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Procedure for the assessment of the conglomerate resources of the Sherwood Sandstone Group

D. P. Piper and P. J. Rogers

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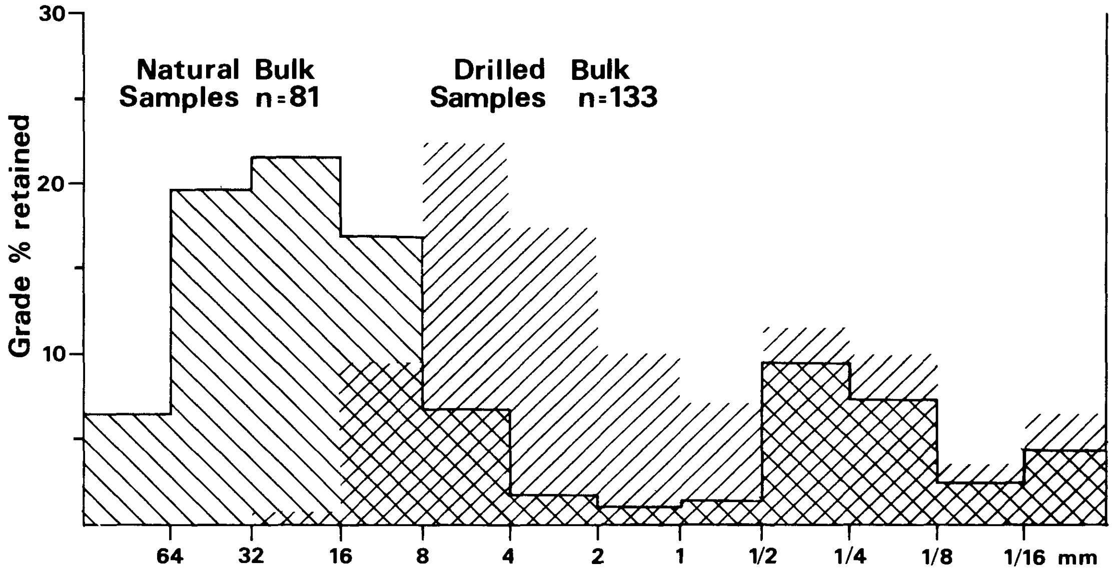
Page 6, Figure 4, top right

For **Natural Bulk Samples n=133** *substitute* **Drilled Bulk Samples n=133**



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The first twelve reports on the assessment of British mineral resources appeared in the Report series of the Institute of Geological Sciences as a subseries. Report 13 and subsequent reports appear as Mineral Assessment Reports of the Institute.

Details of published reports appear at the end of this Report.

Any enquiries concerning this report may be addressed to Head, Industrial Minerals Assessment Unit, Institute of Geological Sciences, Keyworth, Nottingham NG12 5GG.

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Procedure for the assessment of the conglomerate resources of the Sherwood Sandstone Group

D. P. Piper and P. J. Rogers

SUMMARY

Field and laboratory studies to investigate the regional assessment of the conglomerate resources of the Sherwood Sandstone Group (formerly the Bunter Pebble Beds) are described and illustrated. They have included trials of air-flush hammer drilling, the evaluation of the grain-size distribution of comminuted bulk samples taken from boreholes against natural samples and down-the-hole photography. Limiting arbitrary physical criteria are proposed. The integration and presentation of geological and assessment data by means of a resource map and report are outlined.

Bibliographical reference

Piper, D. P. and Rogers, P. J. 1980. Procedure for the assessment of the conglomerate resources of the Sherwood Sandstone Group. *Miner. Assess. Rep. Inst. Geol. Sci.*, No. 56.

Authors

D. P. Piper, BA and P. J. Rogers, BSc, PhD, MIMM
Institute of Geological Sciences,
Keyworth, Nottingham NG12 5GG.

INTRODUCTION

In recent years it has become apparent that more detailed information about the quality, quantity and distribution of bulk mineral deposits is required. Such information will add significantly to the factual background against which planning policies can be decided (Archer, 1969; Thurrell, 1971; Harris and others, 1974).

Since 1968 the Industrial Minerals Assessment Unit of the Institute has been conducting systematic surveys of the aggregate resources of glacial and fluvial sand and gravel deposits. In 1975 a feasibility study was initiated into the assessment of potentially workable aggregate resources within the conglomeratic members of the Sherwood Sandstone Group, formerly the Bunter Pebble Beds. This study, now completed, has established the methods and procedures required to provide suitable data for conglomerate resource assessments of these rocks. A map and report of the study area (1:25 000 sheet SK 04, see Figure 1) is in press (Rogers and others, *in press*) and will be published in the Mineral Assessment Report series.

The assessment of the conglomerate resources of Sher wood Sandstone Group rocks may be divided into four elements: planning, field and laboratory programmes and the preparation of results for publication.

PLANNING

Before field investigations begin, the following preliminary tasks should be completed:

- i Literature survey.
- ii Examination of unpublished borehole records held in the national archive at the Institute and data from civil engineering investigations, etc.
- iii Consultation with the quarrying industry on geological and production experience in excavating aggregates in and near the area of the resource survey, preferred prospecting procedures and the assembly of available prospecting information, including that relating to worked-out ground.
- iv Formulation of appropriate lithostratigraphic mapping, drilling and sampling programmes.

FIELD PROGRAMME

FIELD MAPPING

Detailed lithostratigraphic mapping at the scale of 1:10 000 is an essential prerequisite for a resource assessment of the Sherwood Sandstone Group. Mapping at this scale can prove the extent of the laterally discontinuous conglomerate bodies (the principal resource) and identify the major faults. Where possible, a generalised statigraphic column is constructed which may, as in the present study area, identify conglomerate bodies at different stratigraphical levels within the succession.

