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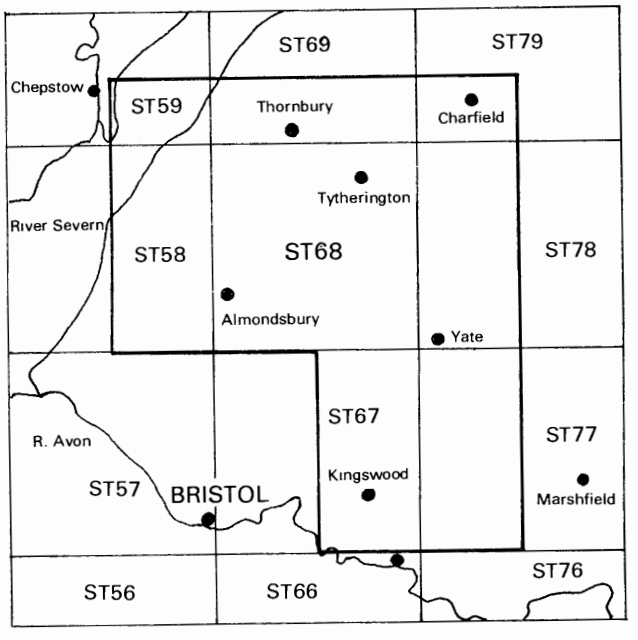

The celestite resources of the area north-east of Bristol

With notes on occurrences north and south of the Mendip Hills and in the Vale of Glamorgan

Description of 1:25 000 resource sheet ST 68 and parts of ST 59, 69, 79, 58, 78, 67 and 77

E. F. P. Nickless, S. J. Booth and P. N. Mosley

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

The asterisk on the front cover indicates that parts of sheets adjacent to that quoted are described in this Report.

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PREFACE

It has become increasingly clear in recent years that an assessment of resources of many minerals should be undertaken. This report describes the celestite resources of the area north-east of Bristol shown on the accompanying 1:25 000 resource sheet and provides additional information on the occurrence and distribution of the mineral south of Bristol, around the Mendips and in South Wales.

The survey was conducted by Mr E.F.P. Nickless, Mr S.J. Booth and Mr P.N. Mosley. The help of Mr A.R. Clayton, Mr D.G. Oldershaw and vacation students is acknowledged.

The work is based on 1:10 560 geological surveys carried out between 1934 and 1961 by Mr G.W. Green, Dr G.A. Kellaway, Dr F.B.A. Welch and others.

Mr J.W. Gardner CBE (land agent) was responsible for negotiating access to land for drilling and trenching. The ready cooperation of the industry, landowners and tenants in this work is gratefully acknowledged.

Plate 4 is reproduced with the permission of Mr R. Pauley (Bristol Mineral Company).

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The geological maps of the Institute of Geological Sciences, pre-existing borehole information and 19 boreholes drilled for the Mineral Assessment Unit, a regional geochemical survey and examination of working pits and temporary exposures form the basis of the assessment of the celestite resources of the area north-east of Bristol.

Potential celestite-bearing areas have been investigated. The results of large-diameter drilling and trenching at 11 sites are presented and include estimates of possible yield and qualitative data.

Areas of indicated, inferred and hypothetical resources, the geology and topography, comments on the distribution of celestite and the position of boreholes are shown on the accompanying 1:25 000 resource map.

The celestite resources of the area north-east of Bristol

Description of 1 : 25 000 resource sheet ST 68 and parts of ST 59, 69, 79, 58, 78, 67 and 77

E. F. P. Nickless, S. J. Booth and P. N. Mosley

1. Introduction

1.1 *BACKGROUND*

Celestite (strontium sulphate, $SrSO_4$) is the main ore of strontium (Thomas, 1973); the only other commercial source is strontianite (strontium carbonate, $SrCO_3$) which may be found on dumps at a number of mines, for example, Free Donald and Whitesmith mines near Strontian, although it is unlikely to be present in sufficient quantity and quality to allow economic recovery.

The survey of the celestite resources of the new non-metropolitan county of Avon, by the Mineral Assessment Unit of the Institute, on behalf of the Department of the Environment, was begun in 1970 following recommendations by the Mineral Resources Consultative Committee and the Central Unit for Environmental Planning. The former agreed that an 'assessment of workable reserves is pressing' and that 'the Institute... might investigate a number of techniques to enable prospecting to be done more efficiently, these could include geophysics, geochemistry and a study of depositional environments'. The Central Unit for Environmental Planning was commissioned in 1966 by the then First Secretary for Economic Affairs to determine the feasibility of large-scale development in the Severnside area. Its report, Severnside, A Feasibility Study, published in 1971, concluded that the region has considerable development potential.

The only celestite deposits of known commercial importance in the United Kingdom occur in the Northavon district of Avon, which until 1968 had supplied 50 to 70 per cent of world production each year since at least 1875. The current working area between Yate [714 828][1] and Cromhall [693 904] is regarded as well located for future urbanisation.

The work was designed to establish the following objectives:

1 provision of information concerning the origin and distribution of celestite; hence

2 recognition of areas likely to contain workable quantities of celestite;

3 establishing sampling techniques which might be applied regionally and locally.

The achievement of these major objectives depends on establishing the sedimentological and stratigraphical relationships of celestite and determining the connection between surface geochemistry and the presence of celestite.

1.2 *EVALUATION OF EXISTING DATA*

Pertinent data held by the Institute include the following.

1 Geological maps at a scale of 1:10 560. These show a 'Celestine Bed' (or Celestine Horizon) which crops out sporadically between Bitton [682 693] and Wapley [714 797].

2 Chemical analyses of 14 celestite samples collected during the course of the primary 1:10 560 geological survey. However, these results relate to the northern part of the Bristol urban area, rather than to the immediate area of interest.

3 Records of natural sections and boreholes sunk in potentially celestite bearing rocks principally in connection with investigations of the coalfield. However, celestite has previously been noted only in the descriptions of temporary pits made for extracting the celestite.

1.3 *FIELD PROGRAMME*

Orientation studies were undertaken in the autumn of 1970, in collaboration with the Radioactive and Metalliferous Minerals Unit of the Institute, to determine whether geochemical sampling techniques provide a suitable method of broadly outlining areas containing celestite and of providing more detailed information on the concentration of the mineral in favourable areas.

As a result of these studies a procedure was adopted in which soil samples were taken at 0.5 m depth from the surface, at intervals of 10, 20 or 50 m dependent on the slope of the ground, along traverse lines 200 to 400 m apart. The strontium content was determined in a field laboratory using a portable isotope fluorescence analyser (PIF) (see section 6).

Between July 1972 and January 1973, 19 boreholes were sunk to investigate the continuity, stratigraphy and sedimentology of celestite. The boreholes were drilled using a BBS 20 rig, under contract, to produce 540 m of SF and PF core. The difficulty of obtaining adequate water supplies led to the use of air flush rather than water or mud flush methods, although these would have been preferable when quartzites and conglomerates were encountered.

The bulk of the core was described on site. Celestite-bearing parts of the core were retained intact for slicing and investigation by means of cellulose acetate peels, staining, thin sections

[1] National Grid references are given in this form. All lie within the 100 km grid square ST.

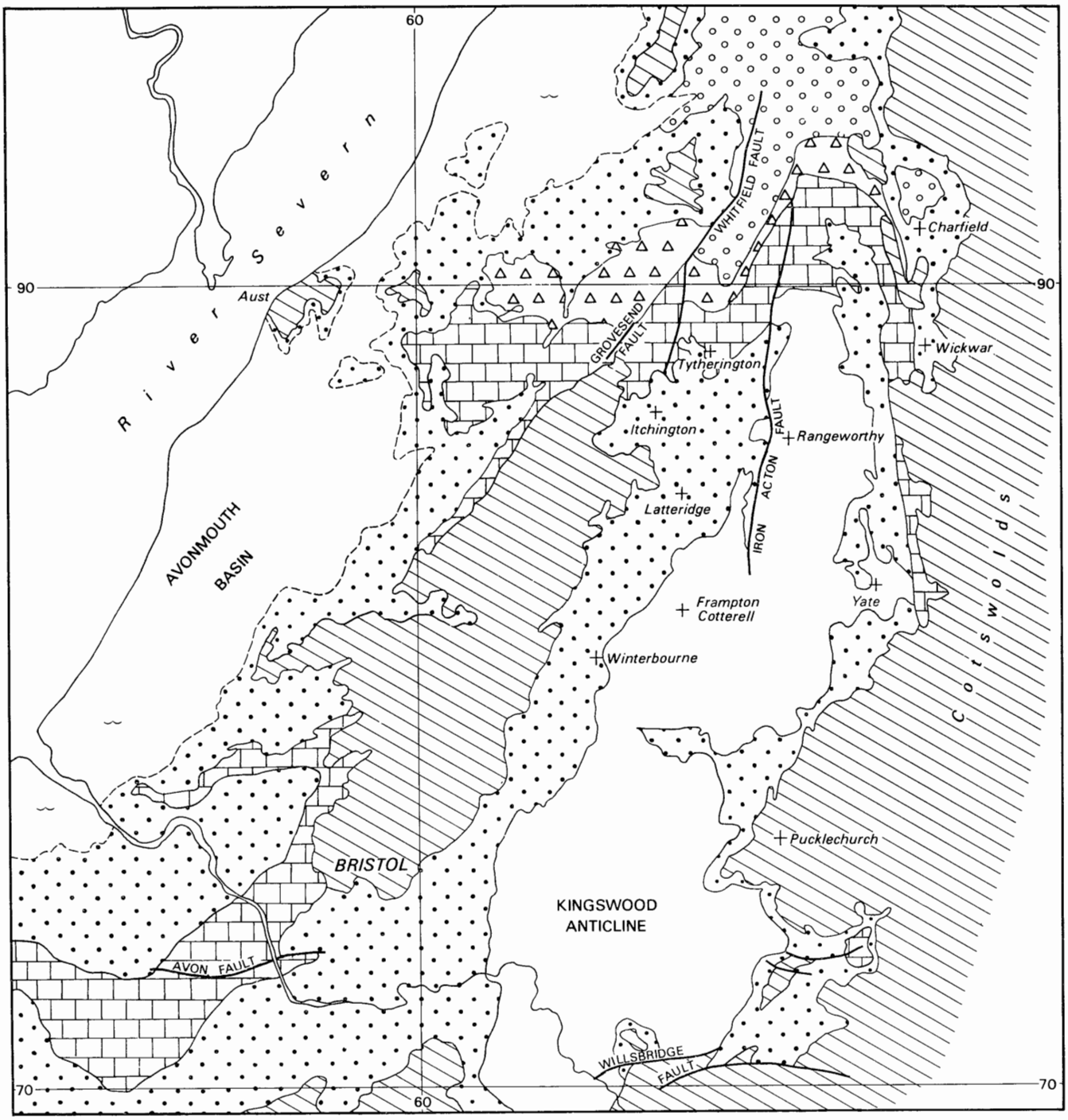

Fig. 1. The area north-east of Bristol

and chemical analysis. Detailed records may be consulted upon application to the Head, Mineral Assessment Unit.

Pits, quarries and temporary sections have been examined and recorded; active celestite workings were visited at regular intervals. Three modes of occurrence of the mineral have been recognised, each affecting the quality and quantity of mineral present and the manner of working (see 2.4).

Two lightweight portable drills (the Minuteman and the Pack-Sack) have been tested in the field with a view to proving the presence of mineral by sampling celestite from depth. Both machines were unable to consistently recover samples from depths of up to 10 m and, therefore, proved unsatisfactory.

The relationship between the strontium content of the flora and the distribution of celestite has also been investigated. Although the results are ambiguous, it is thought that a geobotanical survey may be useful on a regional scale (see 6.3).

The results of the primary six-inch geological survey, examination of aerial photographs, observations made during the present survey and information supplied by local inhabitants and the industry, have been used to determine the areas from which celestite has been extracted and those areas containing indicated, inferred or hypothetical resources (see 3.2).

2. Description of the Area

2.1 *GENERAL*

The area described lies north-east of Bristol. It is bounded to the west by the Severn Estuary and to the east includes part of the Cotswolds. Oldbury upon Severn [610 925] and Charfield [720 911] lie almost at the northern limit of the district. Information on the occurrence of celestite in South Wales and in areas south of Bristol, including the Mendips, is presented in 5.7.

2.2 *TOPOGRAPHY*

The geological map (Fig. 1) shows that the central part of the district north-east of Bristol is occupied by a triangular area of Palaeozoic strata, concealed in part by a covering of Mesozoic and Quaternary rocks.

The distribution of high and low ground is related both to the nature of the underlying strata and their erosional history. Elsewhere in Britain, Palaeozoic rocks, being relatively hard, give rise to areas of moderate to high relief. However, with the exception of the Carboniferous Limestone, the outcrops of Cambrian, Silurian, Old Red Sandstone and younger Carboniferous beds in this district are characterised by low-lying undulating country. The modern landscape has been influenced by removal of the Mesozoic cover exposing a Triassic erosional, arid landscape, composed of Palaeozoic rocks, in which the Carboniferous Limestone and Old Red Sandstone locally stood up as residual hills.

The Vale of Berkeley is overlooked by the scarp of the Cotswolds which are composed of comparatively hard Jurassic limestones.

Adjacent to the Severn, Estuarine Alluvium forms large areas of low-lying ground broken by hills of Mesozoic strata at Aust [573 891] and Ingst [582 879].

All the rivers in the district flow into the Severn Estuary. The Ladden Brook which drains the central part of the district joins the River Frome, a tributary of the Bristol Avon, at Cog Mill Farm [665 828], north of Frampton Cotterell.

2.3 *GEOLOGY*

The geological succession is summarised in Table 1.

The geology of the district is illustrated on the resource map. An outline of the principal features is shown on Fig. 1. Two sets of fold lines can be readily distinguished, one trending north—south or north-east—south-west, the other east—west. The former are represented by the Clevedon-Portishead Ridge and the Avonmouth basin; the latter by the Kingswood anticline[1].

The Cambrian rocks, the oldest known in the district, consist of shales with thin beds of fine grained sandstone. A succession of shales with three interbedded sandy limestones (in the Llandovery, Wenlock and Ludlow Series) and flaggy micaceous sandstones (Lower Devonian) overlie the older rocks unconformably. Conglomerates and quartzites (Upper Devonian) overstep the Lower Devonian to rest in places on Wenlock. The Upper Devonian passes up into Carboniferous strata, comprising predominantly limestones below and sandstones with interbedded shales and coals above.

