown Route, the southerly the Orange Route.

A = Hales-Almington Quarry
B = Lordsley Quarry
C = Willoughbridge Quarry
D = Acton Quarry
E = Trentham M6 Motorway Cutting
F = Kingswood Bank Quarry
G = The Park Hall Country Park quarries (see text-fig. 4, the position of which is located by the rectange on the NE of the map)
H = Quarries between Normacot and Lightwood

the increase in Facies C_1 and eventually C_2 and D, until the Upper Mottled Sandstone, (Wilmslow Sandstone Formation) 'f_3' is reached. This distribution probably reflects a sedimentological response to first increasing then decreasing intraplate extensional basin-forming tectonic events (Ziegler, 1978), though Wills (1970; 1976) maintains that it is climatically controlled, whilst others provide the basis of possible explanations which involve worldwide changes of sea-level, hence local changes of base-level (Vail *et al.*, 1977).

Conservation and Planning Issues

The planning authorities long ago forecast that the high quality sands and gravels of the pebble beds of north Staffordshire would play a vital part in the development of the post-war road network of the northwest Midlands and south Lancashire (Beaver in Abercrombie & Jackson, 1949, p. 83). At that time they recognised no planning or conservation problems:

> "There is so far as we know, no serious local objection to the gravel industry as there is in some parts of the country on grounds of conflict with agriculture, amenity, or town planning: but if there were it should in our view be strongly resisted, for the industry occupies a relatively small amount of land owing to the depth of the quarries, and moreover it plays a very vital part in the economy ..."

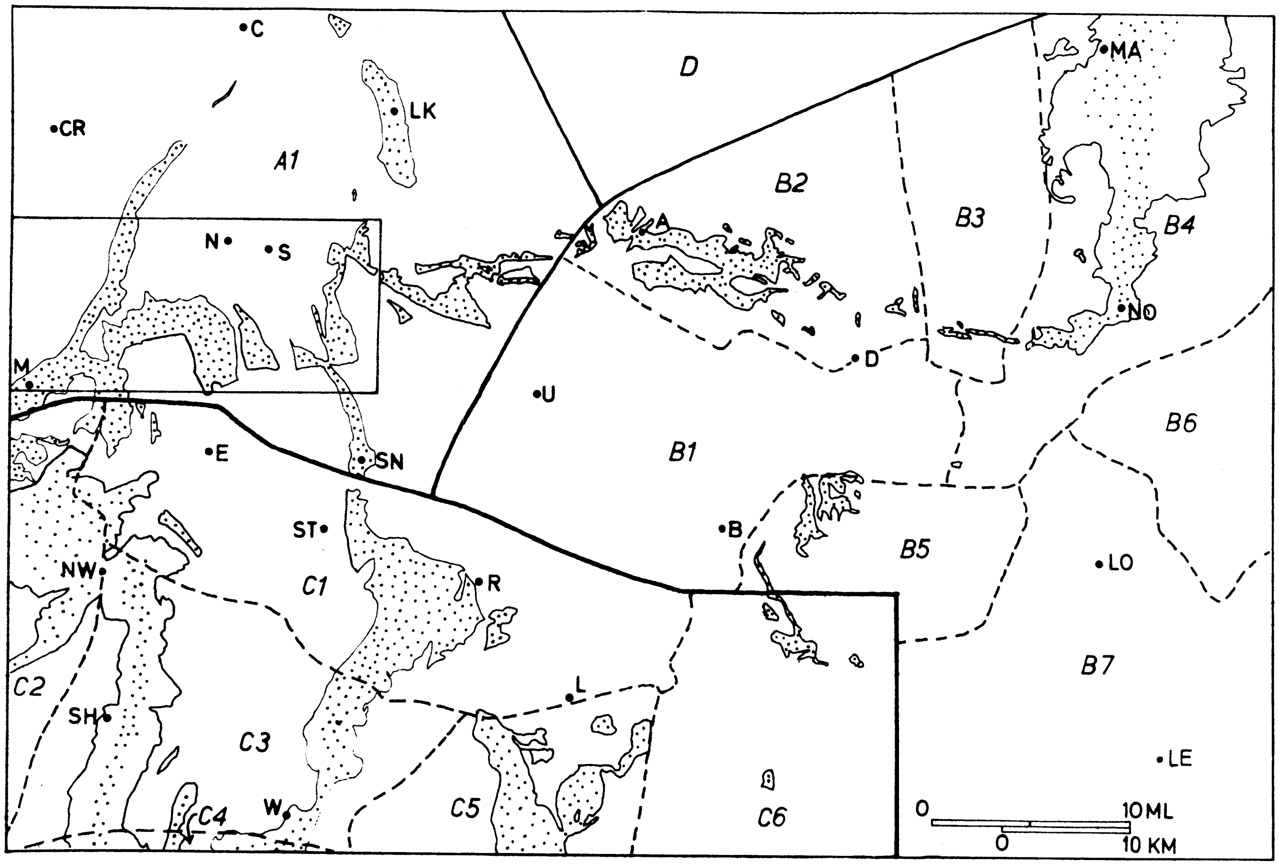
Forecasts of demand for sand and gravel derived from north Staffordshire and the west and east Midlands were reviewed by the Waters Committee (Ministry of Housing and Local Government, 1950; 1952) and were revised upwards by the planners of the County of Stafford (Staffordshire County Council, 1969) as a result of very considerably increased demand between 1950 and 1965. It was recognised that without great changes in transport costs the north Staffordshire area in particular, and the west Midlands and Trent Valley Service Areas in general (text-fig. 3), would continue to export their products to supply the insatiable demand of the conurbations of south Lancashire-north Cheshire, south Yorkshire and the Black Country (Ministry of Housing and Local Government 1950, figs. 1 and 8; 1952, Map B), as well as the needs of local areas, for example between Derby and Stoke (text-fig. 3). In a later report (Staffordshire County Council, 1969), it was acknowledged that gravel was still likely to travel from the Cheadle area to as far afield as Liverpool in the foreseeable future. In forecasting planning permission for greater allocations of land for gravel working in the period up to 1981 (*ibid.*, pp. 45-49), the planners recognised increasing land conservation problems:

> "Of the current areas that are being worked, only a very limited amount has been reclaimed and it is considered that proposals for allocations on the scale indicated by the estimated demand will need to be balanced by a much more effective and comprehensive programme for securing appropriate after-use treatment, than hitherto."

In the 1950s the after-treatment consisted of:

> "surface grading of the quarry floor and battering of the final working faces.... any humus-bearing upper layers of the soil can be respread ... as part of a continuous process of backfilling..."
> (Ministry of Housing and Local Government, 1950, p. 52).

It is common knowledge that the climate of conservation in the late 1970s and early 1980s is not that of former years. There is a greater awareness of public issues and an enhanced appreciation of environmental quality (Black, 1978, pp. 310-334). If major roadworks are to be attempted then they have to be justified both on environmental and economic grounds. Since environmental problems cost money to resolve and greatly affect the lives of the local residents, either indirectly through the paying of rates and taxes or directly through the changing of local ways of life, local communities expect to be informed of the geological and other conditions which make one series of options more desirable than others. It must be said that the public was consulted over the M64 and is being consulted over the A564 to a degree not hitherto attempted (Department of Transport, 1976).



Text-fig. 3: The outcrop in the West and East Midlands of the former 'Bunter' Rocks designated f1-f3 of the Sherwood Sandstone Group on the 1:250,000 map of the Institute of Geological Sciences. "f1", the Lower Mottled Sandstone and "f3", the Upper Mottled Sandstone, are sandy and not pebbly. "f2", the former 'Bunter' Pebble Beds, is the main source of the high quality sands and gravels and its main distribution is shown by the dotted area.

A = Ashbourne	LK = Leek	R = Rugeley
B = Burton-on-Trent	LO = Loughborough	S = Stoke-on-Trent
C = Congleton	M = Market Drayton	SH = Shifnal
CR = Crewe	MA = Mansfield	SN = Stone
E = Eccleshall	N = Newcastle-under-Lyme	ST = Stafford
L = Lichfield	NO = Nottingham	U = Uttoxeter
LE = Leicester	NW = Newport	W = Wolverhampton

The Gravel Regions designated by the Waters Committee (Ministry of Housing and Local Government, 1950; 1952) are plotted on the map as follows:

A = North West Gravel Region
B = Trent Valley Gravel Region
C = West Midlands Gravel Region
D = West Yorkshire Gravel Region

The Service Areas for Sand and Gravel are as follows:

Area B	Area C
1. Cannock Chase	1. Burton and Derby
2. Shropshire	2. Derby 'Solid'
3. Wolverhampton North	3. Unnamed
4. Birmingham	4. Nottingham
5. Coleshill	5. Unnamed
	6. Unnamed
	7. Leicestershire

The rectangle shows the location of text-fig. 2.