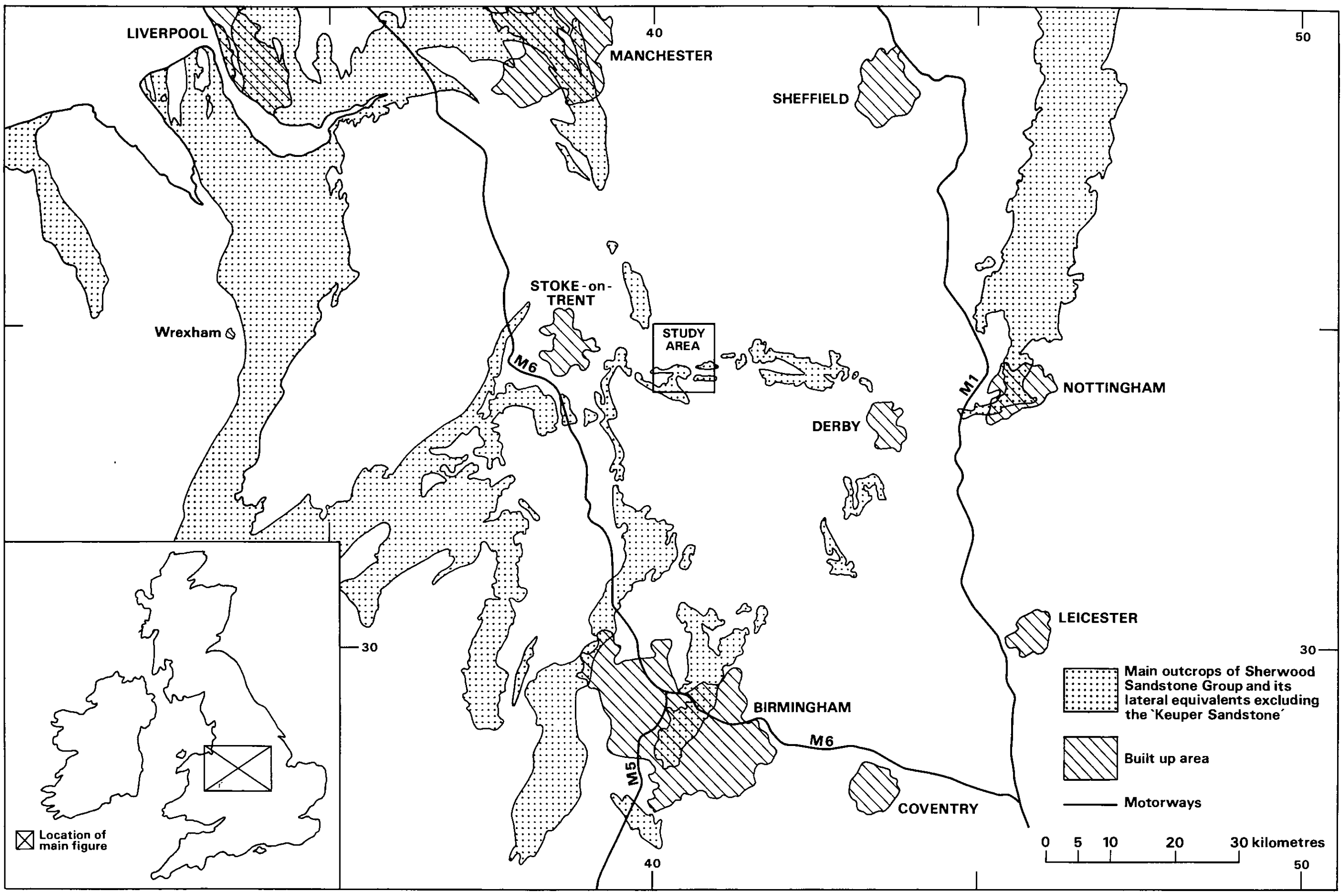


Figure 1 Locality map

The geological map is used to define the areas for assessment and provides guidance for the selection of borehole sites. The map also provides the geological base for the published resource map and the accompanying report.

SAMPLING

For resource assessment purposes sufficient samples are required from each data point to determine the thickness and quality of the aggregate, while the data points (usually boreholes) should be so spaced that the extent and continuity of the resource can be established. Ideally an optimum sampling interval should, therefore, be established for each survey area.

Quarry and natural sections, while providing valuable information on the natural grading characteristics of the deposits, rarely give complete stratigraphic coverage and boreholes must be sunk to determine the thickness and extent of the resource.

BOREHOLES

For the purposes of this survey, which was intended to investigate the resources to 60 m, boreholes of 225-mm (9-in) diameter were drilled uncased by a contractor to 65 m: the margin of 5 m was required to accommodate debris washed from the sides of the holes during preparations for photographic logging.

After a number of drilling contractors and equipment manufacturers had been consulted, a truck-mounted rotary-percussion rig fitted with an air-flush down-the-hole hammer and button bit was chosen as the most suitable for assessment purposes. Test holes drilled in a disused quarry demonstrated that the system had a penetration rate and manoeuvrability compatible with the requirements of a reconnaissance survey of resources. The recovery of an adequate sample relies on the maintenance of a sufficient flow of exhaust compressed air, and for this reason paired compressors each supplying 600 cubic feet per minute (17 m^3/min) at 100 p.s.i. (7 kg/cm^2) were required to maintain sufficient pressure to depths of 65 m. Recovery was found to be much improved when drilling beneath the water table.

Borehole samples

Samples representing each metre drilled were collected with the aid of a deflector screen, and coned and quartered on site to produce samples for grading analysis of 5 to 10 kg (rarely 15 kg in coarse conglomerates).

The drilling method adopted for this survey affected the samples in two ways: the gravel fraction of the sample was broken up by the action of the air-hammer and could only be recovered as chippings; and the samples collected from beneath the water table showed some loss of fines, presumably in suspension with uncollected waste water. Each sample was described in the field in terms of pebble size, rounding, shape and composition; matrix size, shape and composition. The degree of comminution of the gravel fraction was estimated.

Photographic logging

As the bulk samples are not completely representative of the material drilled, photographic logging was carried out above the water table to check the reliability of the bulk samples and to provide information about the original size of the pebbles.