During Triassic times the district was subjected to erosion under arid conditions and basins floored by Palaeozoic strata were filled with material derived from surrounding high ground. The Triassic deposits comprise Dolomitic Conglomerate, a fan breccia and marginal facies found banked up against the old hills, and Keuper Marl, silty calcareous red mudstone, which was deposited on lower ground. Towards the top of the Keuper Marl the authors have noted 'argillaceous limestone nodules' (see borehole logs). These nodules, described by others as 'race', are thought to be pedogenic (Allen, 1974) and to have formed by precipitation of calcite within a soil profile under conditions of seasonal evaporation.

The Keuper Marl is overlain by the Tea Green Marl (calcareous greenish grey clays and mudstones), which in turn is succeeded by the Rhaetic—black shales (Westbury Beds) and greenish grey silts and muds with a splintery calcite mudstone unit at the top (Cotham Beds). The Lias comprises clays and limestones.

Unconsolidated Quaternary sediments are present, deposited in fluvial and estuarine environments, under conditions ranging from temperate to periglacial.

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[1] Underlined terms are explained in the Glossary.

Table 1. List of geological formations and deposits.

		DRIFT	
Quaternary	Recent & Pleistocene		Alluvium Terrace Gravels Estuarine Alluvium Head Deposits
		SOLID	
Mesozoic	Jurassic	Lias	White and Blue Lias
	Triassic	Rhaetic	Cotham Beds Westbury Beds
		Keuper	Tea Green Marl Keuper Marl Dolomitic Conglomerate (marginal facies of Keuper Marl)
		Major unconformity	
Palaeozoic	Carboniferous	Upper Coal Measures	Supra-Pennant Measures Pennant Measures
		Lower & Middle Coal Measures	
		Millstone Grit Carboniferous Limestone	Quartzitic Sandstone Group
	Devonian	Upper Old Red Sandstone	Tintern Sandstone Group Quartz Conglomerate
		Major unconformity	
		Lower Old Red Sandstone	Thornbury Beds
	Silurian	? Ludlow Series Wenlock Series Llandovery Series	
		Major unconformity	
	Cambrian	Tremadoc Series, including	Micklewood Beds

2.4 *OCCURRENCE OF CELESTITE*

In England the Keuper Marl contains two major horizons of gypsum (hydrated calcium sulphate, $CaSO_4 . 2H_2O$)(Sherlock and Hollingworth, 1938). Although celestite may occur at more than one horizon in the Keuper, only that associated with the Severnside Evaporite Bed (the level of the Newark Gypsum of the Midlands (Sherlock in Sherlock and Hollingworth, 1938, p. 81)), some 10 to 15 m below the Tea Green Marl, is important. For the past 100 years celestite in the Keuper Marl and Lower Coal Measures has been commercially exploited at many localities in the Bristol area (Fig. 2). Extraction is now restricted to a belt which extends from Cromhall [693 904] through Hall End [708 869] to Yate [714 828].

The following modes of occurrence have been recognised (see also Fig. 3).

Type A. Within the Keuper Marl, nodular and disseminated celestite, thin stringers and veins (Plate 1), forming the Severnside Evaporite Bed, typically 10 to 15 m below the base of the overlying Tea Green Marl.

Type B. Nodular and disseminated celestite contemporaneous with the Severnside Evaporite Bed at the unconformity between the Keuper Marl and the underlying Palaeozoic rocks (mainly Coal Measures).

Type C. Veins, sheets and vuggy infillings of redistributed celestite in Keuper Marl and in Palaeozoic rocks beneath the present or former cover of Keuper Marl (Plate 2). In some instances celestite forms the matrix in breccias of Palaeozoic rock.

(The horizontal and vertical relationship between these modes of occurrence are shown schematically in Fig. 3).

The geological survey of the north-east Bristol area by Dr G.A. Kellaway and Dr F.B.A. Welch, demonstrated the presence of a prominent greyish green, calcareous, sandy mudstone, lying approximately 10 to 15 m below the base of the Tea Green Marl. It was informally termed the Stoke Park Rock Bed (Kellaway, 1961), and was mapped over a large part of the Triassic outcrop, extending northwards from Bristol as far as [6435 8241] near Kingmore. Between Bitton [682 693] and Wapley [714 797] the same horizon was indicated on the published maps by Welch and Kellaway (1959, 1961) and Kellaway (1960) as the Celestine Bed or Celestine Horizon. However, no formal description of any of these lithostratigraphical units has been published.

Detailed study during the present investigation has shown that evaporite occurrences north-east of Bristol can be related to the same general stratigraphic level within the Keuper Marl and have been followed for a distance of over 50 km along the outcrop. The detailed lithological succession has been worked out with the aid of 19 cored boreholes drilled in connection with this survey. The distinctive lithostratigraphical unit which includes the Celestine Bed or Horizon and the Stoke Park Rock Bed of Kellaway and Welch, is termed the Severnside Evaporite Bed (Nickless and others, 1975).

Boreholes show the Severnside Evaporite Bed to range from 0.5 to 2 m in thickness. Nodular fabrics are most common, although gradations from small nodules to cumulate layers were seen. Characteristically, nodular anhydrite (calcium sulphate, $CaSO_4$) or gypsum is replaced, to a greater or lesser extent, by celestite, usually with minor amounts of calcite (calcium carbonate, $CaCO_3$) and/or quartz (silicon dioxide, SiO_2), although these minerals may locally dominate. In a fully developed sequence, it shows a gradational passage upwards from isolated nodules in mudstone, to a cumulate, coalesced layer, commonly truncated by an erosion surface (Plate 1), although in some exposures the Bed is represented solely by seams of ovate celestite nodules in an unbroken mudstone succession.

South of Wapley [714 797] the Severnside Evaporite Bed is underlain by up to 25 m of Keuper Marl but northwards the Bed progressively oversteps the underlying Keuper Marl so that in the neighbourhood of Yate it rests almost directly on the Lower Coal Measures. Between Yate and Cromhall the Severnside Evaporite Bed (type B) is discontinuous having been formed in shale-bottomed depressions between ridges of Coal Measures sandstone or quartzite, in which masses of celestite and sometimes gypsum up to several tonnes in weight have been found. The arenaceous Carboniferous strata presumably controlled the level of the water table in the surrounding shales and so may have assisted the formation of gypsum and anhydrite and their diagenetic alteration to celestite (Nickless and others, 1975) (see also 4.7). The present surface of the Palaeozoic rocks has been degraded very little below the level of the sub-Keuper Marl unconformity, and in places nodules of celestite occur in deeply weathered Palaeozoic rocks.

It is thought that quartzites and sandstones have also partly controlled the redistribution of celestite (type C). Veins of celestite, usually concordant with the bedding and tapering downwards, have been found in Wenlock Shales near Little Whitfield Farm [6740 9125] (Reed and Reynolds, 1908) and in Lower Coal Measures, for example, at Cowship Lane [703 887], Barbers Court [707 881], Leechpool [707 852], Hartstrow [714 852] and Goose Green [714 834], where the greatest concentrations of celestite were seen in shales and clays adjacent to beds of sandstone or quartzite. Except for one occurrence in a pit [6988 8898] south of Cowship Lane, where celestite cemented a brecciated sandstone in the Lower Coal Measures, celestite has not been observed in direct association with sandstone. The arenaceous rocks presumably permitted the easy movement of celestite-bearing solutions and the shales and clays which easily adsorb cations such as strontium, provided a suitable secondary depositional environment. However, leaching of any mineral that may have been present in arenaceous strata may be a contributory factor.

Between Yate and Cromhall, Keuper Marl banked up against the Carboniferous Limestone and thinning rapidly away from the high ground,

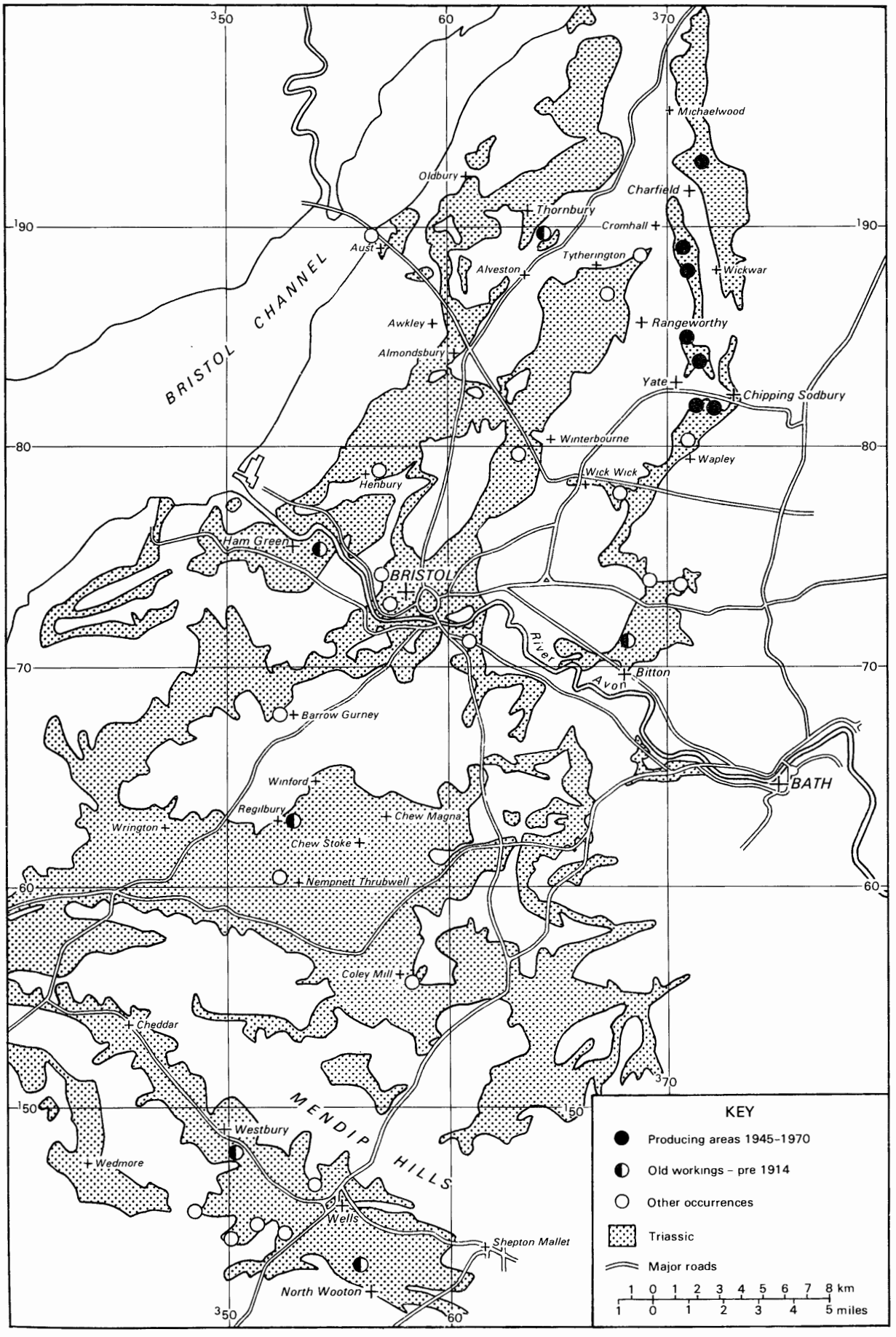


Fig. 2. Celestite in the Bristol area (after Thomas, 1973)

forms an outcrop averaging 1 km in width and locally exceeding 2 km. Over much of the district a veneer of deeply weathered Keuper Marl generally overlies the Coal Measures and some temporary sections show complex involutions of Keuper and Carboniferous material, presumably formed under periglacial conditions.

Coal Measures shales weather to a stiff, yellowish grey clay, often in excess of 3 m in thickness, with strontium values, as determined from X-ray fluorescence analysis of soil samples, of generally less than 100 ppm, that is, less than the background values (see 6.2.4). Traversing adjacent to, and sampling from pits in Coal Measures shales containing veins of celestite has not detected strontium in excess of background, either in the weathered mantle or in the host shales. It is thought that the minimal dispersion of strontium may be due to leaching through the highly fractured Coal Measures. Waters pumped from the Coal Measures at Frampton Cotterell are 99 per cent saturated with respect to strontium (Edmunds and Morgan-Jones, 1970).

The distribution of vein celestite appears to be structurally controlled as towards the nose of the syncline the veins are thicker and run deeper than veins found on the flanks. In the Cromhall area veins were worked to a depth of 10 m from the surface, whereas, at Leechpool and Hartstrow, working depths of 5 or 6 m were the norm.

The celestite of the Severnside region is thought to be diagenetic after gypsum and/or anhydrite (Nickless and others, 1975). The primary minerals were formed in a supratidal mudflat environment (sabkha) similar to that found in the Persian Gulf today. Although celestite occurs as a primary mineral in modern sabkhas (Kinsman, 1969; Shearman, 1966), it is only present in minor amounts usually accounting for less than 1 per cent of the authigenic minerals.

Trace amounts of celestite are also formed on conversion of anhydrite to gypsum, strontium being exsolved from the anhydrite lattice. With regard to the deposits north of Bristol, examination of thin sections shows that replacement of calcium by strontium in either gypsum or anhydrite took place during early diagenesis, while the host sediment was still mobile, as the celestite laths are frequently bent, presumably from the increasing weight of overlying sediments. Late diagenetic replacement of both anhydrite and celestite by calcite and quartz has been observed, particularly in the Latteridge [664 846]—Tytherington [669 884] area, where Dolomitic Conglomerate and Coal Measures sandstones and quartzites almost immediately underlie the Severnside Evaporite Bed. It is thought that these rudaceous and arenaceous rocks acted as solution pathways both at the time of formation of the evaporite and subsequently.

Calcium carbonate, the principal constituent of limestones, occurs both as a primary chemical or organic precipitate and in fossil shells. Of the two polymorphs, calcite is the more stable under normal surface conditions, but metastable aragonite is often initially precipitated and recrystallises in time to calcite. Aragonite may hold up to 8000 ppm strontium within its lattice, but calcite only 400 ppm (Kinsman, 1969).

Celestite and limestone associations have been described elsewhere, for example, by West (1973). Thin sections, stained cellulose acetate peels and field observations show that in the Bristol area there is a relationship between the distribution of the primary evaporite and its subsequent diagenetic history, the permeability of the substrate and the distance from outcrops or subcrops of Carboniferous Limestone. On the margins of the depositional basins adjacent to the limestone almost all the gypsum or anhydrite has been converted to celestite: moving away from the limestone the degree of alteration of the primary evaporite is seen to progressively diminish and within the depositional basins, gypsum occurs with almost no celestite. The conversion of aragonite to calcite in the Carboniferous Limestone, with the consequent expulsion of excess strontium from the crystal lattice, therefore is considered to be the source of the strontium required for the diagenetic alteration of gypsum or anhydrite to celestite in the Triassic strata of the Bristol area.