When construction materials have to be provided for such schemes, it is almost certain that they will have to come whenever possible from on-site sources or from the use and extension of existing off-site sources, for the short-term development of new quarries is unlikely (Ministry of Housing and Local Government, 1950; 1952; Staffordshire County Council, 1969).

For owners of existing quarries who may wish to respond to such possibilities, it is necessary to have planning consent for approximately 15 years ahead and to have plans for working a quarry well into the future which include the ability to increase production rapidly. One needs to have geologists involved in a team which prospects reserves and ascertains the quality of resources, whilst a manager makes tentative requests and seeks agreements concerning finance from the board of the company. Piecemeal planning is not viable these days, and proper planning takes several years (Rae, 1976).

Issues involving the restoration of land

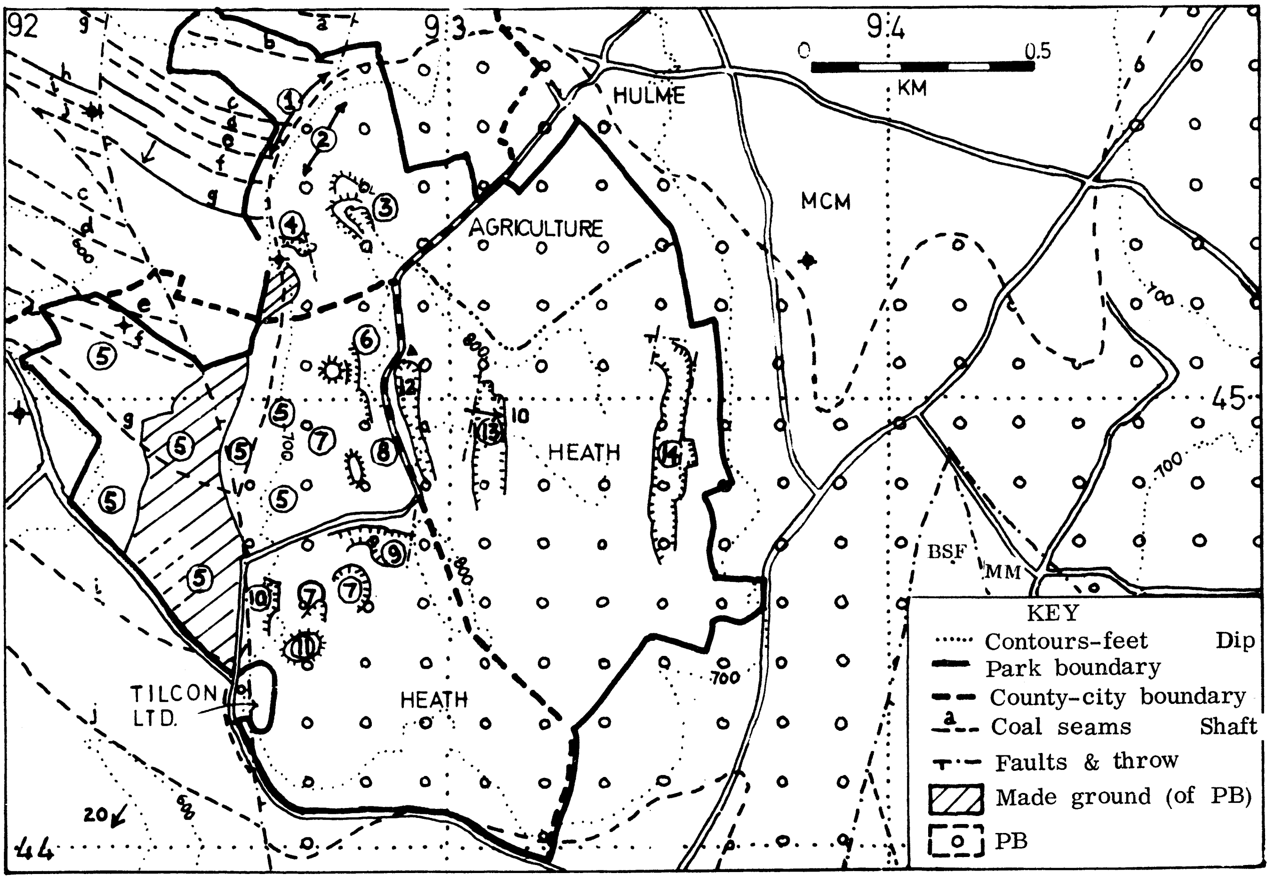
The restoration of worked out areas of pebble beds is notoriously difficult (Beaver, 1968, and pers. communications, 1980). The visual effects, particularly on a skyline, of abandoned quarry faces, piles of gullied and overgrown waste, heaps of graded product and active or abandoned headworks, are increasingly debated. The restoration of quarried-out areas, that is, those which supplied material to the M6 in the north Staffordshire area in the 1960s, is often long overdue, for example, at Lordsley and for much of the Willoughbridge area.