The logging system uses a Hasselblad 500EL/M camera body fitted with a motor drive unit, a 70-exposure cassette holder, Zeiss 80-mm Planar and No. 1 supplementary

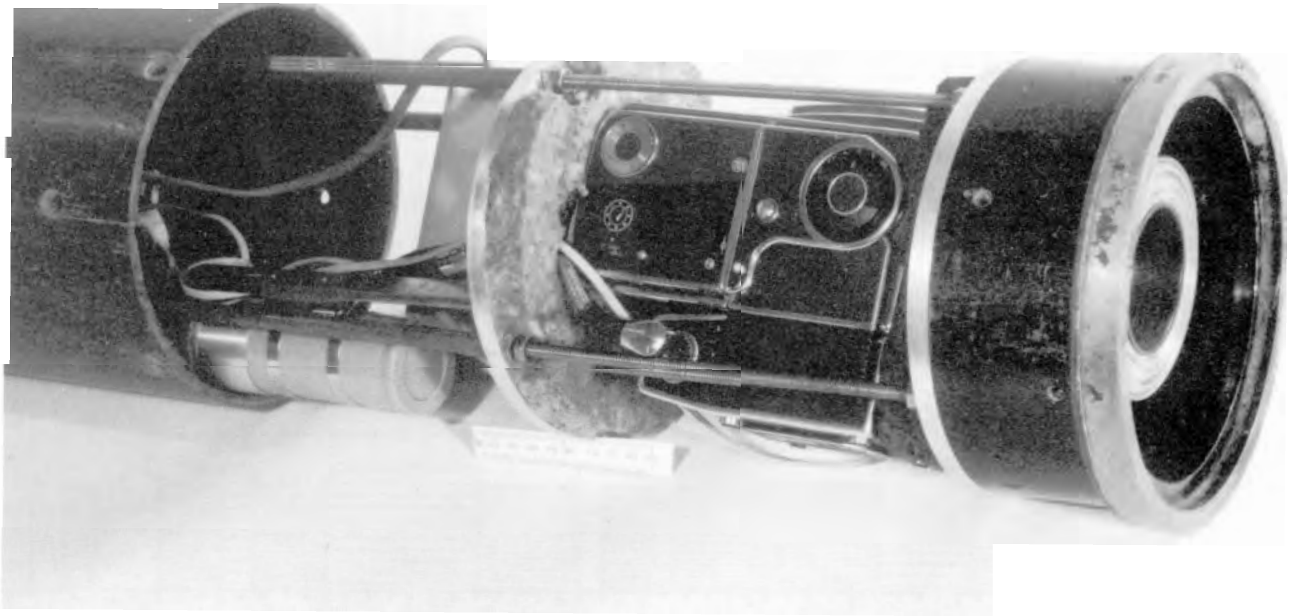


Plate 1 The photographic logging system developed for use in dry boreholes

AA 00 AA 11 1234 5678 **Block A**

Windmill Drive, Swacking Cuckoo

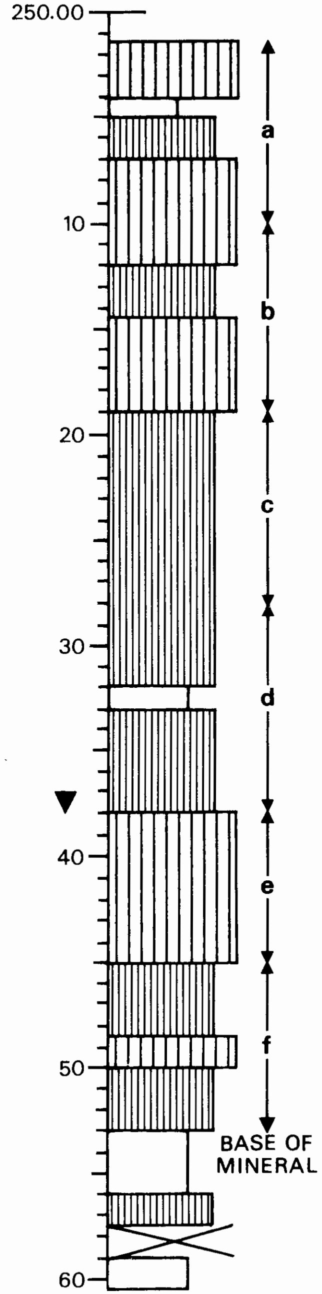
Surface level +250.00 m
Rest water level +212.0 m
Down-the-hole hammer, with air flush
225-mm diameter
November 1979

Overburden 1.5 m
Mineral 51.5 m

Grading

Mineral sample	Depth below surface (m)	*percentages* Fines $-\frac{1}{16}$	Sand $+\frac{1}{16}-\frac{1}{2}$	Gravel $+\frac{1}{2}$
a	1.5–10.0	12	53	35
b	10.0–19.0	15	72	13*
c	19.0–28.0	12	34	54
d	28.0–38.0	18	36	46
e	38.0–45.0†	10	16	74
f	45.0–53.0†	15	24	61
Mean for deposit	1.5–53.0	14	40	46

* Samples unreliable
† Samples taken below the water table with some fines loss



Log

Soil: sandy, pebbly
Conglomerate
Gravel: coarse and fine, maximum diameter 40 mm, well rounded quartzite and vein quartz
Sand: medium and coarse, well rounded to subangular quartz
'Clayey' Sandstone with Pebbles
'Clayey' Sandy Conglomerate
Gravel: coarse and fine, maximum diameter 33 mm, quartzite and vein quartz
Sand: medium and fine, subrounded to well rounded quartz
'Clayey' Conglomerate
Gravel: coarse and fine, maximum diameter 30 mm, quartzite and vein quartz
Sand: fine and medium, subangular to well rounded quartz with mica
Fines: silty clay, especially 7.0–10.
'Clayey' Sandy Conglomerate
Gravel: fine,maximum diameter 10 mm, well rounded quartzite and vein quartz
Sand: fine and medium, angular to subrounded quartz with mica
Fines: clayey silt; quartz and mica observed
'Clayey' Conglomerate
Gravel: fine, maximum diameter 5 mm, very well rounded quartzite and vein quartz
Sand: fine and medium, subangular to subrounded quartz
Fines: clayey silt
'Clayey' Sandy Conglomerate
Gravel: fine,maximum diameter 6 mm, coarser at top, well rounded quartzite and vein quartz
Sand: medium and coarse with fine, subangular to well rounded quartz with mica
Fines: clayey micaceous silt
Cementation: deposit very loose