3. Resource Assessment

3.1 *BACKGROUND*

In response to increasing pressures on land and to ensure continued mineral production, the Celestine Conference held in 1951, involving interested Government Departments, planning authorities, mineral operators and the Geological Survey (now part of the Institute of Geological Sciences), distinguished economically viable areas, where phased exploitation might be closely linked with agricultural, social and environmental requirements, from known mineral-bearing land. The Conference recognised the following.

a. 459 hectares where the mineral was proved to occur, of which 340 hectares were then being worked, the remainder being held by the industry for ensuring production.

b. 399 hectares of probable celestite-bearing land.

c. 573 hectares of possible celestite-bearing land.

Excepting category c which includes parts of the Little Avon Valley and the Latteridge—Tytherington area, most of the ground lies in a north-south belt between Yate and Cromhall, bounded to the east by the Carboniferous Limestone ridge but with no definite western boundary (see Fig. 4).

Deciding how much productive land remains at present, rests partly on the recognition of the extent of old workings. Before 1939, methods of working celestite were primitive but extraction and restoration by mechanical means are now the rule. The mineral was formerly located by means of probing to 3 or 4 m with a steel rod, after which it was dug by hand from small pits, which were later back-filled (Plate 4). Such a procedure did not interfere greatly with agriculture, but the working of celestite was

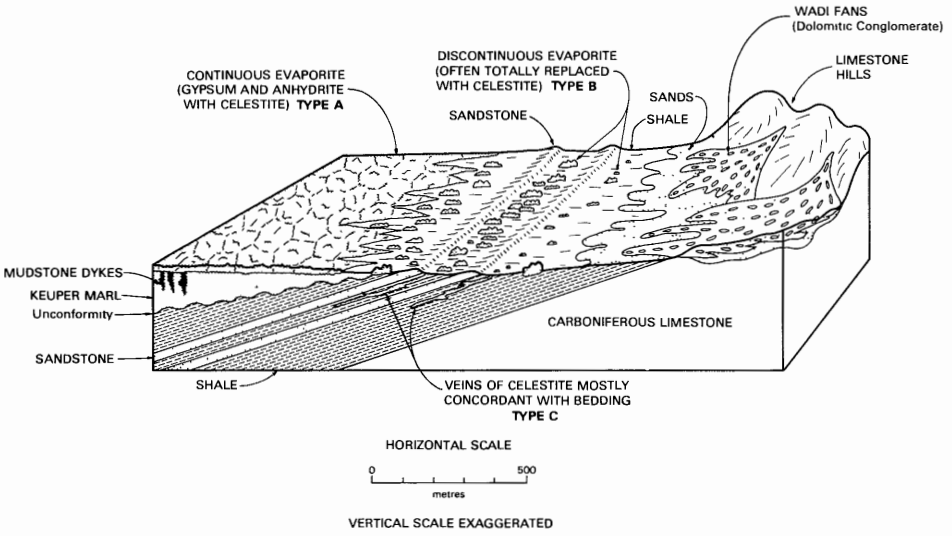


Fig. 3. The horizontal and vertical relationships between the three modes of celestite occurrence (schematic)

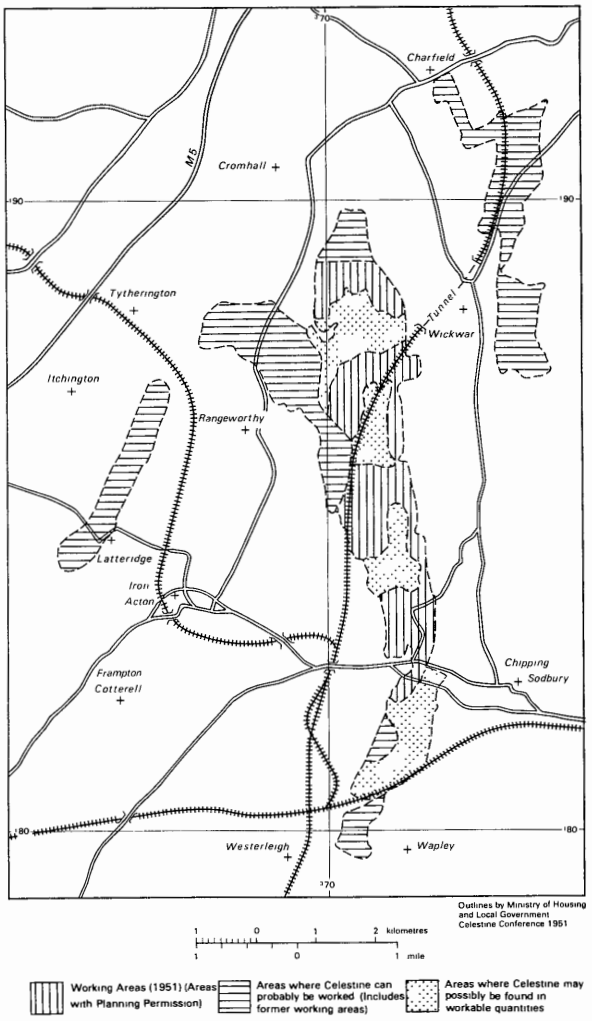


Fig. 4. Categories and extent of celestite-bearing land recongnised by the Celestine Conference (1951)

intermittent and very superficial, with the result that areas previously worked in this manner may retain considerable quantities of the mineral. No information survives on the precise location of such workings and their yields.

In recent years celestite has been produced mainly from the Yate—Cromhall area. The modern method of extraction utilises bulldozers ('Traxcavators') to dig shallow open-cast pits, usually less than 10 m deep (Plate 3). The mineral is sorted from the spoil by hand. The direction of working depends on the 'lie' of the deposits and backfilling takes place concurrently with working, except during the winter when the pits are liable to flood. Most of the pits have a life of only a year or two, and after reinstatement the ground is usually returned to agriculture within two years.

The following sources have been used to delimit, very approximately, the extent of worked ground shown on the resource map.

1 The primary 6-inch survey by F.B.A. Welch between 1943 and 1952
2 The Gloucestershire County Council land use survey of 1966
3 Information supplied by the industry
4 The study of aerial photographs taken in 1946 and 1965
5 Observations made in the course of the present study
6 Conversations with landowners and tenants

Many of the older workings have probably not been identified and within the area of worked ground there may be areas where the mineral has not been extracted.

3.2 *CLASSIFICATION OF RESOURCES*

This survey is concerned with the estimation of resources (which include deposits that are not currently exploitable but have a foreseeable use), rather than reserves (which can only be assessed in the light of current, locally prevailing, economic considerations). Clearly the economic and social factors used to decide whether a deposit may be workable in the future cannot be predicted as they will change with time. The improved knowledge of the distribution of the resource, and its variability which this survey seeks to provide, will improve the factual background against which planning policies can be evolved. It will also assist in the selection of the best targets for further work by industry, which must still establish the whereabouts of reserves and prove their size and quality by the customary detailed investigations. Deposits not currently economically workable may become exploitable as prices increase (for example, as higher grades or alternative materials become scarce) or as costs are lowered (for example, by improved processing techniques).

The present investigations permit a reappraisal of the probable and possible celestite-bearing areas recognised by the Celestine Conference (1951) according to the classification (Fig. 5) evolved in the USA (see, for example, McKelvey, 1973; 1974). In this report the resource estimates extend along the 'degree of geological assurance' axis beyond the double vertical line which represents the boundary between known and undiscovered deposits and deposits are included that extend along the whole of the 'feasibility of economic recovery' axis, that is, deposits are included that are regarded as sub-economic resources as well as those that are now recoverable. The shaded area of the diagram indicates the categories of resources that are included in this report. The degree of assurance about the estimates increases from right to left and the economic feasibility of recovery increases from bottom to top.

In this report the resource is regarded as identified at the indicated level where geological investigations have demonstrated that stratiform celestite is present. Qualitative and quantitative estimates for small sites with stratiform celestite are assumed to be representative of the surrounding area of similar geology. Discussions with landowners often reveal that the resource may have been worked on a very minor scale before 1939, but the precise locations of such workings are usually not known.

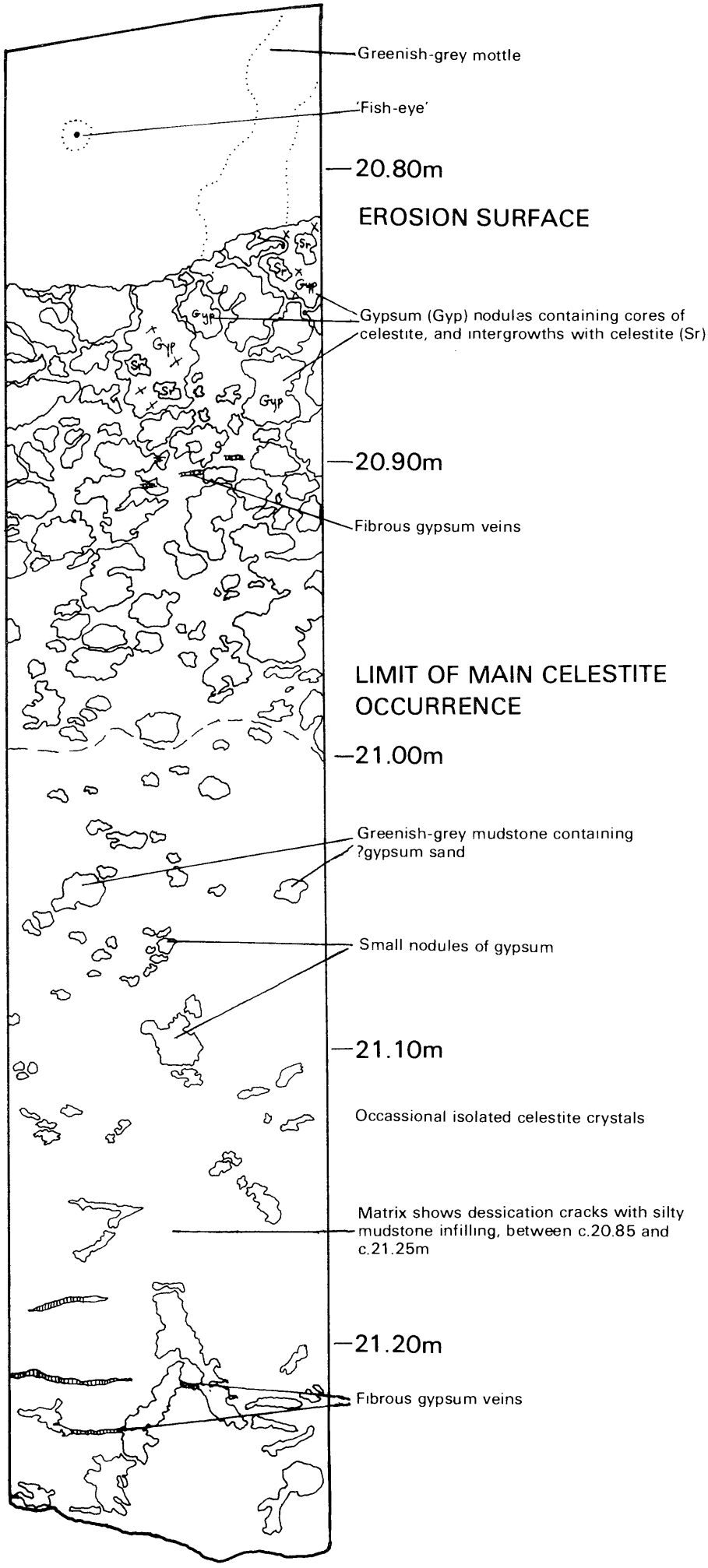
The resource is classified at the inferred level of assurance where the investigations suggest that haphazardly distributed celestite occurs in nodular, or vein, or both habits. Estimates of quality and yield for small sites show wide variations and must therefore be interpreted cautiously. The area between Yate and Cromhall, which includes the current workings, is assigned to this category.

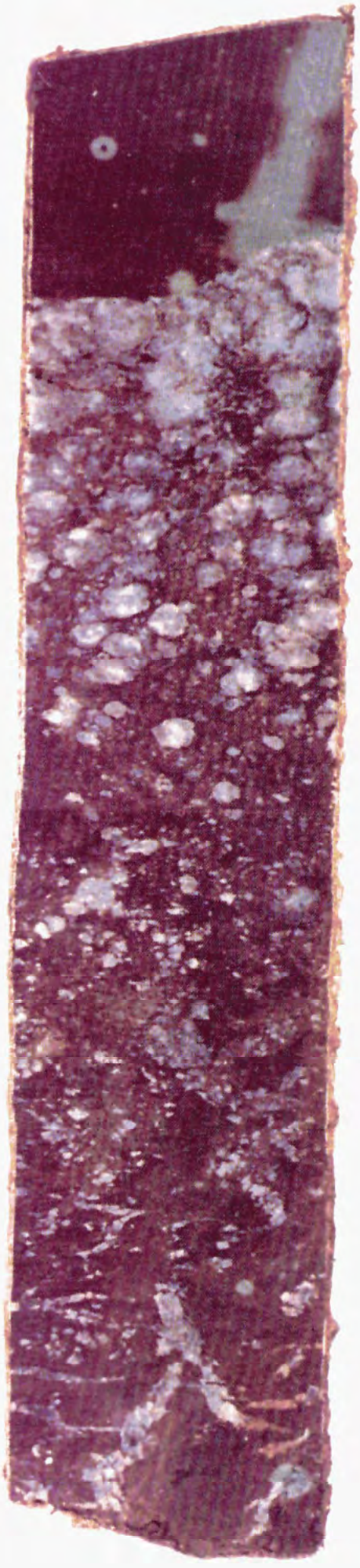
The resource is classified at the hypothetical level where there is reason to believe that celestite may be present locally, either as veins or in isolated pockets, although such deposits may never have been worked.

Apart from the urban area of Yate—Chipping Sodbury, no account has been taken of any factors, for example, roads, villages and areas of high agricultural and landscape value, which might stand in the way of celestite being exploited. The estimates (Table 2) therefore bear no simple relationship to the quantities that could in practice be worked.

Although three modes of celestite occurrence have been recognised, the precise vertical and lateral distribution of the mineral particularly at, or near, the Triassic/Carboniferous unconformity and within Palaeozoic strata, is very imperfectly known. In some sections nodular celestite is distributed vertically through several metres of rock: elsewhere it forms a bed up to 1 m thick, but averages 200 mm. Only strata enclosing stratiform celestite (type A) can be classified in terms of overburden and mineral thickness. Such terms, however, are considered to be too specific for deposits of types B and C (see 2.2).