In some areas where restoration has been attempted, for example, at Kingswood Bank and Acton, the result is barely acceptable. Near to Willoughbridge Wells, however, the area near the former spa has been improved very acceptably by the local farmer, Mr. Wright. Often the eventual restoration of the land after quarrying has to be negotiated, partly, if not wholly, from the outset. One consortium in the Peak District which has been seeking permission to work minerals within the Carboniferous Limestone has been asked to place a bond for this purpose prior to starting extraction. In pebble bed quarries, working plans have to include long-term provision of land for disposing of the 20% waste in settlement lagoons, for these are classified as active under the Mines, Quarries and Tips Act and require strong retaining walls. With good planning, existing quarry walls can be used. Good practice involves feeding solids from the direction of the weakest wall so that it is easy to use a dragline to heap material against the wall and so strengthen it. Liquids and slurries should be allowed to run towards the most solid wall and the position of the supply pipe should be altered frequently. New settlement lagoons should be brought into use in the winter months so that the bottom of the lagoon will be sealed by the settling and compaction of argillaceous matter at a time when loss of water is not critical. Clean water should be weired off for re-use throughout the life of the lagoons which are usually drainable after 1-2 years. After they reach reinstatement level, the lagoon areas are regraded and reused, in some cases for agricultural purposes. Careful planning is needed so as not to be caught with lagoons filled to the brim with sediment and affording no possibility of recycling water (Rae, 1976).

The new Park Hall Country Park (text-figs. 2 & 4), sited largely on the pebble beds between Hulme and Weston Coyney (SJ 9345) and visited by the East Midlands Geological Society in April 1979, provides a magnificent example of what can be done, given goodwill, imagination and considerable financial support, to restore to public use a huge area (435 acres) honeycombed by waste heaps, tips, quarries and abandoned headworks. This seventeenth century heathland, resembling that of other areas underlain by pebble beds such as Cannock Chase, was initially cleared for agriculture, but became encroached upon and surrounded by the wasteheaps of the coal mines of the early industrial revolution from adits like Hulme Colliery (SJ 925.455) and larger pits like Adderley Green Colliery (SJ 922.445), Park Hall Colliery (SJ 925.437) and Mossfields Colliery (SJ 915.450). These collieries worked the seams of the Middle Coal Measures between the Mossfield and the Cockshead seams adjacent to, and beneath, the Triassic unconformity (text-fig. 4). The waste heap of the Gainmore pit shaft to the southeast of Willfield High School (SJ 926.453) has been cut through purposely in the present restoration scheme in

Table 1: The relationship between the geological features of the former quarried areas of the Park Hall County Park, Longton, and their adaptation and use as a public amenity. (See text-fig. 4 for the location of the numbered features.)