'Clayey' Pebbly Sandstone
'Clayey' Sandy Conglomerate
Gravel: fine, maximum diameter 5 mm, well rounded quartzite and vein quartz
Sand: medium and fine, subangular to well rounded quartz
Fines: silty clay

Conglomerate
Gravel: fine and coarse, maximum diameter 20 mm, well rounded quartzite and vein quartz
Sand: medium and coarse, subangular to well rounded quartz
Fines: red-brown silty clay, especially at 41.0–43.0

'Clayey' Sandy Conglomerate
Gravel: fine, maximum diameter 8 mm, well rounded quartzite and vein quartz
Sand: fine and medium, subangular to well rounded quartz
'Clayey' Conglomerate
Gravel: fine,well rounded
Sand: medium and coarse, very well rounded quartz
Fines: red-brown silty clay
'Clayey' Sandy Conglomerate
Gravel: fine, maximum diameter 7 mm, well rounded quartzite and vein quartz
Sand: medium and fine, well rounded quartz
'Clayey' Pebbly Sandstone
'Clayey' Sandy Conglomerate
Gravel: fine, maximum diameter 4 mm, well rounded quartzite and vein quartz
Sand: medium and coarse, subrounded to well rounded quartz
No data
'Clayey' Pebbly Sandstone

Figure 2 An example of a written and graphic log

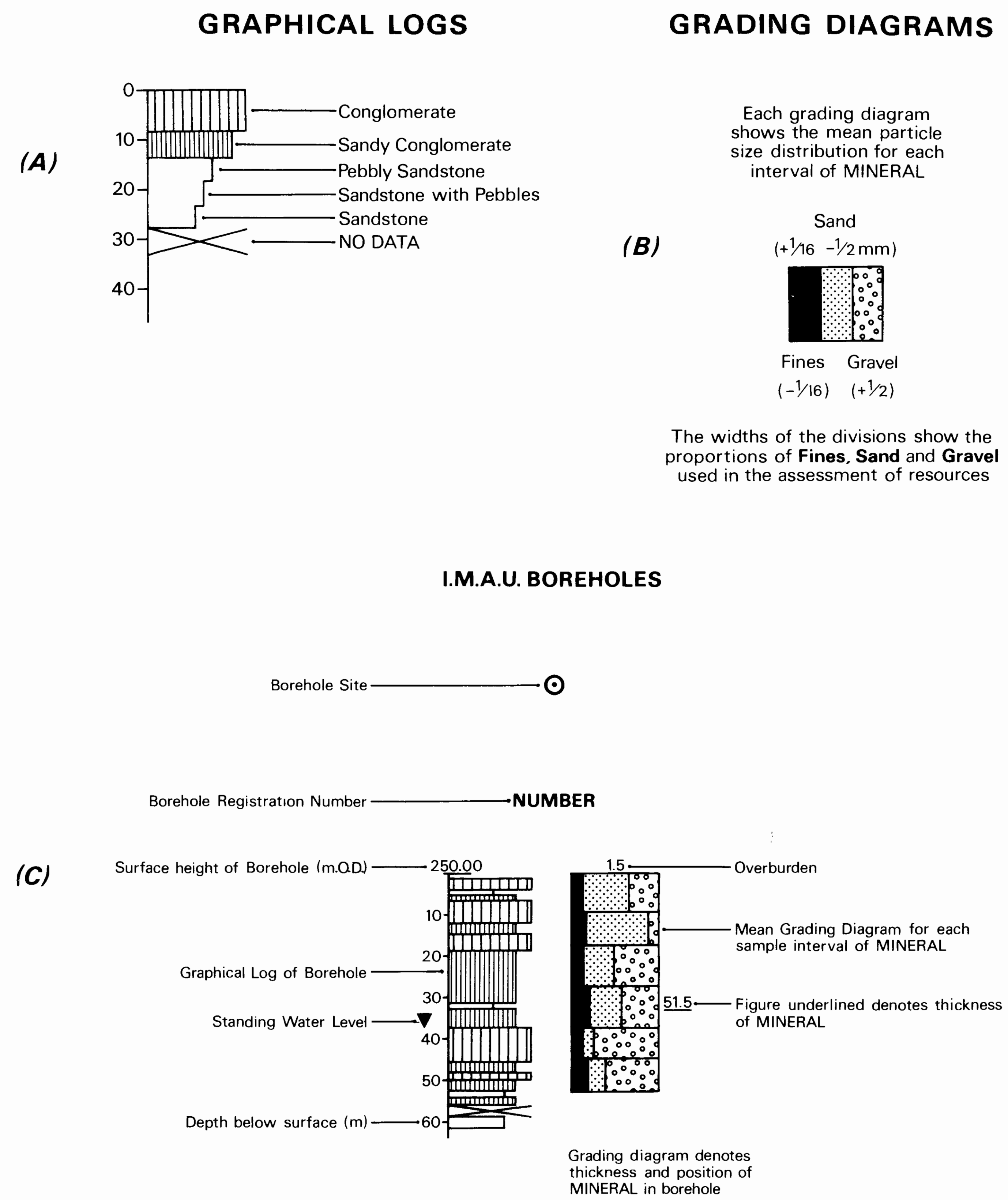
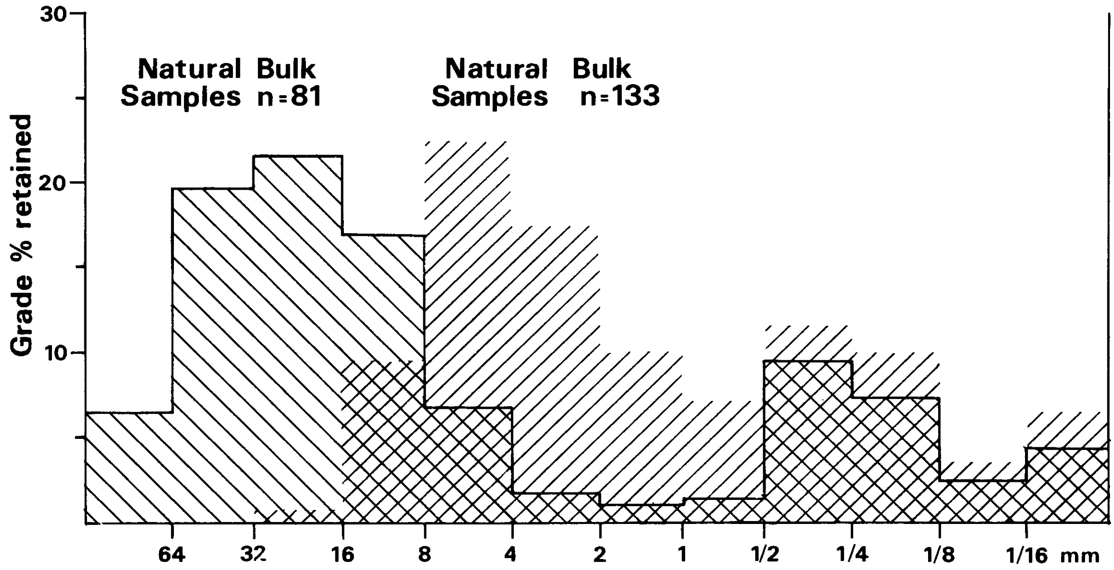