From discussions with industry, it is understood that yields per hectare may range up to 800 tonnes and that an average of 200 tonnes was necessary in 1973/74 for economic working of deposits from depths of up to 10 m: higher yields would be necessary to enable celestite to be worked from greater depths. As these are likely to occur only exceptionally, in this report


Greenish-grey mottle
'Fish-eye'
20.80m
EROSION SURFACE
Gypsum (Gyp) nodules containing cores of celestite, and intergrowths with celestite (Sr)
20.90m
Fibrous gypsum veins
LIMIT OF MAIN CELESTITE OCCURRENCE
21.00m
Greenish-grey mudstone containing ?gypsum sand
Small nodules of gypsum
21.10m
Occassional isolated celestite crystals
Matrix shows dessication cracks with silty mudstone infilling, between c.20.85 and c.21.25m
21.20m
Fibrous gypsum veins



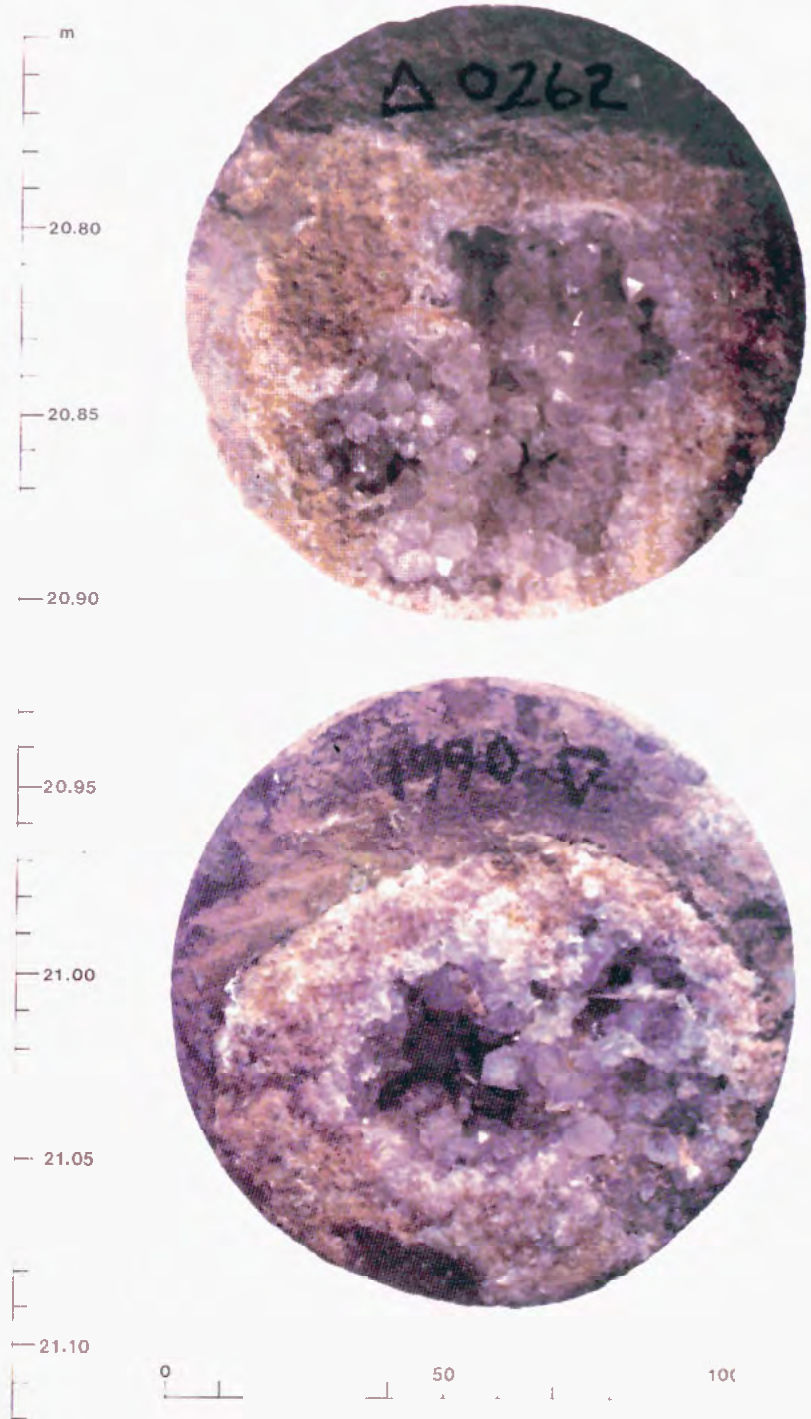


Plate 1B. Vug in coarsely crystalline celestite (Severnside Evaporite Bed) lined with bi-pyramidal amethystine quartz containing acicular ?rutile. Borehole ST 77 NW 22 [7048 7932] from 26.95 to 27.05 m depth.

Plate 1A. Sectioned core of the Severnside Evaporite Bed showing the gradational passage upwards from isolated nodules of gypsum within mudstone to a coalesced unit truncated by an erosion surface. The gypsum here is only partially replaced by celestite, which is developed in the cores of some of the nodules. For further explanation see annotated sketch.

Plate 2. Celestite veins in post-depositionally hematised Coal Measures which dip at 40° towards the west (that is, towards the observer). Former celestite working [711 836] near Goosegreen, Yate, 1971.

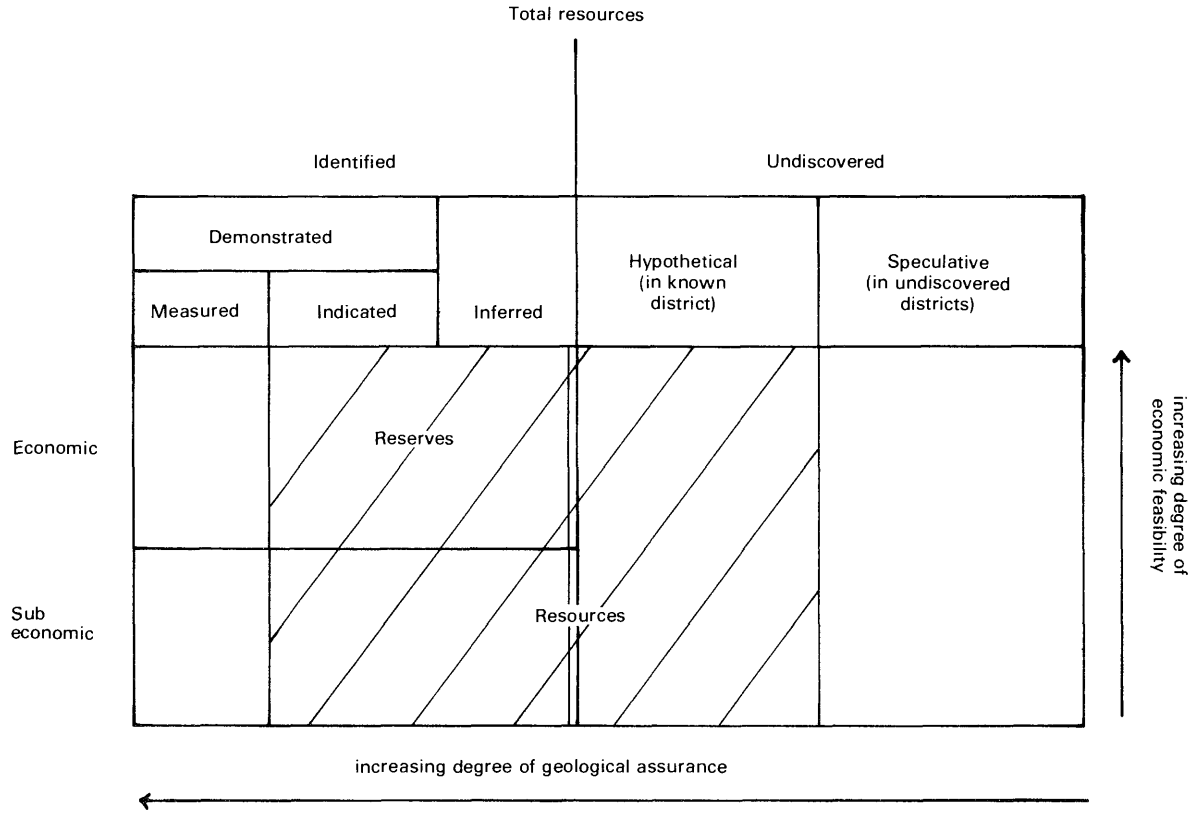


Fig. 5. Classification of resources (after McKelvey, 1973)

only deposits within 10 m of the surface have been considered.

Trenches approximately 1 by 5 m and up to 5.2 m deep, or 1 m diameter auger holes averaging 4 m in depth, have been used to gain very approximate yield estimates at randomly selected sites. Mineral was hand-picked from the spoil and weighed. It is inevitable, however, that some celestite, particularly fragmentary material, was overlooked. Nevertheless, it is thought that the quantities extracted approximate to that which would in practice be recovered during routine extraction by the industry. The amounts produced by each trench or borehole are expressed in kilograms per square metre and have been used to estimate yields in tonnes per hectare for the area in the vicinity of the sites. For each trench or borehole, details of yield and the depth range over which celestite was recovered are given in section 5. This data and general geological considerations have been used to estimate a possible average yield and the range within which it would be likely to fall, for each of the six districts identified in section 4. The information is insufficient to allow confidence limits to be calculated.

Analytical information for celestite or gypsum samples from many localities throughout the region including the sites which were investigated by trenching or large diameter drilling is shown in Tables 3 to 8. Details of the analytical method employed are given in section 6.4 and coefficients of variation at the 95 per cent probability level for celestite containing 50 per cent or more SrO appear in Table 10. Samples were analysed for strontium, barium, calcium, magnesium, aluminium, silicon and sulphur, expressed as percentages of the oxides. The shortfall when the results are totalled represents undetermined constituents, for example, sodium, potassium, water and carbonate.

Thomas (1973) states that 'celestite sold in the United Kingdom normally contains a minimum of 95 per cent $SrSO_4$, not more than about 2.0 per cent each of barium sulphate ($BaSO_4$) and silica (SiO_2) and approximately 0.5 per cent each of calcium carbonate ($CaCO_3$) and iron oxide (Fe_2O_3).' Further information on specifications for particular end-uses may be found in Thomas (1973) but generally most manufacturers demand celestite comparable in quality to that in the US National Stockpile Purchase specification P-10-R3 dated 25 April 1968, namely, $SrSO_4$ 96 per cent (minimum), $CaSO_4$ 2.0 per cent (maximum), free moisture not more than 2.0 per cent by weight. However, specifications of $SrSO_4$ content in the range of 92 to 97 per cent are known.

It must be emphasised that details of yields and composition should be interpreted with utmost caution for although the sites selected for detailed investigation were chosen randomly, the extent to which they are representative of the deposit as a whole has not been determined.

3.3 *THE MAP*

The resource map is folded into the pocket at the end of this report. The base map is the Ordnance Survey 1:25 000 Outline Edition in grey, on which the topography is shown by contours in brown, the geological data including notes on the distribution and quality of celestite in black and the resource categories in shades of green.

The geological boundary lines and conventions are taken from the geological map of the area which was originally surveyed at the scale of 1:10 560 between 1934 and 1961, and amended in the light of recent information. The geological boundaries are regarded as the best interpretation of the information available at the time of survey. However, it is inevitable, particularly in areas where residual Keuper Marl overlies Coal Measures or Old Red Sandstone, that local irregularities or discrepancies will occur.

The outcrop of the Severnside Evaporite Bed is indicated by a dark green line — a broken line denotes uncertainty about its position. Borehole data, a graphic log showing the stratigraphic relationships, details of depth to the Severnside Evaporite Bed and generalised comments on the composition and distribution of celestite are shown. More precise information is given in sections 4 and 5 of the report.

Areas where celestite (with or without gypsum, calcite or quartz) is present beneath less than 10 m of overburden are shown in green. No attempt is made to distinguish areas where celestite may be present beneath more than 10 m of overburden from areas where celestite is absent. Such areas are uncoloured. Shades of green are used to show where the resource has been assessed at the indicated, inferred and hypothetical levels. Usually a geological boundary line is used to separate these categories, but where there is uncertainty about their extent a green zig-zag line is used. The symbol is intended to convey an approximate location within the likely zone of occurrence, its width being determined largely be cartographic considerations.

4. Results

4.1 *INTRODUCTION*

The Severnside Study (Central Unit for Environmental Planning, 1971, paragraph 5.31) mentions three sites for urban development in the north-east Bristol area. The largest, centred on Frampton Cotterell, 'would constitute in effect a major expansion of Bristol. Wapley could provide for continuation of that expansion; though if it were developed without the Frampton Cotterell site it could be regarded as a further development of that already begun at Yate. The Thornbury site is relatively small and would cater for some peripheral expansion beyond that already agreed for the town'.

Fig. 2 shows the reported occurrences of celestite. The principal potentially mineral bearing regions north of the Avon are: Tytherington—Winterbourne; Michaelwood—Wickwar; Thornbury—Oldbury; Aust—Henbury; Wapley—Bitton; Yate—Cromhall.

Details of measured sections and additional geological notes, analyses of samples and borehole logs are given in section 5. Estimates of resources are summarised in Table 2.

4.2 *TYTHERINGTON-WINTERBOURNE*

The principal topographic feature of the district is the north-east to south-west trending Marle Hills which between Lower Lark's Farm [672 858] and the M4 motorway form an east-facing scarp. On the lower ground near Frampton Cotterell [668 820], the Ladden Brook has an extensive floodplain (Fig. 6).

The Severnside Evaporite Bed may be traced from north of Lower Lark's Farm to the neighbourhood of Winterbourne [614 810]. The isochemical pattern (Fig. 7) derived from 43 traverses across the area, accords closely with observations made both during the present investigation and by Welch in his primary six-inch geological survey.

In the vicinity of Tytherington [669 884] the Severnside Evaporite Bed rests almost directly on Carboniferous strata and contains a single seam of nodular celestite often almost totally replaced by quartz and usually less than 150 mm thick.

Between Moorleaze [670 872] and Lower Lark's Farm the Bed contains up to three almost continuous seams of nodular celestite with an aggregate thickness of approximately 200 mm distributed through 1 to 2 m of mudstone. Individual seams are generally less than 80 mm thick and in the Moorleaze area show extensive replacement by quartz.