Location on Fig. 4	Feature of pebble beds and mineral extraction process	Amenity, adaptation and use
1	Smooth steep contours of west facing scarp; sand and gravel succession - mostly sandy.	Toboggan run.
2	Scarred steep contours of scarp.	Badger runs: nature area.
3	Natural rounded knoll at top of scarp.	"Maiden Castle" vantage point.
4.	Sand quarry near base of succession (Facies C, D) restricted in extent by a major fault. Type area for studying lowest part of succession.	"The Quarry" picnic area and site of geological interest for training geologists (bedding, contrasting lithologies, faults, joints, crossbedding, etc.)
5	Old quarries, mostly of gravelly facies, worked in unorganised fashion in the early days and tipped into in an uncontrolled way.	Regraded, covered by excess sand and gravel; for use eventually as a municipal golf course.
6	Length of quarry in Facies A, B, C.	The "Kyber Pass" - part of a principal walkway.
7	Sand and gravel; Facies A, B, some C.	Picnic and kick-about bowl (similar on east side of road).
8	Eminence formed of former quarry walls; Facies A, B.	"Old Man of Hoy" vantage point.
9	Quarries in Facies A, B, C crossed by faults.	The Gulch Car Park; Picnic Hollow.
10	Abandoned headworks and approaches plus former quarry face in faces B and C	Hopper Fort and Rough Hill Car Park.
11	Abandoned mounds of unused product.	The Sand Heap (grassed).
12	Elongate quarries with fault lines controlling abandonment of mining along certain walls.	Amphitheatre: circular wall and 'bandstand' at north end. Sides of quarry smoothed and lowered.
13	North central quarry; west side fault controlled. Type area for main succession. Site of special scientific interest for study of sand and gravelly braided river deposits.	Adventure playground. Site for training geologists.
14	North eastern quarry; fault controlled.	Walk along "Canyon" to pond.



Text-fig. 4: The restoration of abandoned quarries and sand in the area of the Park Hall Country Park, northeast of Longton (see inset on text-fig. 2). Geological boundaries are taken largely from the revision of the six inch (1:10560) sheet Staffordshire XVIII NE publihsed in 1948 and in the case of the pebble beds should be regarded as somewhat approximate especially on the east site of the Park. A key to the coal seams a - j (all in the Middle Coal Measures) is as follows (oldest first):

a - Cockshead	f - Bowling Alley
b - Seven-foot Banbury	g - Ten Feet
c - Stinkers	h - Birches
d - Hard Mine	i - Yard
e - Holly Lane	j - Mossfield

BSF = Bromsgrove Sandstone Formation
MM = Mercia Mudstone Group
MCM = undifferentiated Middle Coal Measures
PB = Pebble Beds

Ringed figures refer to the features of the Country Park which are cited and explained in table 1. The location of these features is taken from maps of the Department of Environmental Services, City of Stoke-upon-Trent.

making a major pathway. The side slopes of the tip are searched by local geology students who collect Carboniferous rocks, minerals and fossils which are otherwise rarely exposed in the Potteries Coalfield today.

In the early days of the Industrial Revolution the pebble bed outcrop was worked mainly for building sandstones of Facies C as well as for small volumes of gravel. Gravel working from the pebble beds was increased considerably in this area between 1939 and 1970, latterly in part to supply material locally whilst the M6 was making great demands upon the resources of the area. Extraction started on natural gravel outcrops to the west of the Hulme Road and, in the absence of planning controls, a vast area of shallow pits was developed. These shallow workings were then abandoned and filled for years with wholly noxious materials (sewage sludge, chemical wastes and general industrial and household rubbish) such that the environment became intolerably smelly, windswept, despoiled and groundwater polluted; and this remained so even until 1975. Extraction from the pebble beds in the 1950s and 1960s progressed downdip to the east across several small fault blocks (text-fig. 4) and to areas east of the Hulme Road, and this required exploration by borehole, the removal of considerable amounts of sandstone overburden and the initiation of numerous extensive elongate quarries aligned north-south, with faces up to 20 m high. Fortunately, however, this took place at a time when planning controls required the erection of screens of woodland, the conifers of which are now (in 1979) quite mature. During the present restoration work, the early waste-filled quarries to the west of the Hulme Road have been largely bulldozed over and other waste heaps re-surfaced with a metre-thick cover of sand and gravel which is to form the basis of a golf course. The large quarries to the east of the road have been imaginatively utilised to provide picturesque, relatively safe 'canyons' which, by means of skilful landscaping, are rendered part of the amenities of the park (table 1; text-fig. 4). Only one quarry (Tilcon Ltd.) is still working and was due to release its land in 1979, but this has not yet happened.

Lest it be thought that restoration of old workings in pebble beds outcrops like these, to something of their natural state is an easy matter, to be applied to every area, it is well to recognise that the administrative problems were great. A major county/city boundary crosses the area, 160 acres belonging to the county and 218 acres to Stoke-on-Trent and some land is still privately owned (text-fig. 4). Fortunately, before the present restoration exercise, Blue Circle Aggregates bought up most of the pits and quarries (378 acres), presumably with commercial activity in mind, but later gave the land to the city, otherwise there would have been problems of multiple ownership to deal with in addition. The reclamation scheme required the setting up of a joint management committee of the county and city councils and a working party of these two bodies plus the Countryside Commission and the Department of the Environment, the last of which eventually provided £646,000 of the total cost of £858,000. The very considerable proportion of the cost borne by the national exchequer is accounted for by the fact that Stoke is part of a Derelict Land Clearance Area.