Figure 3 Borehole tablet and explanation of symbols from a resource assessment map



Grade mm	Natural Bulk Samples: Grade % retained	Natural Bulk Samples: Cumulative % retained	Drilled Bulk Samples: Grade % retained	Drilled Bulk Samples: Cumulative % retained
+64	6.67	6.67	0.04	0.04
+32	19.73	26.40	0.02	0.06
+16	21.60	48.00	0.90	0.96
+8	17.00	65.00	9.64	10.60
+4	6.70	71.70	22.55	33.15
+2	1.90	73.60	17.50	50.65
+1	1.10	74.70	10.12	60.77
+1/2	1.50	76.20	7.30	68.07
+1/4	9.60	85.80	11.64	79.71
+1/8	7.40	93.20	10.07	89.78
+1/16	2.30	95.50	3.62	93.40
-1/16	4.50		6.60	

Figure 4 Mean grading results of 81 natural and 133 drilled bulk samples of conglomerate from the Sherwood Sandstone Group

lenses. Light is provided by a Minicam electronic ring-flash. The camera is powered and controlled from the surface, and up to 70 exposures can be taken before the camera must be retrieved. Each exposure gives an axial view of a 0.5-m section of the borehole 0.4 m in front of the camera housing. Ektachrome 72-mm colour transparency film has been used successfully.

Plate 1 shows the camera and accessories mounted in the protective housing designed by the authors in consultation with Mr K. E. Thornton of the Institute's Photographic Department at Leeds. The ring flash can be seen below the camera within the heavy steel base ring. Mounted on the plate above the camera are the mains convertor and accumulator for the ring flash unit. When in operation the camera is protected by lightweight PVC tubing (visible on the left) which fits over the module and is screwed down to the base ring. The housing is completed by a heavy steel top plate which is secured by butterfly nuts onto the four long studs visible in the photograph. The module is lowered by winch on a steel cable with the flash unit cable and the shutter release cable payed out from ancillary drums. The system has an overall length of one metre with an outside diameter of 195 mm and weighs approximately 25 kg. It is easy to transport and assemble as well as robust, reliable and simple to use. The system may be made watertight by the addition of a glass plate into the base ring but this refinement was not used during this study because good results were precluded by the murky water.

Television logging

Closed-circuit television logging was carried out in conjunction with the Institute's Hydrogeology Unit. A 100-mm-diameter camera preceded by a shielded light source was used to give an axial view of the borehole. The pictures were monitored on site and recorded on videotape for later examination in the laboratory. The camera was controlled from the surface, and power was provided by a mains generator.

In air, the black and white television picture is inferior to still photographs because it lacks resolution and contrast. However, below the water table television provided better results, especially in murky water. The low picture quality and the problems of picture distortion caused by the 'pulsing' of the generator made the videotapes difficult to interpret in the laboratory. With the general improvement in sample recovery below the water table, it is thought that television work will only be required for future surveys where effective sampling has failed.

Preparation of borehole logs

For publication purposes, the borehole logs will be shown graphically on a resource map and in an appendix to the accompanying report. The logs represent the principal data on which the statistical assessment of resources is based and are compiled from the field log, bulk sample grading results and photographic and television logging work.

The graphical logs are drawn to show the distribution of the different lithologies within the borehole. Each lithology is represented by a rectangular bar the height of which is proportional to the thickness of the beds while its width reflects the description of the deposit within the proposed scheme of descriptive categories (Figure 5). Conglomeratic lithologies have wider bars than sandy lithologies, and Conglomerates and Sandy Conglomerates are further emphasised by the use of ruled ornaments; sandier deposits are not ornamented (Figure 3a). For cartographic reasons the 'clay' content (see p. 9) is omitted.

In the report the graphical log will be accompanied by an abbreviated written log alongside which lettered arrows will show the series of units into which the total thickness of mineral is divided. Mean grading information for each of these sample intervals will appear in tabular form with the site reference data for the borehole (Figure 2).

On the resource map the graphical log will be accompanied by grading boxes (Figure 3b) showing the mean grading of each mineral unit. An example of a borehole tablet and the explanation of the symbols used appears in Figure 3c.

Borehole information is being stored in a standard format on computer files and many of the basic statistical operations have been performed by computer.

NATURAL AND QUARRY SECTIONS

Natural exposures and quarry sections were measured and sampled to provide details of the lithologies, bed thicknesses and sedimentary structures, and the total thickness of the mineral present was estimated. Sections are rarely complete or readily accessible and the information gained is not generally as useful as borehole data. Grading and pebble count results for samples collected from the natural and quarry sections were used as controls for the analysis of the comminuted borehole samples (see below).

SPACING OF THE SAMPLE POINTS

A small sampling interval was available for experimental use during the feasibility study: specially drilled IMAU boreholes were complemented by a large number of other borehole records and quarry sections. It seems unlikely that such a high density of data points will be achieved in a future regional assessment. Because of the financial restraints on a publicly funded resource investigation, the maximum sampling interval compatible with producing useful results must be established. This has been done by comparing the results for the total data set with the results from various subsets of the total data, selected by using sample grids of various sizes. Results indicate that a data point spacing of one per 4 km^2 would provide sufficient data. That is, 25 points would be required to cover the area of one 1:25 000 sheet (100 km^2). It is estimated that as many as half of these points might be provided by natural and quarry sections and by pre-existing boreholes so that typically, perhaps no more than 12 or 13 specially commissioned boreholes might be required to complete the sampling grid.