Near Itchington [659 868] the Severnside Evaporite Bed is up to 1 m thick and contains white nodular sugary celestite with only traces of quartz and calcite. Carboniferous sandstones underlie the Bed at no great depth, probably a metre or two.

From Latteridge [664 846] to Perrinpit Farm [6548 8275] the Severnside Evaporite Bed crops out on both the scarp face of the Marle Hills and locally on its dip slope. Borehole ST 68 SW 12 [6235 8066] proved that more than 19 m of Keuper Marl underlies the Bed. Borehole ST 68 SE 21 [6540 8327] shows reddish brown mudstone with four seams of nodular, often vuggy, celestite usually less than 50 mm thick. The variability of the Bed is further demonstrated by borehole ST 68 SE 20 [6578 8368] situated 600 m to the north where only veins and stringers of celestite, usually less than 10 mm thick, were recorded. At Perrinpit Farm, an old marl pit on the scarp face of the Marle Hills exposes four seams of nodular, vuggy celestite partially replaced by calcite.

Southwards, towards Winterbourne, the Severnside Evaporite Bed contains a single poorly developed seam of vuggy nodules of calcite with only traces of celestite.

Seven 1 m diameter auger holes were sunk over two fields, [6525 8315 and 6535 8305], on Perrinpit Farm (see 5.1.2). The amount of celestite recovered varied from 0 to 19 kg/m^2.

Table 2. The celestite resources of the area north-east of Bristol

District	Area (in hectares) and 'level' or degree of geological assurance*			Possible range of yields in tonnes per hectare			Possible average yield in tonnes per hectare			Estimated yield in tonnes		
	Indicated (a)	Inferred (b)	Hypothetical (c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Latteridge—Tytherington		1 455			50-200			100			145 500	
Michaelwood—Wickwar	22	8		50 to 100	Up to about 50		75	20		1 650	160	
Thornbury—Oldbury		65			Up to about 50			30			1 950	
Aust—Henbury		10			Up to about 20			15			150	
Wapley—Bitton	262			500 to 1 500			800			209 600		
Yate—Cromhall	135	311	430	200 to 1 500	Up to about 800	?	750	200	?	101 250	62 200	?
TOTALS**	419	1 849	430							300 000	200 000	?

* See section 3.2 and Fig. 5. ** Figures may not add to totals shown because of rounding.

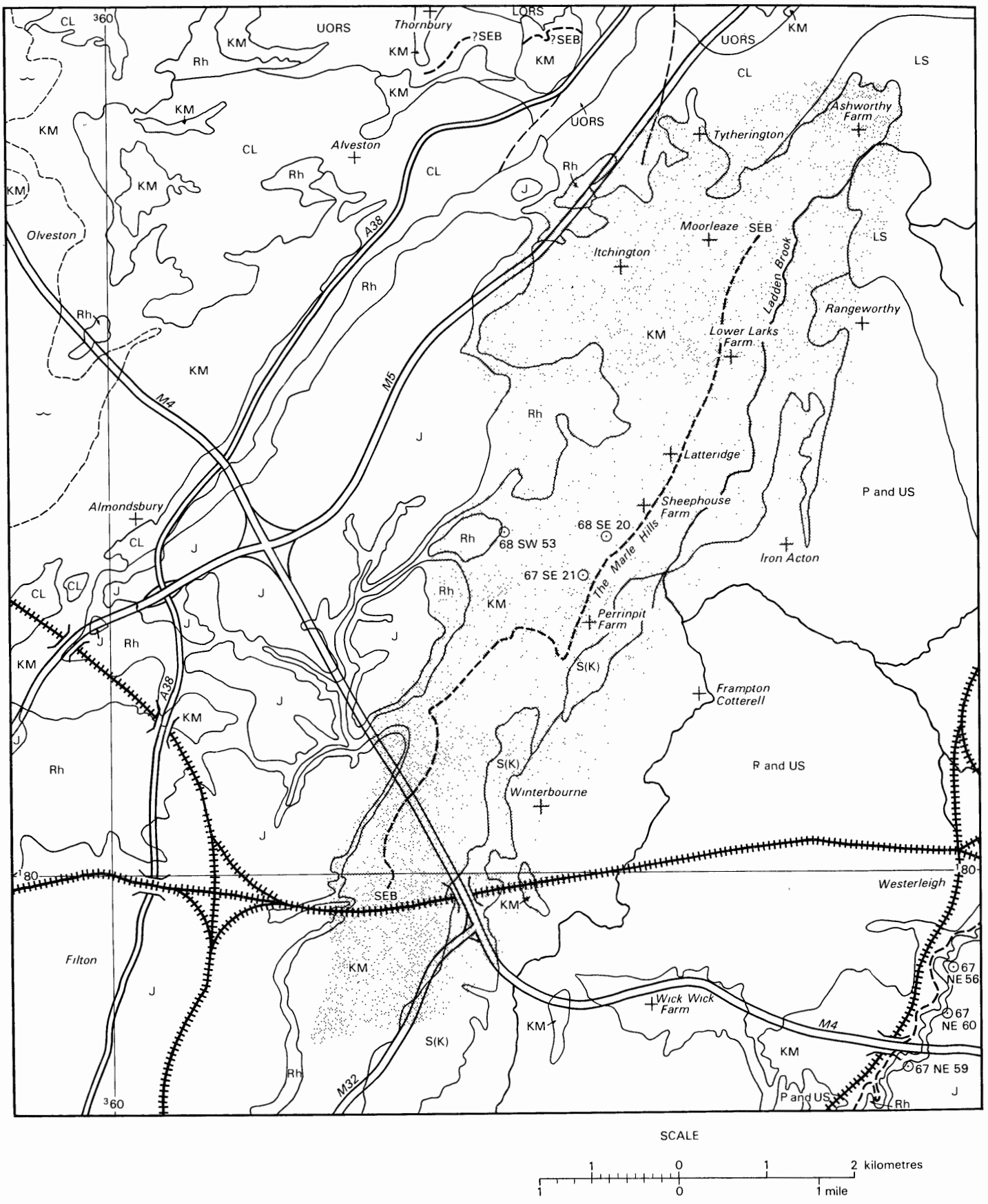


Fig. 6. Tytherington–Winterbourne area
Note: TGM and DCg included in KM. For explanation of symbols see resource sheet (in pocket)

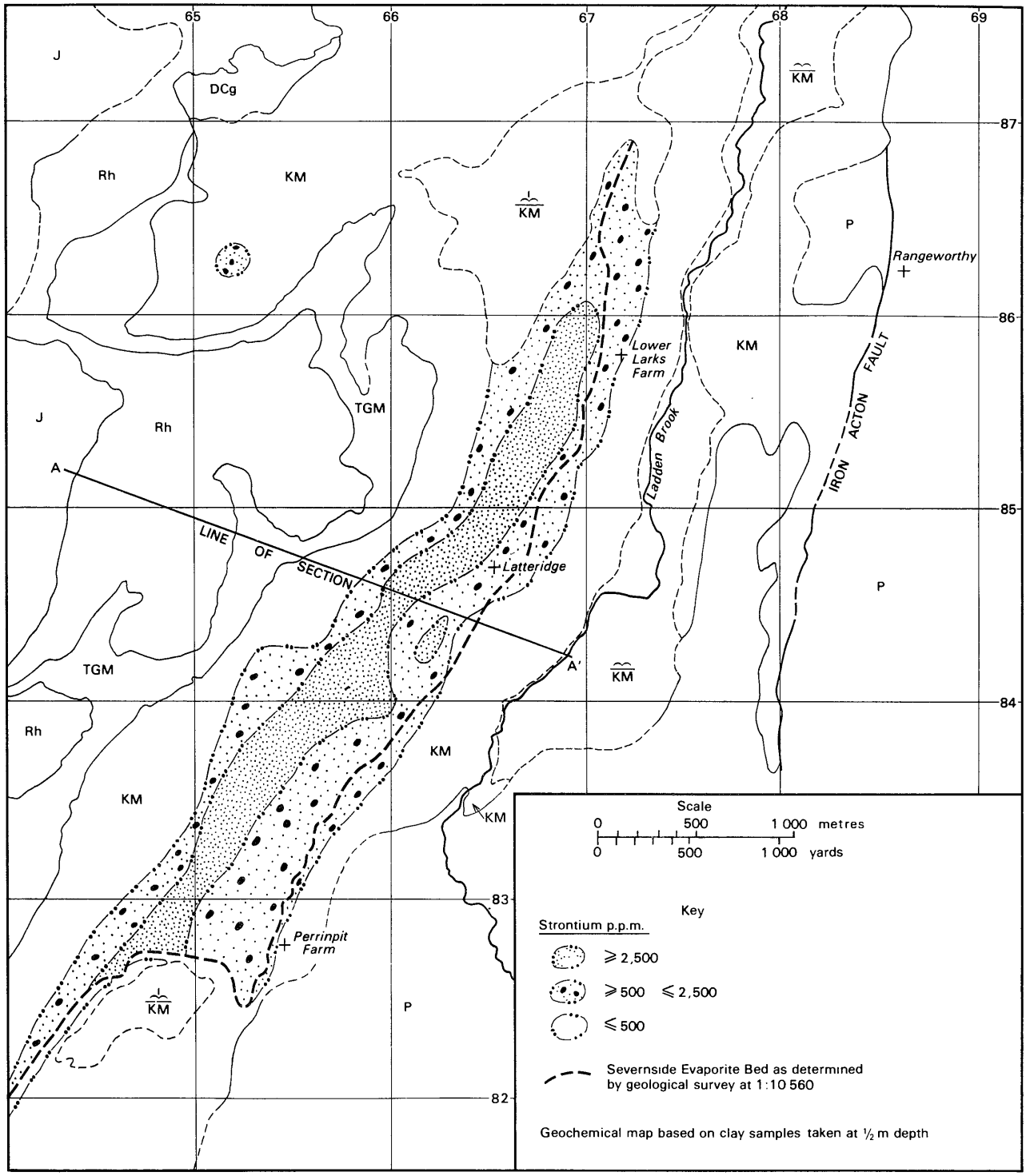


Fig. 7. Geochemical map of the Latteridge area (cross section included in Fig. 25)
Note:For explanation of symbols see resource sheet (in pocket)

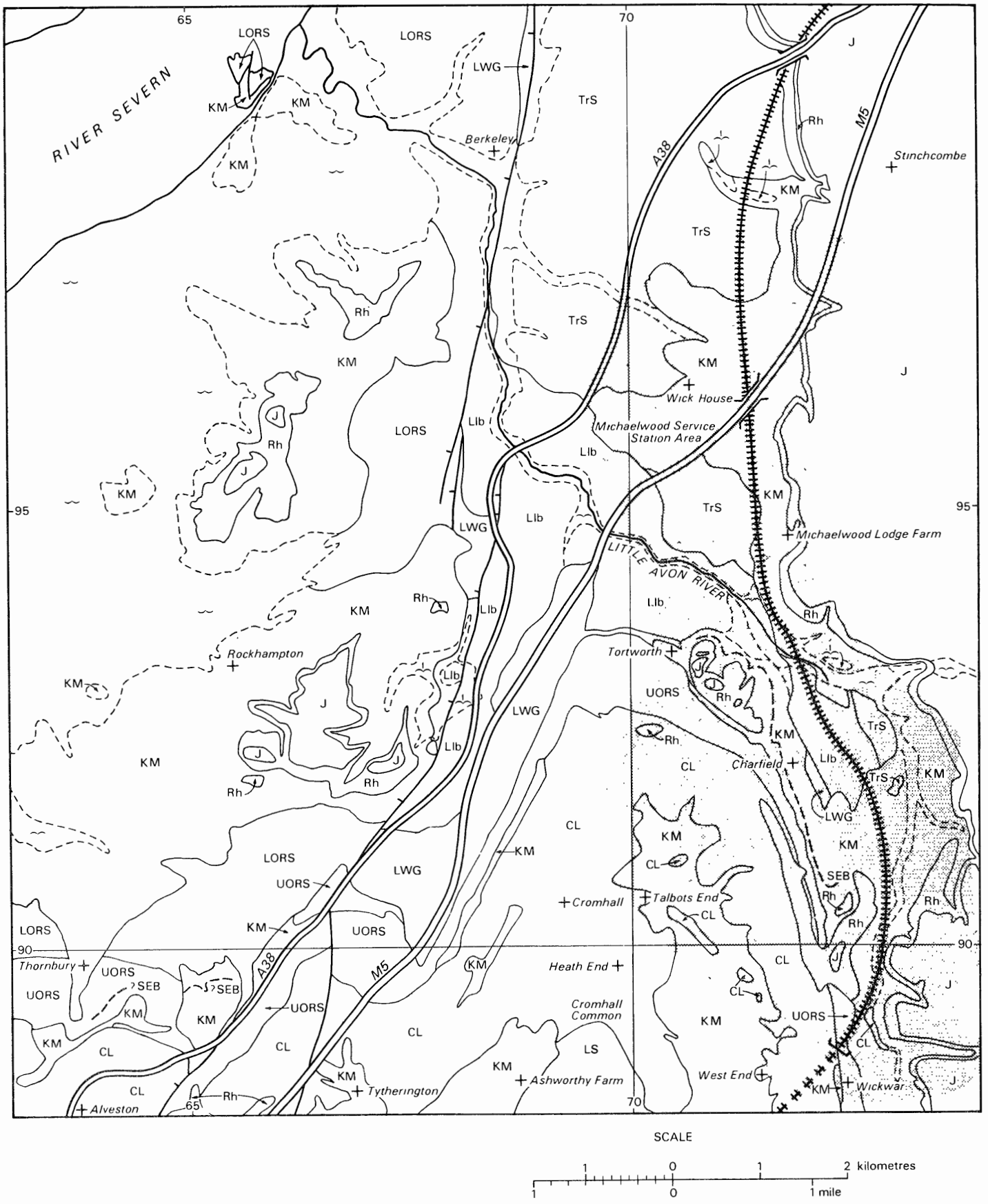


Fig. 8. Michaelwood–Wickwar area
Note: TGM and DCg included in KM. For explanation of symbols see resource sheet (in pocket)

The mineral occurred within 2.4 m of the surface. It is possible, however, that minor amounts of redistributed vein or disseminated celestite may be present at greater depths. On the basis of the yields no systematic variation in mineral distribution can be determined, but the highly variable amounts recovered suggest that celestite is impersistent over much of the study area and that a yield of 60 tonnes per hectare might be expected.