In 1978 the restoration scheme was awarded first prize in the annual national reclamation awards scheme organised by the Royal Institution of Chartered Surveyors and the Times newspaper. In 1979 the scheme was given a further reclamation award by the Sand and Gravel Association.

The availability and cost of on-site in relation to off-site construction materials

Details have been given previously (Buist & Thompson, 1982) of methods of exploitation of the pebble beds as material for highway construction. For reasons of confidentiality, however, nothing could be discussed there with respect to the planning of the exploitation of these materials for maximum cost-benefit in the Beech to Fulford section of the A564. Estimates for aggregate requirements for motorways and A-class roads show significant differences in amount. For motorways the average value varies from 62,500 tonnes per km (Knill, D.C., 1978, p.168) to 85,000 tonnes per km (Buist, pers. comm.). The corresponding figure for A-class roads is much less at 12,500 tonnes. Transport costs add greatly to the burden of supplying such materials from off-site areas and on-site availability during the construction of the A564 would be very welcome.

Many of the possible lines of the projected roads pass across the pebble bed outcrops for a good deal of their length and many of the proposed lines are of such varied relief that they would require cut and fill operations (see text-fig. 1). In contrast to the practice adopted with the construction of the M6 when most material came from off-site quarries up to 20 km away, the contention here is that much of the materials for the fill, the sub-base and the roadbase, for the concrete for the bridges and paths, etc. of road section 1 could be derived from on-site excavations from the pebble beds at carefully selected places along the projected highway. This would require that some of the machinery, techniques of exploration and exploitation described previously (Buist & Thompson, 1982) be assembled and employed on-site along the line of the road. The duplication of plant at several small sites is expensive and normally avoided (Knill, D.C., 1978, p.169). Temporary assembly of sophisticated plant and machinery for the processing of materials at a series of sites 10 km apart adjacent to a motorway has proved to be feasible and economic in the latest episode of the resurfacing of the M6 between Stafford and Stoke (1978-9).

The author suggests that machinery and plant could first be assembled on-site at a strategic place adjacent to the deep cutting (text-fig. 1) on the eastern part of the projected roadway between Cocknage and Fulford, the line of which lies mostly on pebble beds, so long as the planning is geared to providing water for screening and washing and to constructing cuttings of such width and slope that adequate raw materials are available for continuous processing. The costs of disposing of waste by creating settlement lagoons could probably be taken care of on-site as easily as off-site. The feasibility of such an enterprise needs to be carefully investigated, and the economics may differ at the western and eastern ends of the Fulford-Trentham stretch, for whilst the western end of the area is well supplied by efficient quarries, the eastern part is currently less well served and could benefit from the use of on-site material. For the area east of Fulford (road section 2 of text-fig. 1), the line of the projected routes lies well to south of the pebble beds, on Drift deposits and those of the Mercia Mudstone Group, and on-site materials could not be used. It is unlikely that sufficient on-site materials from section 1 of the highway will be available to furnish the construction materials needed for section 2, hence off-site materials will be required. Planning permission for working old pebble beds quarries south-east of Cheadle is held extensively by Blue Circle Aggregates, whilst other supplies are at Willington (Blue Circle) and Etwall (Redland), both in the Derby 'Solid' Service area (text-fig. 3) and hence less economical because of the distance involved. The companies may seek to open up further (abandoned) quarries in this eastern part of the route (see Staffordshire County Council Gravel Resources Report, 1969).

Comments on current site investigation practices in the pebble bed outcrops of the Sherwood Sandstone Group

Basically the engineering geologist is in a position to advise the planning team led by the Chief Highway Engineer only after he has carried out the following investigations and evaluated their results:

(a) Made a survey of the appropriate geological, sedimentological and engineering-geological literature.

(b) Examined published and unpublished borehole records along the route greater than 15 m deep held by the Institute of Geological Sciences and those less than 15 m deep held by private companies (e.g. civil engineering contractors) and private individuals.