LABORATORY PROGRAMME

ANALYSIS OF SAMPLES

The bulk samples collected from sections and boreholes during the field programme were commercially graded according to B.S. 1377 (1967) and the results checked in the Institute's own laboratories. The results provide the principal quantitative data on the grain-size of the deposit and allow the samples to be classified into the various descriptive categories used for the borehole log.

Pebble counts were performed on natural bulk samples to identify the proportions of the principal pebble lithologies, particularly the deleterious material. If

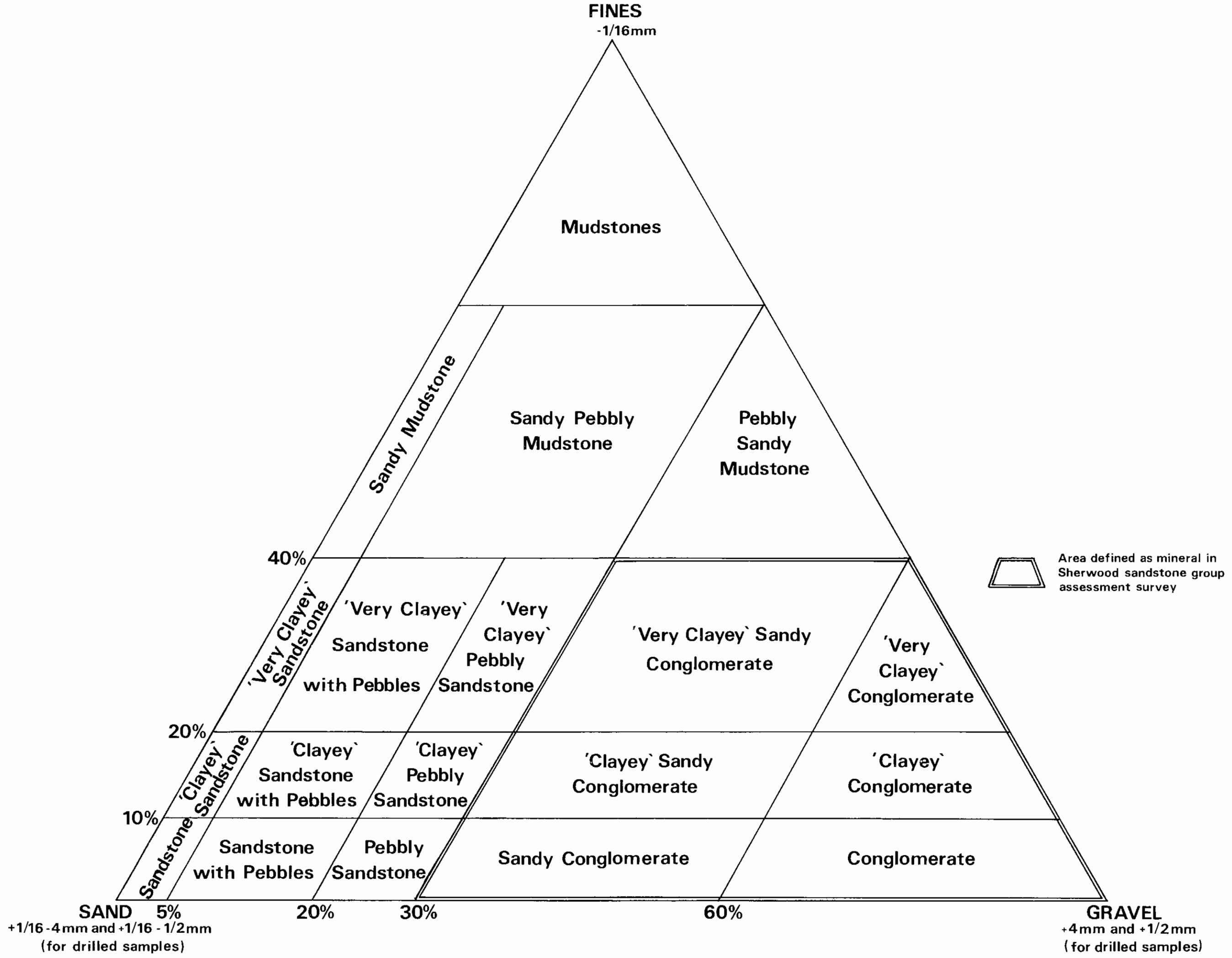


Figure 5 Scheme of descriptive categories used in the classification of samples of the Sherwood Sandstone Group

required, petrographical thin sections can be taken to help identify pebbles of uncertain mineralogy. Only a small number of pebble counts were performed on samples which had been comminuted by the drilling process because it proved impractical to count the smallest grades of chippings which were recovered. Because less durable lithologies were preferentially destroyed by the action of the drill bit the results were not thought to be as accurate as those from pebble counts carried out on natural and quarry section samples.

CLASSIFICATION AND DESCRIPTION OF SAMPLES

Grading results for natural bulk samples illustrate the bimodality of the conglomerates found in the Sherwood Sandstone Group, with gravel and sand grade modes at +16 and +0.25 mm respectively. These modes are separated by an interval (+0.5 to –4 mm) represented by less than 8% of the total sample weight while 71.7% by weight of the main grading of the natural samples has a grain-size greater than 4.0 mm (see Figure 4).

The mean grading of the drilled bulk samples is similarly bimodal but the position of the modes is altered by the action of the down-the-hole-hammer which breaks up the coarse particles of gravel. The gravel grade mode is reduced from +16 mm to +4 mm, and the +0.5 –4.0 mm interval is increased from a mean of 4.5% by weight for the natural samples to 34.9% by weight for the drilled samples, while only 33.2% by weight has a grain-size greater than 4.0 mm. The position of the sand grade mode remains at 0.25 mm but it will be noted that all the sand grades are somewhat increased in the mean grading of the drilled bulk samples.