Analyses of representative samples from four localities are given in Table 3. Samples from Perrinpit Farm show SrO to vary from 32.7 to 36.9 per cent, and CaO and SiO_2 to vary from 8.81 to 12.0 and 7.05 to 13.0 per cent respectively. A sample from Sheephouse Farm, Latteridge [6445 8418], contained SrO 52.6 per cent, CaO 1.89 per cent and SiO_2 1.35 per cent. To the north, analysis of samples from Itchington and Moorleaze shows a concomitant increase in SiO_2 as the proportion of SrO decreases.

Although the Celestine Conference considered that 60 hectares of ground between Itchington and Latteridge probably contained celestite (Fig. 4), generally at or near the surface, resources are inferred over 1455 hectares, the thickness of overburden increasing north-westwards. From a study of temporary sections it is thought that the yield estimated in the vicinity of Perrinpit Farm may not be representative of the district as a whole, for which significantly higher yields, though probably not in excess of 200 tonnes per hectare, might be expected. Assuming an average yield of 100 tonnes per hectare the resources of the district would be 145 500 tonnes.

4.3 *MICHAELWOOD-WICKWAR*

This district of gently rolling hills is overlooked by the Jurassic scarp to the east. The rocks are Triassic mudstones which rest unconformably on a broad ridge of inclined Palaeozoic strata. The Little Avon River has cut a steep valley into and, near Charfield [720 921], through the Triassic cover (Fig. 8).

Within the Keuper Marl some 10 m below the base of the Tea Green Marl, a bed of celestite or gypsum, correlated with the Severnside Evaporite Bed, may be present but is only laterally persistent in the Tortworth area, where it has been traced for some $2\frac{1}{2}$ km along the outcrop. Deposits of Head between Stinchcombe [729 898] and Michaelwood [705 952] restrict geochemical sampling of the bedrock. As in other districts permeable rocks at no great depth below celestite or gypsum may have affected both its thickness and composition.

In the north of the district traces of celestite have been detected near Wick House [7078 9677]. In the M5 motorway cutting through Michaelwood a deposit of gypsum, up to 3 m thick, occurs on the irregular surface of Cambrian strata but no celestite has been noted. To the south-east of Michaelwood at [7130 9440] small friable nodules of celestite occur in sandy Keuper Marl which rests unconformably on the Cambrian. In a clay pit [716 926] exposing Tea Green Marl, Keuper Marl and Wenlock Shales (see 5.2.1) in Tortworth Copse, up to four seams of nodular celestite in green mudstone are present and until 1950, the mineral was dug as a by-product. Some 300 m to the east of Poundhouse Farm a brash of coarsely crystalline nodular celestite covers the field at [7203 9163]. To the south no celestite has been observed but gypsum occurs, for example, near Little Bristol.

A field [7320 8785] south-east of Wickwar is believed to have been worked for celestite prior to 1939, but no information on the precise location of the workings or their yields is available.

It is thought that the district does not contain sizeable resources of celestite as the mineral has been found only sporadically and only small-scale working is known.

Steep slopes and rapidly increasing thicknesses of overburden would inhibit working in the Charfield area. Nevertheless, resources (probably sub-economic) are indicated over 22 hectares with less than 10 m of overburden. Quantitative information cannot be provided for the area as a whole, but from geological considerations it is thought that yields generally would not exceed 100 tonnes per hectare and that a minimum yield of 50 tonnes per hectare might be expected. Analyses of samples of celestite from Charfield Brickpit shows 50.2 to 53 per cent SrO (see Table 4).

Although celestite is reported to have been dug south-east of Wickwar resources (probably sub-economic) may be inferred to remain over 8 hectares. A yield of up to 50 tonnes per hectare is expected. It is estimated, on the basis of an average yield of 20 tonnes per hectare, that 160 tonnes would be present. However, the Severnside Study (Central Unit for Environmental Planning, 1971, para. 5.17) considered this part of the Little Avon Valley as of high landscape value.

4.4 *THORNBURY-OLDBURY*

The main topographic feature of the region is an arcuate ridge of Carboniferous Limestone which bounds the area to the east and south and separates the Thornbury—Oldbury area in the north from the Aust—Henbury area to the south (Fig. 9). Complex folding and faulting during the Armorican orogeny (mainly Permo-Carboniferous in age) and subsequent erosion formed a depositional basin floored by Silurian and Devonian strata and flanked by Carboniferous Limestone in which Dolomitic Conglomerate and Keuper Marl were deposited on a highly irregular land surface during Triassic times.

Celestite has been reported from the Whitfield area (Reed and Reynolds, 1908) where it occurs as vein infillings in Silurian shales at [6740 9130] and from the railway cutting [6520 8920] near Grovesend (Welch and Trotter, 1961). The only record of the mineral being worked is in the fields 300 m north-north-west of the northern portal of the Grovesend tunnel [6520 8920], which were dug in 1914.

The outcrop of the Keuper Marl, south of Thornbury, is thought to be more extensive than is shown on the map and thin residual Keuper

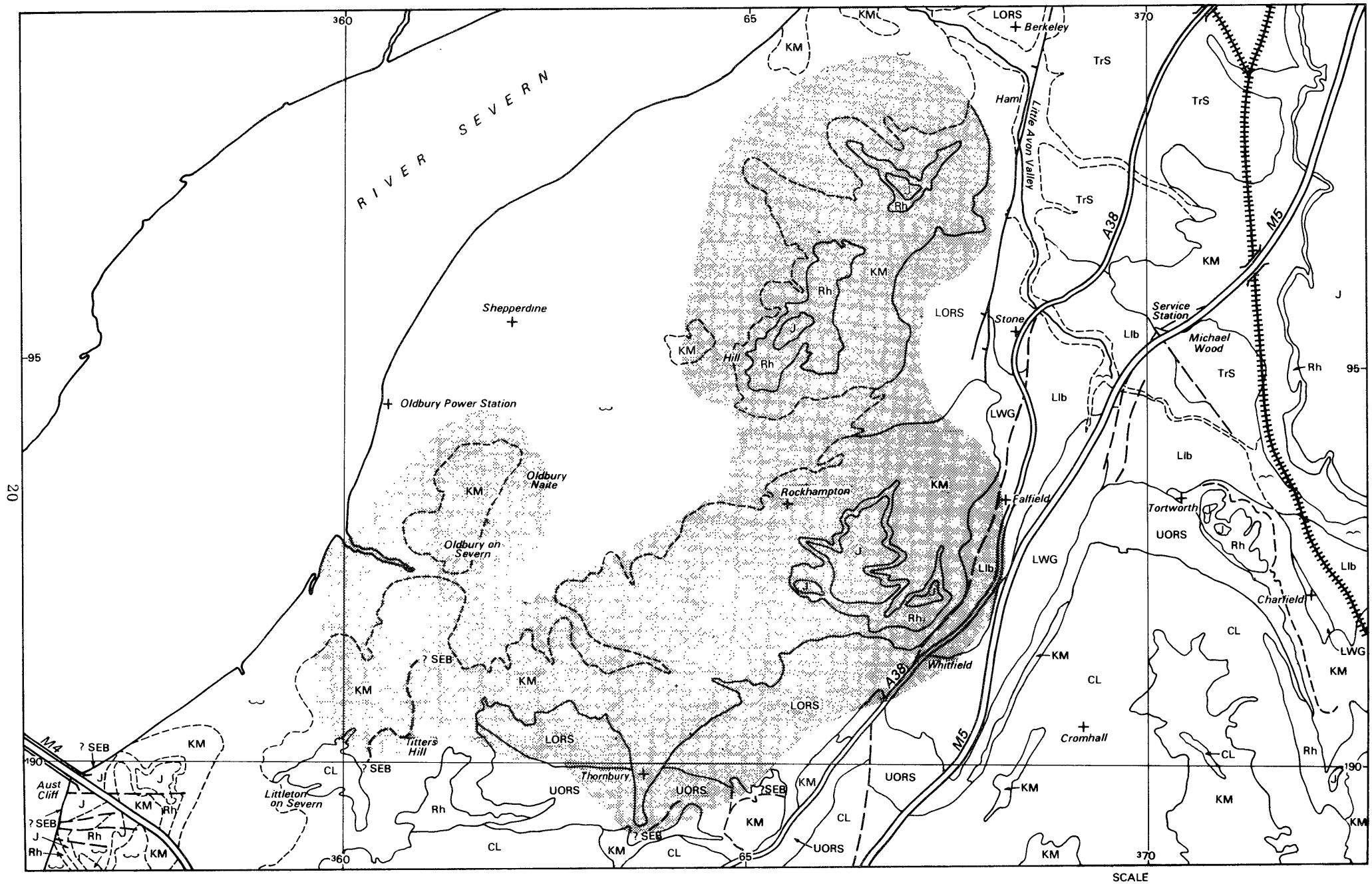


Fig. 9. Thornbury–Oldbury area
Note: TGM and DCg included in KM. For explanation of symbols see resource sheet (in pocket)

Table 3. Chemical analyses : Tytherington—Winterbourne

Locality	Grid Ref.	SrO	BaO	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Total[1]
ITCHINGTON	6595 8670*	41.10	1.80	12.00	0.07	0.00	0.24	0.55	34.20	89.96
MOORLEAZE[2]	6696 8720*	13.00	1.00	0.32	0.00	0.00	0.11	26.00	8.00	48.43
SHEEPHOUSE FARM, LATTERIDGE	6445 8418*	52.60	0.81	1.89	0.03	0.07	0.34	1.35	41.90	98.99
PERRINPIT FARM, FRAMPTON COTTERELL	6547 8317+	32.70	0.76	8.81	1.39	1.83	4.24	13.00	26.70	89.43
	6514 8308+	34.10	1.50	12.00	0.74	0.56	2.45	9.55	28.10	89.00
	6528 8314+	36.90	1.20	11.00	0.69	0.28	1.91	7.05	29.90	88.93
	Mean	34.57	1.15	10.60	0.94	0.89	2.87	9.87	28.23	89.12

Source of samples: * natural section
+ large diameter auger hole

[1] See section 3.2

[2] Partially silicified celestite

Table 4. Chemical analyses: Michaelwood—Wickwar

Locality	Grid Ref.	SrO	BaO	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Total[1]
CHARFIELD BRICKPIT	716 925**	53.00	0.74	0.53	0.16	0.14	0.55	2.15	41.80	99.07
	"	50.20	1.33	1.38	0.50	0.24	0.83	3.20	40.60	98.28
	Mean	51.60	1.04	0.96	0.33	0.19	0.69	2.68	41.20	98.68

Source of sample : ** disused pit.

[1] See section 3.2

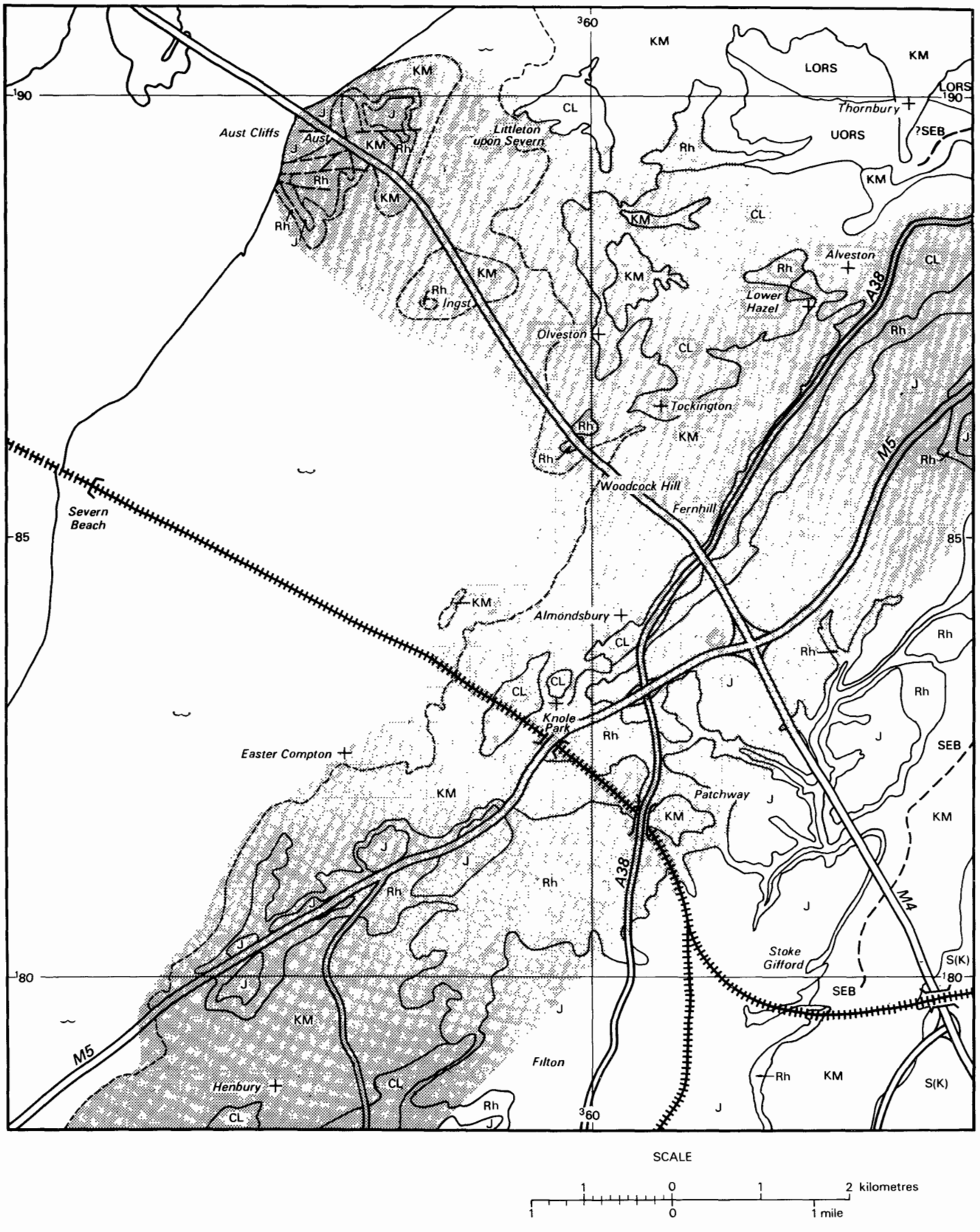


Fig. 10. Aust–Henbury area
Note: TGM and DCg included in KM. For explanation of symbols see resource sheet (in pocket)

Marl, containing celestite, has been found at [6375 8905] and [6325 8945] (see 5.3.1).