(c) Studied large scale 1 : 10,000 or 1 : 2500 geological maps to determine the extent of the deposits and their outcrops; drawn detailed geological cross-section across those maps to predict the sub-surface stratigraphy.

(d) Consulted the representatives of the quarrying industry on their exploration and production experience in excavating aggregates in the vicinity of the route and their ability to respond to greatly enhanced temporary demand in the vicinity of the resources area.

(e) Consulted town planners on the environmental issues at stake.

(f) Devised plans and costings for geological surveys *en route* and possible drilling and sampling programmes.

(g) Made appropriate investigations of local successions at outcrop and taken samples in order to determine the physical properties of the rocks (density; porosity; permeability; crushing, tensile and shear strengths; grain size distribution; petrography) and their geochemical environment at outcrop and within 30-45 m of the land surface.

Buist & Thompson (1982) commented on the need to improve geological mapping and the logging and description of successions, and acknowledged that site investigations would be necessary to prove a very variable and partly unpredictable succession. Whereas traditional site investigations are quite effective when dealing with sandstone successions of Facies C_2, problems are exacerbated with Facies C_1, B and A. These materials prove difficult to sample in an adequate and representative way when techniques and approaches appropriate to sandstone are applied. The majority of the comments in the previous paper show that many exploration methods are inadequate, and it was suggested that the greater use of trial trenches, down-the-hole photography or the use of an inverted periscope, would best cope with the problem of describing the facies and the succession. What was not mentioned, however, was that many of the problems of site investigation were due to: (i) continuing to use an exploration method because it was not recognised to be inadequate, and (ii) using bad or inadequately supervised drilling practices. Both these matters relate to failures of management, as do problems which relate to demands for extra payments for drilling in situations which can be construed as being beyond the terms of the legal contract. In some cases, programmes were halted because of the extra cost of the technique. What should have been borne in mind in planning is not the cost of one technique, but its cost-benefit contribution to the whole programme. Because of the variability of the lateral and vertical distribution of the pebble beds many pits and boreholes are likely to be needed, but in areas where sands greatly dominate gravels at the bottom and top of the succession, one relatively deep, well-planned, expensive borehole which is likely to give representative and accurate information, may be more cost-effective than twenty seemingly inexpensive shallow ones in terms of predicting the geological and engineering problems of an area.

It is also apparent that there is still a yawning gap, albeit a little narrower than when the M6 was planned 20 years ago, between the outlook, training and experience of the engineer and the geologist. Each still needs to assimilate more of the theory and practice of the other, and this problem is enhanced as knowledge increases so rapidly. In the case of pebble beds the problems of exploring and exploiting the sandstones tend to hide these differences, those of the conglomerates to magnify them. Several geologists and engineers to whom first drafts of the previous paper (Buist & Thompson, 1982) were given for comment complained respectively that the technicalities of both the engineering techniques and the sedimentology were too great and they asked that the account should be simplified, and this was done. On the other hand a relatively youthful former student of the author, having taken a joint honours degree in geology and physics and subsequently having undergone the specialised training of an M. Sc. Engineering Geology course, called for the inclusion of much more detailed sedimentology, a greater discussion of the details of the techniques of site investigation and a whole section on the management skills appropriate to work on areas of the pebble beds. The author believes that both the geological and engineering professions should pay much more attention to the organisation of both the pre-service and in-service training of their personnel in interdisciplinary applied studies.

Acknowledgements

The author is pleased to be able to record his thanks to Professor Emeritus S.H. Beaver (formerly Senior Geological Research Officer of the Ministry of Town and Country Planning, from 1943, and geologist to the Waters Committee from 1946 onwards), Mr. M. Rae, M.B.E. (formerly of Amey Roadstone Ltd.), and Dr. D.S Buist (formerly of the Department of Transport, Midland Road Construction Unit) for useful comments on early drafts of this paper. Thanks are also due to Doreen Thompson for secretarial work.

References

ABERCROMBIE, P. & JACKSON, H. (Eds.) 1949. *North Staffordshire Plan.* Advanced Edition. London; Ministry of Town and Country Planning. 328pp.

BEAVER, S.H. 1949. *Physical Background and Natural Resources.* pp. 73-114 in ABERCROMBIE, P. & JACKSON, H. (Eds.)

BEAVER, S.H. 1968. *The geology of sand and gravel.* London; Sand and Gravel Association. 66pp.