A scheme of descriptive categories which has a gravel/sand boundary at 4 mm cannot be applied directly to drilled bulk samples of conglomerate in which the +4 mm fraction has been artificially reduced by a substantial amount. Experience shows that by lowering the gravel/sand boundary for the drilled bulk samples from 4.0 mm to 0.5 mm the effect of the comminution on the sample classification is largely overcome. Drilled bulk samples classified in this manner give percentage readings for gravel and sand which closely approximate to those of the natural bulk samples with the gravel/sand boundary at 4.0 mm.

The scheme of descriptive categories into which the natural and drilled bulk samples are classified is shown in Figure 5. It differs from the scheme adopted by IMAU for sand and gravel assessments (Nickless, 1971) in that gravel is regarded as the sole aggregate resource rather than sand and gravel taken together; sand is regarded largely as waste in most extractive operations in the Sherwood Sandstone Group. Thus the field boundaries along the sand–gravel axis are not drawn with regard to the sand:gravel ratio but along lines of absolute percentage of gravel. The field boundaries have been constructed from Folk (1954), available commercial schemes and empirical work by the authors. The scheme retains the 'clayey' and 'very clayey' prefixes of the standard IMAU scheme.

DEFINITION OF MINERAL

The statistical assessment of the conglomerate resources of the Sherwood Sandstone Group is based on that part of the deposit which is defined as potentially workable and called mineral.

The definition of mineral used in sand and gravel assessment reports (Nickless, 1971) is inappropriate to the deposits of the Sherwood Sandstone Group because it does not take account of the different stratigraphical and structural setting, differences in lithology and the dissimilarity in extraction aims and methods.

Accordingly for the Sherwood Sandstone Group the following criteria are proposed for the definition of mineral:

i The deposit should average at least 5 m in thickness.
ii The ratio of overburden to conglomerate should be no more than 1:2.
iii The proportion of gravel (material greater than 4 mm) should be greater than 30% by weight.
iv The proportion of 'clay' (material passing 1/16 mm) should not exceed 40% by weight.
v The deposit must lie within about 60 m of the surface, this being taken as the likely maximum working depth under most circumstances. It follows from the application of the second and fifth criteria that boreholes are drilled no deeper than 20 m if no gravel has been proved.

As far as possible the conglomerates which were proved in the boreholes and which satisfy the definition of mineral are correlated with the conglomeratic members of the Sherwood Sandstone Group identified at outcrop during the preliminary mapping survey: care is taken to sink boreholes where overburden is not expected to exceed 20 metres. The predominantly sandy formations of the Group may contain thin conglomeratic lenses suitable for use as aggregate but the exclusion of these lenses from the assessment calculations does not significantly affect the magnitude of the estimates of the resource because they contain relatively little material. Such formations are included, therefore, in the overburden where they overlie the conglomerate members.

Currently, problems of wet working and planning restrictions to preserve this important aquifer have confined commercial extraction to those parts of the Sherwood Sandstone Group lying above the water table. This assessment of resources is not so confined and attempts are made to bottom the conglomerate sequence whenever possible.

STATISTICAL ASSESSMENT OF RESOURCE DATA

For assessment purposes, the Sherwood Sandstone Group is divided into a number of resource blocks each having a sufficient quantity of data points to allow a statistical analysis to be carried out. As far as possible, block boundaries are defined by geological boundaries, often major faults, so that they enclose geologically similar occurences of mineral.

An arbitrary size of 10 km^2 has been adopted for sand and gravel surveys with resource blocks based on a sampling interval of about one sample point in each square kilometre. The wider spacing used for assessments of the Sherwood Sandstone Group may require the adoption of larger resource blocks to include sufficient data for a meaningful statistical assessment to be made.

The volume of mineral within each block is calculated by simple methods consistent with the amount and density of data provided by the survey. It is calculated as the product of the two variables, the sampled area and the mean thickness of mineral calculated from the individual thicknesses at the sample points. Conventional symmetrical confidence limits are calculated for the 95% probability level: that is, there is a 5% or one in twenty chance of a result falling outside the stated limits. The statistical method is identical to that published in previous resource assessments in the Mineral Assessment Report series and is included here as Appendix A.

The result for each block will be shown in a table in the report together with area and volume calculations for overburden and for mineral already extracted. No account is taken of factors such as roads, villages and high agricultural or landscape values which might stand in the way of conglomerate being exploited. Urban areas are excluded from the survey at the planning stage.

PREPARATION OF RESULTS FOR PUBLICATION

The results of the survey and resource assessment, in the form of a map and an accompanying report, are to be published in the Mineral Assessment Report series of the Institute.

RESOURCE MAP

The map of the study area, based on the Ordnance Survey 1:25 000 Outline Edition, will be similar to other IMAU assessment maps with lettered resource blocks and borehole tablets portraying IMAU borehole data (see Figure 3). Other public record boreholes are to be similarly displayed but generally they lack the accompanying grading data. The map will show up to six categories of deposit (listed below) each distinctively coloured. As far as possible, the boundaries between the categories will be drawn along geological boundaries so that they correspond to a large degree with the lithostratigraphical units recognised during the mapping of the area. The following categories are proposed for the study area:

i Exposed mineral, generally thicker than 25 m thick
ii Mineral, generally greater than 25 m thick beneath overburden
iii Exposed mineral, generally less than 25 m thick
iv Mineral, generally less than 25 m thick beneath overburden
v Exposed Sherwood Sandstone Group rocks generally barren
vi Rocks other than the Sherwood Sandstone Group

It is considered that dividing the mineral into units greater than and less than 25 m in thickness is geologically valid and useful in the assessment of the resources of the study area; future assessments, however, might not require such a distinction or might require different thickness values to be used.

The resource map is accompanied by horizontal sections which illustrate the relationships of the mapped units at depth while a generalised vertical section shows the thickness of the beds and their stratigraphical correlations. The symbols and conventions used are explained in a key.

In view of the complex geology of the study area only those geological lines relating to the assessment of the conglomerate resource are shown on the resource map; a conventional geological map has been prepared at the same scale to appear alongside it.