A bed of nodular and/or disseminated celestite with trace amounts of gypsum, tentatively identified as the Severnside Evaporite Bed, has been traced near Grovesend, from Cleve Wood [6548 8944] to near the disused railway line at [6491 8936], on the Thornbury Industrial Estate, from the disused railway line at [6420 8946] to [6397 8925], and in the Titters Hill area, from [6020 9018] northwards to [6082 9122]. The Triassic rocks dip gently westwards and the bed falls from about 76 m above OD at Cleve Wood to about 60 m on the Thornbury Industrial Estate, and 22 m in the Titters Hill area. No evidence of the Severnside Evaporite Bed has been found in the Pullens Green [613 922], Oldbury [613 926], Oldbury Naite [622 935] area where the Keuper Marl, though arenaceous, forms low lying ground, generally less than 20 m above OD, nor eastwards in the Rockhampton—Hill [650 932 — 646 952] area where much of the higher ground is capped by Tea Green Marl and Rhaetic clays.

Apart from old workings near Thornbury, there is no record of celestite production from this region. Scattered nodules of celestite have been used to trace a bed of nodular and disseminated celestite near Thornbury and north of Titters Hill. However, it is thought that the geological evidence is insufficient to identify areas of resources at the indicated level, but a total area of 65 hectares in which resources are inferred to be present has been delineated on the map.

Examination of temporary sections suggests that yields might range up to 50 tonnes per hectare but average 30 tonnes per hectare. On this basis the estimate for the district will be 1950 tonnes. Qualitative data are given in Table 5.

4.5 *AUST-HENBURY*

This roughly triangular shaped district is bounded to the north and east by Carboniferous ridges which abut almost at right angles south of Thornbury [640 902]. The floodplain and estuary of the Severn lie to the west (Fig. 10), where extensive Alluvium obscures the Keuper Marl and fans of Dolomitic Conglomerate which radiate from the high ground and infill a basin floored by Carboniferous strata. Exposures of the solid formations are restricted to the margins of the basin and the hills at Aust [537 891] and Ingst [582 879] which rise above the Alluvium. Locally, Keuper Marl is succeeded by Tea Green Marl and Rhaetic: at Aust and Ingst Jurassic strata overlie the Trias.

In the classic Aust Cliff section [5724 8098] Reynolds (1947) described nodular gypsum beds, associated with satin spar veining and thin gypsum sheets, forming a band about 5 m thick, approximately 15 m below the base of the Tea Green Marl. Although sampling has shown only trace amounts, Mr I.H. Ford (personal communication) found nodular celestine hereabouts.

Celestite has not been observed between Aust and Awkley, where a road cutting [5960 8582] exposes a veinlet of celestite up to 0.1 m thick (see 5.4.1). In the shallow valley running from Lower Hazel [6262 8740] to Tockington [6086 8656] gypsum nodules, commonly replaced by calcite and quartz with traces of celestite, occur in thin Keuper Marl resting on Dolomitic Conglomerate.

In the area of Woodcock Hill [6033 8547] and Fernhill [6119 8508] a bed of gypsum containing minor amounts of celestite showing replacement by fine grained calcite, crops out impersistently, approximately 18 m below the base of the Tea Green Marl. However, adjacent to the limestone ridge gypsum occurs at about 5 m below the base of the Tea Green Marl. The relative difference in the level of the bed, probably reflects a depositional dip, rather than structural control.

Nodular celestite at the Triassic/Carboniferous unconformity occurs at [6060 8474] near Lower Court Farm, Almondsbury. Farther south, at Knowle Park [5960 8355] and near Cattybrook Brickpit [5880 8325] bedded gypsum with up to 30 per cent by volume of celestite and calcite crops out, falling from about 58 m above OD in the east to 13 m in the west. Nearby [between 5897 8020 and 5937 8072] stratiform celestite, tentatively correlated with the Severnside Evaporite Bed, is shown on the map. It has not been possible to recognise its continuation south of Over Court [5990 8680] where Tea Green Marl and Rhaetic, clay wash and made ground invalidate geochemical sampling, but to the south-east near Elmsleigh Farm [5713 8052] strontium values in excess of background (see 6.2.4) were recorded.

Dr G.A. Kellaway (personal communication) recorded celestite and gypsum nodules in red and green mudstone at Henbury [5633 7879] and Lawrence Weston [5415 7787] when these areas were developed for housing in the 1930's.

Although celestite has been recorded at Awkley, Almondsbury and Henbury, there is no report of the mineral being worked in this region. There is insufficient information regarding the stratiform celestite traced near Over Court to justify the indicated level of assessment and consequently an area of 10 hectares inferred to contain resources is shown on the map. Quantitative data is lacking, but field observations suggest that yields of up to 20 tonnes per hectare might be expected. Assuming an average of 15 tonnes per hectare, the estimated yield for the district would be 150 tonnes. Qualitative data are given in Table 6.

4.6 *WAPLEY-BITTON*

Triassic mudstones which crop out for approximately 12 km between Wapley [714 796] and Bitton [683 695] form low ground beneath a west-facing escarpment of Jurassic limestones, mudstones and clays (Fig. 11).

The Mesozoic rocks overstep the south-eastern part of a major syncline of Palaeozoic strata (Fig. 1), the Carboniferous Limestone flanks of which formed high ground during Triassic times. Although Keuper Marl crops out at the foot of the escarpment along its entire length, the Severnside Evaporite Bed is only sporadically

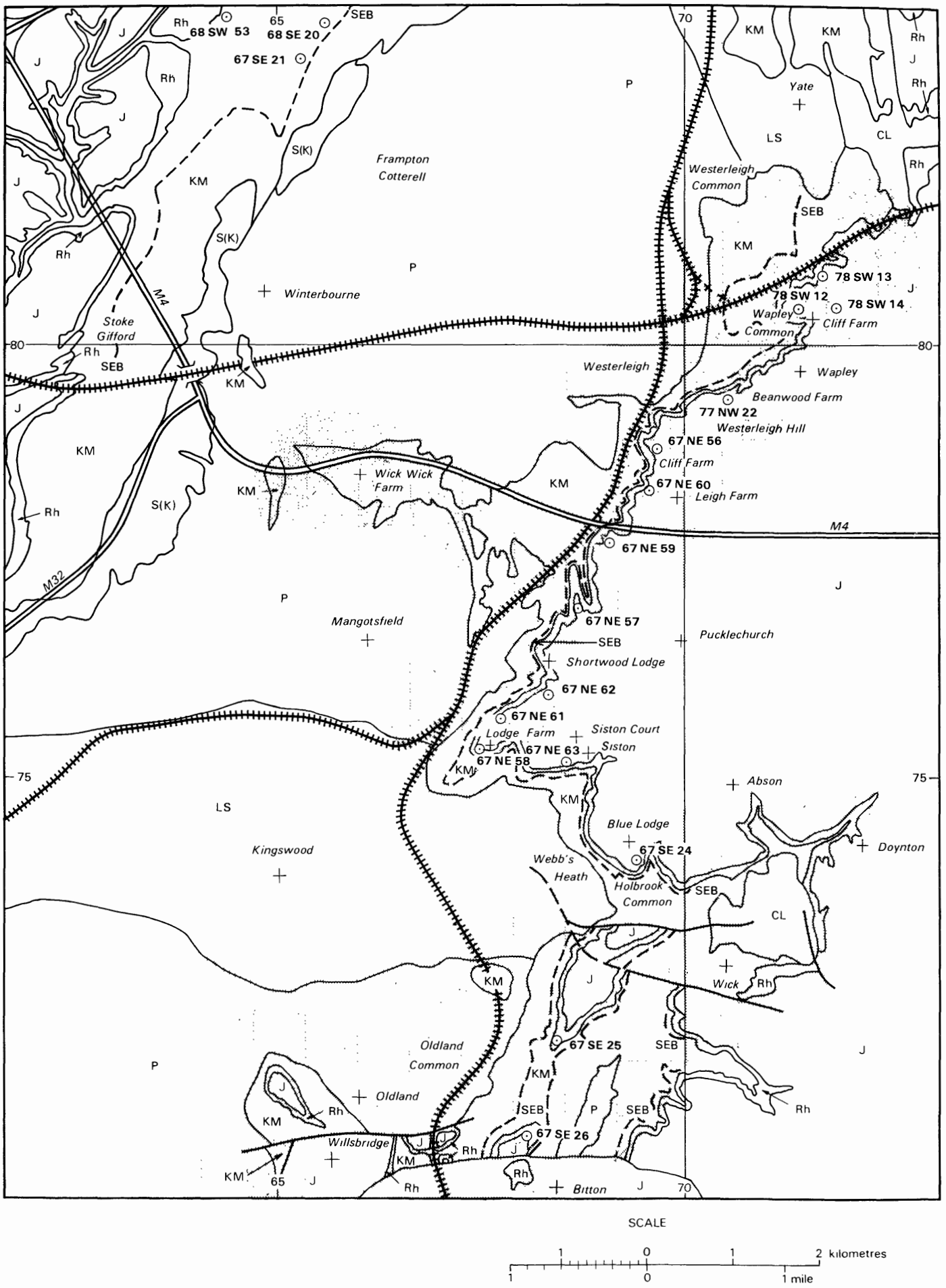


Fig. 11. Wapley–Bitton area
Note: TGM and DCg included in KM. For explanation of symbols see resource sheet (in pocket)

Table 5. Chemical analyses : Thornbury—Oldbury

Locality	Grid Ref.	SrO	BaO	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Total[1]
THORNBURY IND. ESTATE	6400 8930***	52.80	0.83	0.20	0.00	0.38	0.83	2.15	41.40	98.59
STOCK HILL, AUST	608 909****	48.00	1.30	5.33	0.42	0.00	0.48	2.35	38.00	95.88

Source of samples : *** temporary section
**** surface brash

[1]See section 3.2

Table 6. Chemical analyses : Aust—Henbury

Locality	Grid Ref.	SrO	BaO	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Total[1]
AWKLEY	5960 8584***	52.80	2.30	0.30	0.09	0.14	0.40	0.95	42.70	99.68
AUST CLIFF[2]	555 897*	1.00	0.00	20.00	0.87	0.00	1.23	3.45	60.00	86.55
LITTLETON-ON-SEVERN[3]	598 893***	2.00	0.00	2.55	0.00	0.00	0.68	65.00	1.00	71.23
LOWER COURT FARM, ALMONDSBURY	6060 8475*	52.40	2.80	2.01	0.01	0.00	0.09	0.15	42.50	99.96

Source of samples : * natural section
*** temporary section

[1] See section 3.2

[2] Gypsum

[3] Silicified evaporite

exposed, being obscured by extensive areas of Tea Green Marl and Rhaetic downwash material, especially between Westerleigh Hill Farm [7035 7920] and Shortwood Lodge [6833 7628]. Between exposures geochemical traverses have been used to establish its position, except beneath hillwash where borehole evidence has been used.

Fifteen cored boreholes sunk at scattered locations between Wapley and Bitton show the Severnside Evaporite Bed to be nearly continuous beneath Jurassic cover. The presence of inliers of Carboniferous Limestone near Doynton [721 741] and Codrington [729 788] suggests that the Keuper Marl thins out eastwards against a buried ridge of Carboniferous rocks.

In the Yate—Wapley Common area the Severnside Evaporite Bed underlies a plateau, the curved limit of which forms a subsidiary feature abutting the Jurassic escarpment. Temporary sections to the north of the Bristol-Swindon railway line showed bedded celestite up to 0.4 m thick (see 5.5.1). South of the railway line the Bed crops out near Poole Farm [7075 8030] and continues eastwards under increasing overburden so that at Wapley Bushes about 8 m of cover overlie the mineral.

Seven 1 m diameter auger holes with a mean depth of 5 m were sunk on Wapley Common; all proved celestite, yields ranging from 9 to 270 kg/m^2. Samples from two of the auger holes show quartz, 23 to 27 per cent, and calcite, 7 to 10 per cent (see 5.5.3). East of Wapley Common, borehole ST 78 SW 12 [7124 8029] proved 0.4 m of nodular coarsely crystalline celestite. Boreholes ST 78 SW 13 and 14 [7167 8082 and 7167 8035] show that the Severnside Evaporite Bed contains celestite nodules usually less than 50 mm across, scattered throughout approximately 1 m of sandy Keuper Marl or Dolomitic Conglomerate.

South of Wapley Common fragments of celestite in soil allow the Severnside Evaporite Bed to be traced more or less continuously at outcrop through Beanwood Farm [7072 7962] towards Westerleigh Hill [704 791] where it crops out in a road-cutting [7038 7950]. Borehole ST 77 NW 22 [7048 7932] and samples from ditches and trenches dug in fields to the north of Beanwood Farmhouse show celestite to contain up to 20 per cent by volume of coarsely crystalline quartz, which occurs as 'cores' up to 20 mm in size.

South of Westerleigh Hill, borehole ST 67 NE 56 [6869 7876] indicates that the Severnside Evaporite Bed contains three seams of gypsum nodules each seam usually less than 40 mm thick.

Extensive areas of hillwash cover the hillsides and obscure the outcrop southwards to Shortwood Hill [684 759]. Boreholes ST 67 NE 57, 59 and 60 [6867 7698, 6904 7763 and 6949 7827] proved gypsum with only traces of celestite.

The Severnside Evaporite Bed has been traced in the vicinity of Lodge Farm [6770 7528], where it underlies a small plateau-feature standing out from the base of the Jurassic escarpment. Boreholes ST 67 NE 58 and 61 [6750 7523 and 6769 7560] and geochemical evidence indicate the presence of celestite at two levels. The upper level comprises nodules (up to about 0.2 m mean diameter) of celestite with quartz and only trace amounts of gypsum; the lower level consists only of vein material, usually celestite with calcite and gypsum, in greenish grey mudstone. Yields from five auger holes sunk to a mean depth of 4.0 m on a field [673 751] on Lodge Farm range from 6 to 93 kg/m^2. Analysis of representative samples shows SiO_2 to vary from 4 to 19 per cent and SrO values of 9 to 53 per cent.

Borehole ST 67 NE 63 [6867 7508] near Saint Anne's Well shows the Severnside Evaporite Bed to contain celestite nodules with considerable quantities of coarsely crystalline quartz, but southwards borehole ST 67 SE 24 [6943 7393] proved gypsum. Near Doynton, celestite, occurring at the same stratigraphic level, infills vugs and cavities in Dolomitic Conglomerate which fringes the Carboniferous Limestone inlier.

Between Doynton and Bitton, the Jurassic escarpment lies to the east of Golden Valley and the Severnside Evaporite Bed, forming small bench-like features on the hillsides, has been found sporadically along the eastern side of the valley, for example at [697 715] and [696 713]. Celestite nodules with vuggy infillings of calcite and trace amounts of gypsum have been recorded.