BLACK, G.P. 1978. *Geology in conservation.* Ch. 13, pp. 310-334 in KNILL, J.L. (Ed.)

BUIST, D. & THOMPSON, D.B. 1982. Sedimentology, Engineering Properties and Exploitation of the Pebble Beds in the Sherwood Sandstone Group (?Lower Triassic) of North Staffordshire with particular reference to highway schemes. *Mercian Geol.*, vol. 8, no. 4, pp. 241-268.

DEPARTMENT OF TRANSPORT 1976. *Stoke-Derby Link. 'Your views are needed'.* Leamington Spa; Department of Transport. Midland Road Construction Unit. Broadsheet; no pagination.

KNILL, D.C. 1978. *Aggregates, sand, gravel and constructional stone.* Ch. 8, pp. 166-195, in KNILL, J.L. (Ed.). *Industrial Geology.* Oxford Univ. Press. 344pp.

MINISTRY OF HOUSING AND LOCAL GOVERNMENT 1950. *Report of the Advisory Committee on Sand and Gravel (The Waters Committee), Part 3: Trent Valley; Part 4; West Midlands.* London; HMSO, 81pp.

MINISTRY OF HOUSING AND LOCAL GOVERNMENT 1952. *Report of the Advisory Committee on Sand and Gravel (The Waters Committee), Part 10; North-West Gravel Region.* London; HMSO, 38pp.

RAE, R.M. 1976. (*Unpublished address to members of the Sand and Gravel Association*) Shrewsbury; Amey Roadstone Ltd., 7pp. (available from the present author upon request).

STAFFORDSHIRE COUNTY COUNCIL 1969. *Town and Country Planning Act 1962. County Development Review. Sand and Gravel; Report of Survey.* Stafford; Staffordshire County Council, 49pp.

STEEL, R.J. & THOMPSON, D.B. (In preparation.) Structure and texture in Triassic (?Scythian) braided stream conglomerates in the Pebble Beds of the Sherwood Sandstone Group in North Staffordshire, England.

VAIL, P.R., MITCHUM, Jr. R.M., TODD, R.G., WIDMIER, J.R., THOMPSON, S., SANGREE, J.B., BUBB, J.N. & HATFIELD, W.G. 1977. Seismic stratigraphy and global changes of sea level in PAYTON, C.E. (Ed.); Seismic stratigraphy, Application to Hydrocarbon Exploration. *Am. Assoc. Pet. Geol. Mem.*, vol. 26, pp. 42-212.

WARRINGTON, G., AUDLEY-CHARLES, M.G. ELLIOTT, R.E., EVANS, W.B., IVIMEY-COOK, H.C., KENT, P., ROBINSON, P.L., SHOTTON, F.W. & TAYLOR, F.M. 1980. A Correlation of Triassic rocks in the British Isles. *Geol. Soc. Lond.*, *Special Report*, No.13, 78pp.

WILLS, L.J. 1970. The Triassic succession in the Central Midlands in its regional setting. *Q. Jl. geol. Soc. Lond.*, vol.126, pp.225-85.

WILLS, L.J. 1976. The Trias of Worcestershire and Warwickshire. *Rep. Inst. Geol. Sci.*, No.76/2, 221pp.

ZIEGLER, P.A. 1981. *Evolution of Sedimentary Basins in North-West Europe.* pp.3-42 in ILLING, L.V. & HOBSON, G.D. *Petroleum Geology of the Continental Shelf of Northwest Europe.* London, Heyden & Son for the Institute of Petroleum, 521pp.

D.B. Thompson, B.A., M.Sc., F.G.S.,
Department of Education,
University of Keele,
Staffs. ST 5 5BG.

Postscript:

As this paper and the previous one (Buist & Thompson, 1982), have been prepared for publication the following have been published by the Institute of Geological Sciences (UK).

PIPER, D.P. 1981. The conglomerate resources of the Sherwood Sandstone Group of the country east of Stoke-on-Trent, Staffordshire. Resources sheet SJ94. *Mineral Assessment Report*, No.91, Institute of Geological Sciences, HMSO, London.

ROGERS, P.J., PIPER, D.P., & CHARSLEY, T.J. 1981. The conglomerates of the Sherwood Sandstone Group of the country around Cheadle, Staffordshire. Resources sheet SK04. *Mineral Assessment Report*, No.57. Institute of Geological Sciences, HMSO, London.