REPORT

The resource map is an integral part of the report in which a synopsis of the geology is followed by detailed descriptions of the mineral-bearing ground in each resource block. Grading analysis and pebble-count data are represented in tabular form as are the statistical results for each block. Detailed written and graphical logs of IMAU boreholes (see Figure 2) are included as an appendix.

ACKNOWLEDGEMENTS

The authors are grateful to their colleagues in the Institute for valuable discussion and in particular to Mr J. H. Hull and Mr T. J. Charsley for their continued advice and support. Thanks are also due to the staff of the Institute from the Computer, Hydrogeology and Petrology units, and the Photographic Department, all of whom helped with various aspects of the work. The ready collaboration of members of the quarrying and drilling industries has proved invaluable and is much appreciated.

APPENDIX A

STATISTICAL PROCEDURE

The simple methods used in the calculations are consistent with the amount of data provided by the survey. Conventional symmetrical confidence limits are calculated for the 95 per cent probability level, that is, there is a 5 per cent or one in twenty chance of a result falling outside the stated limits.

The volume estimate (V) for the mineral in a given block is the product of the two variables, the sampled areas (A) and the mean thickness ($\bar{\ell}_m$) calculated from the individual thicknesses at the sample points. the standard deviations for these variables are related such that

$$S_V = \sqrt{(S_A^2 + S_{\ell m}^2)} \quad . \qquad [1]$$

The above relationship may be transposed such that

$$S_V = S_{\bar{\ell}_m} \sqrt{(1 + S_A^2/S_{\bar{\ell}_m}^2)} \quad . \qquad [2]$$

From this it can be seen that as $S_A^2/S_{\bar{\ell}_m}^2$ tends to 0, S_V tends to $S_{\bar{\ell}_m}$.

If, therefore, the standard deviation for area is small with respect to that for mean thickness, the standard deviation for volume approximates to that for mean thickness.

Given that the number of approximately evenly spaced sample points in the sampled area is n with mineral thickness measurements $\ell_{m_1}, \ell_{m_2}, \ldots \ell_{m_n}$, then the best estimate of mean thickness, $\bar{\ell}_m$, is given by

$$\Sigma(\ell_{m_1} + \ell_{m_2} \ldots \ell_{m_n})/n \quad .$$

For groups of closely spaced boreholes a discretionary weighting factor may be applied to avoid bias (see note on weighting below). The standard deviation for mean thickness $S_{\bar{\ell}_m}$, expressed as a proportion of the mean thickness, is given by

$$S_{\bar{\ell}_m} = (1/\bar{\ell}_m)\sqrt{[\Sigma(\ell_m - \bar{\ell}_m)^2/(n-1)]}$$

where ℓ_m is any value in the series ℓ_{m_1} to ℓ_{m_n} .

The sampled area in each resource block is coloured brown on the map. Wherever possible, calculations relate to the mineral within mapped geological boundaries (which may not necessarily correspond to the limits of deposit). Where the area is not defined by a mapped boundary, that is, where the boundary is inferred, a distinctive symbol is used. Experience suggests that the errors in determining area are small relative to those in thickness. The relationship $S_A/S_{\bar{\ell}_m} \leq 1/3$ is assumed in all cases. It follows from equation [2] that

$$S_{\bar{\ell}_m} \leq S_V \leq 1.05\, S_{\bar{\ell}_m} \quad . \qquad [3]$$

The limits on the estimate of mean thickness of mineral, $L_{\bar{\ell}_m}$, may be expressed in absolute units $\pm\ (t/\sqrt{n}) \times S_{\bar{\ell}_m}$ or as a percentage
$\pm\ (t/\sqrt{n}) \times S_{\bar{\ell}_m} \times (100/\bar{\ell}_m)$ per cent, where t is Student's t at the 95 per cent probability level for $(n-1)$ degrees of freedom, evaluated by reference to statistical tables. (In applying Student's t it is assumed that the measurements are distributed normally.)

Values of t at the 95 per cent probability level for values of n up to 20 are as follows:

n	t	n	t
1	infinity	11	2.228
2	12.706	12	2.201
3	4.303	13	2.179
4	3.182	14	2.160
5	2.776	15	2.145
6	2.571	16	2.131
7	2.447	17	2.120
8	2.365	18	2.110
9	2.306	19	2.101
10	2.262	20	2.093

(from Table 12, Biometrika Tables for Statisticians, Volume 1, Second Edition, Cambridge University Press, 1962). When n is greater than 20, 1.96 is used (the value of t when n is infinity).

In calculating confidence limits for volume, L_V, the following inequality corresponding to equation [3] is applied: $L_{\bar{\ell}_m} \leq L_V \leq 1.05\ L_{\bar{\ell}_m}$.

In summary, for values of n between 5 and 20, L_V is calculated as

$$[(1.05 \times t)/\bar{\ell}_m] \times [\sqrt{\Sigma(\ell_m - \bar{\ell}_m)^2/n(n-1)}] \times 100$$

per cent, and when n is greater than 20, as

$$[(1.05 \times 1.96)/\bar{\ell}_m] \times [\sqrt{\Sigma(\ell_m - \bar{\ell}_m)^2/n(n-1)}] \times 100$$

per cent.

If the sampled area of mineral in a resource block is between 0.25 km^2 and 2 km^2 an assessment is inferred, based on geological and topographical information usually supported by the data from one or two boreholes. The volume of mineral is calculated as the product of the area, measured from field data, and the estimated thickness. Confidence limits are not calculated.

In some cases a resource block may include an area left uncoloured on the map, within which mineral (as defined) is interpreted to be generally absent. If there is reason to believe that some mineral may be present, an inferred assessment may be made.

No assessment is attempted for an isolated area of mineral less than 0.25 km^2.

Note on weighting The thickness of a deposit at any point may be governed solely by the position of the point in relation to a broad trend. However, most sand and gravel deposits also exhibit a random pattern of local, and sometimes considerable, variation in thickness. Thus the distribution of sample points need be only approximately regular and in estimating the mean thickness only simple weighting is necessary. In practice, equal weighting can often be applied to thicknesses at all sample points. If, however, there is a distinctly unequal distribution of points, bias is avoided by dividing the sampled area into broad zones, to each of which a value roughly proportional to its area is assigned. This value is then shared between the data points within the zone as the weighting factor.

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