From Holbrook Common [695 736] to Bitton, the Severnside Evaporite Bed crops out on the eastern and western sides of an elongated north-south hill, capped at both ends by Rhaetic and Lias mudstones and clays. Boreholes ST 67 SE 25 and 26 [6839 7180 and 6806 7067] and five auger holes sunk to a mean depth of 3.8 m in a field [6845 7145] on Redfield Hill Farm show that the Severnside Evaporite Bed contains up to three seams of nodules, each up to 200 mm thick, composed of celestite, gypsum, quartz and calcite. Augerhole yields range from 19 to 135 kg/m^2 and analysis of samples indicates SiO_2 to be less than 8 per cent; CaO values to vary from 0.33 to 20 per cent; SrO to vary from 13.0 to 53.5 per cent.

Thomas (1973) recorded celestite from the triangular shaped outlier of Triassic deposits at Wick Wick which is confirmed by borehole ST 67 NE 64 [6682 7862] and field investigations to be restricted to the flanks of a ridge of Pennant Sandstone buried beneath Keuper Marl. To the west of the ridge, scattered nodules of celestite occur mainly in the vicinity of Wick Wick Farm [6615 7850]. On the eastern side of the ridge, massive celestite locally forms a bed which crops out in the banks of the Folly Brook.

The Keuper Marl in this area forms a residual veneer which unconformably overlies the Palaeozoic strata and includes much Coal Measures debris. Celestite occurs at or near the unconformity and in this respect the Wick Wick occurrences compare with those in the Yate — Cromhall district to the north rather than to the scarp outcrop of the Severnside Evaporite Bed between Westerleigh and Bitton.

Throughout the region, steep slopes and potential difficulties in reinstating and stabilising worked ground, may limit mineral extraction to

areas where the Severnside Evaporite Bed forms plateau features abutting the Triassic-Jurassic escarpment. Assuming that mineral is dug from outcrop to beneath 10 m of overburden, resources over 262 hectares are indicated. Investigations at Wapley, Lodge Farm and Redfield Hill indicate that yields of 1100, 540 and 650 tonnes per hectare respectively might be anticipated in the vicinity of these sites. It is thought that yields would range from 500 to 1500 tonnes per hectare and average 800 tonnes per hectare. On this basis the estimated yield for the district as a whole would be 209 600 tonnes. Qualitative data are given in Table 7.

4.7 *YATE-CROMHALL*

During Triassic times the major north-south syncline of Carboniferous rocks which occupies the district formed an area of continental, arid sedimentation. The Carboniferous Limestone on the flanks of the structure stood up as high ground encircling a lower-lying area of shales and sandstone with an undulating topography. Fans of limestone debris fringed the high ground, but towards the centre of the depression mudstone sedimentation was dominant (Fig. 13).

In the extreme south of the area, the Severnside Evaporite Bed is underlain by either Keuper Marl or Dolomitic Conglomerate. Northwards the Bed progressively oversteps the older Triassic deposits so that north of Yate [713 828] it rests directly on Lower Coal Measures. Between Yate and Cromhall [692 905] the Severnside Evaporite Bed is discontinuous, being restricted to shale-bottomed depressions between ridges of Coal Measures sandstone or quartzite. Clearly, although Triassic sedimentation in the south began in pre-Severnside Evaporite Bed times between Yate and Cromhall, the Severnside Evaporite Bed marks the onset of Keuper sedimentation.

An area between Cromhall and Yate, where no celestite is known, is thought to have formed high ground during Severnside Evaporite Bed times. The extent of this area of non-deposition may be greater or less than that shown on Fig. 13.

Inspection of working pits and trenches dug in connection with the survey show that arenaceous Coal Measures strata closely control the distribution of celestite. It is thought that during Severnside Evaporite Bed times the regional water table stood above the general level of the shale hollows. High evaporation and seepage of water along the junction of shales and quartzites allowed calcium sulphate minerals to concentrate in the hollows where masses of celestite up to several tonnes in weight have been recorded. Although the latter commonly occurs as hollow nodular masses with overgrowths of selenite (hydrated calcium sulphate, $CaSO_4.2H_2O$, a crystalline variety of gypsum), thin sections show relict calcium sulphate minerals in such celestite (see 2.4).

Nodular celestite in residual Keuper Marl and weathered Coal Measures, and Lower Coal Measures with veins of mineral which taper with depth, comprise the resource.

The extent of worked ground, and the area over which resources are indicated, inferred or hypothetical, are shown on the map. Qualitative data are given in Table 8.

It is thought that of the 459 hectares set aside for mineral production in 1951, 200 hectares north of the Yate-Chipping Sodbury urban area remained largely unworked at the end of 1973. The residue has not been identified on the map.

Resources are indicated over 135 hectares and comprise the unworked areas of Keuper Marl. Celestite at, or near, the Triassic/Carboniferous unconformity was proved by trenching at West End Farm [711 875], Hall End [708 867], Limekiln Plantation [705 860], Hunter's Hall [697 891], and Cowship Cottages [705 888] (see 5.6.3). Yields from these sites vary from 70 tonnes per hectare at Hall End to 1510 tonnes per hectare at Limekiln plantation. However, not all trenches on each site proved mineral, demonstrating the wide variations within the deposit and there is doubt that the yield for Hall End is representative. Details of the trenches, which were dug to a mean depth of 4.2 m, are given in 5.6.3. It is thought that yields would range from 200 to 1500 tonnes per hectare and average 750 tonnes per hectare. On this basis the estimate of resources would be 101 250 tonnes.

Two areas totalling 430 hectares where resources are hypothetical have been identified on the basis of regional geological investigations. Celestite may occur either as isolated pockets resting on, or as haphazardly distributed veins in Lower Coal Measures. There is no record of any celestite having been found in or worked from either area where the present-day topography lies not far below the projected plane of Triassic/Carboniferous unconformity. The northern boundary of the Cromhall area and southern margin of the Bagstone-Yate area coincide respectively with the inferred southern and northern limits of high ground, which during Severnside Evaporite Bed times formed areas of non-deposition (Fig. 13). Reported mineral occurrences, field observations and the extent of ground dug for celestite have been used to draw an inferred boundary between areas of hypothetical resources and a belt, 311 hectares in area, extending from south of Cromhall Common to Goose Green, over which resources are inferred. Since 1951, parts of this area, which the Celestine Conference considered probably contained celestite, have been worked, for example, Leechpool [707 852], Hartstrow [714 852], Goose Green [714 834] and Barbers Court [718 881]. It is understood that the mineral occurred as pockets in residual Keuper Marl, and except for the last mentioned locality, vein celestite was also worked. However, there is insufficient information to classify the resource at the indicated level. Trenching at Bristol Cottages [698 894] and the Rose Garden [695 885] failed to prove any celestite within the Palaeozoic rocks. Details are given in 5.6.2.

A recent working [6988 8898] in Lower Coal Measures south of Cowship Lane is believed to have produced up to about 800 tonnes per hectare:

Table 7. Chemical analyses : Wapley—Bitton

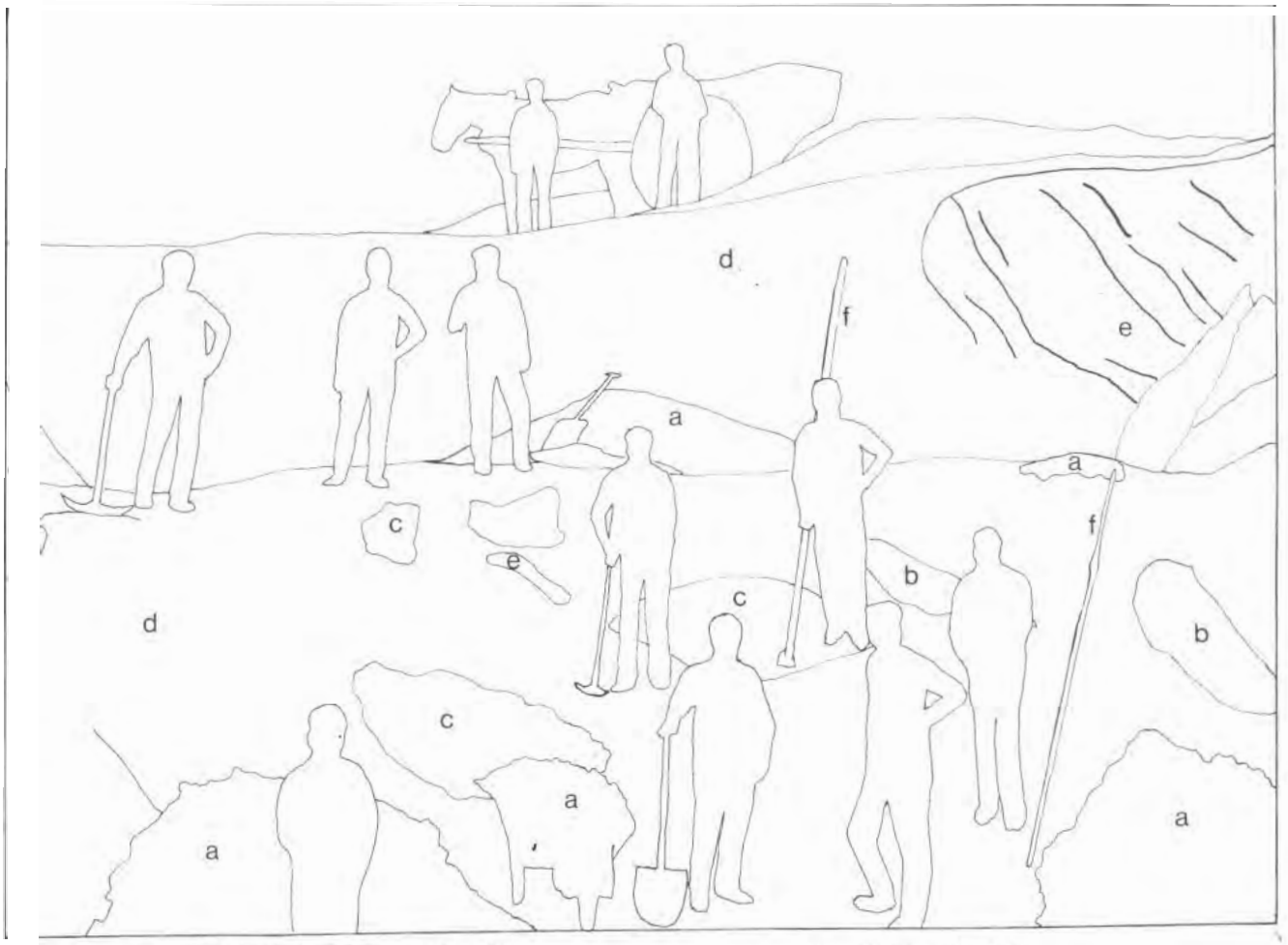
Locality	Grid Ref.	SrO	BaO	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Total[1]
WAPLEY COMMON, WAPLEY	7094 8052+	54.10	1.50	0.59	0.86	0.09	0.35	0.60	42.50	100.59
	7095 8038+	46.40	2.00	3.92	0.15	0.05	0.40	0.90	37.70	91.52
	7097 8031+	47.30	2.10	1.77	0.24	0.30	0.93	2.45	37.90	92.99
	" " +	45.80	1.00	2.95	0.34	0.34	1.33	3.75	37.30	92.81
	7086 8042+	53.50	0.63	1.08	0.00	0.14	0.42	1.35	42.00	99.12
	" " +	51.90	1.20	1.62	0.05	0.17	0.73	1.55	40.30	97.52
	7082 8036+	32.20	0.56	7.59	0.17	0.48	1.23	23.00	25.20	90.43
	7088 8034+	24.00	0.35	10.00	0.35	0.46	2.38	27.00	19.20	83.74
	7090 8029+	51.20	0.48	1.70	0.10	0.26	0.69	5.30	40.00	99.73
	Mean	45.16	1.09	3.47	0.25	0.25	0.94	7.32	35.79	94.27
LODGE FARM, SISTON	6719 7502+	52.80	0.90	0.54	0.06	0.14	0.61	4.45	40.50	100.00
	" " +	9.00	0.00	20.00	1.90	1.40	4.54	14.00	6.00	56.84
	6734 7517+	38.70	1.30	9.07	0.57	0.12	1.35	5.60	30.20	86.91
	6729 7501+	32.20	0.97	0.55	0.72	0.29	2.12	9.30	24.20	70.35
	6739 7500+	41.60	0.64	0.66	0.11	0.00	0.72	19.00	31.60	94.33
	6714 7496+	36.90	1.20	8.49	0.54	0.36	2.20	11.00	28.30	88.99
	Mean	35.20	0.84	6.55	0.65	0.39	1.92	10.56	26.80	82.90

Locality	Grid Ref.	SrO	BaO	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Total[1]
REDFIELD HILL FARM, BITTON	6831 7154+	35.90	1.00	16.00	0.22	0.06	0.40	1.20	28.60	83.38
	6838 7151+	23.00	0.44	20.00	0.90	0.34	1.73	6.85	17.50	70.76
	" " +	53.50	0.69	2.19	0.00	0.00	0.18	0.30	41.60	98.46
	6840 7145+	52.70	2.60	0.33	0.03	0.11	0.49	1.25	42.00	99.51
	" " +	44.00	0.76	6.83	0.19	0.02	0.61	3.65	34.40	90.46
	" " +	42.70	0.66	7.97	0.25	0.07	0.68	1.80	33.40	87.53
	6844 7139+	23.10	0.37	19.00	0.85	0.60	2.26	7.35	17.10	70.63
	6834 7142+	46.30	3.00	0.32	0.17	0.23	0.94	4.65	36.80	92.41
	" " +	39.10	0.61	12.00	0.24	0.00	0.58	1.40	30.30	84.23
	" " +	28.10	0.50	17.00	0.76	0.23	1.84	5.80	21.20	75.43
	" " +	13.00	0.00	5.60	0.58	0.16	1.90	6.90	9.00	37.14
	Mean	36.49	0.97	9.75	0.38	0.17	1.06	3.74	28.35	80.90
SARGEANT'S FARM, YATE	7110 8078***	53.40	0.51	0.40	0.02	0.12	0.47	3.65	42.00	100.57
BEANWOOD FARM, WAPLEY	7037 7951*	40.80	0.58	0.20	0.00	0.22	0.79	26.00	31.00	99.59
ST. ANNE'S WELL, SISTON	6832 7490***	47.70	0.70	1.22	0.00	0.08	0.33	13.00	37.10	100.13
OLDLAND COMMON	6794 7151****	55.70	0.72	0.38	0.07	0.00	0.03	0.05	44.00	100.95
WILLSBRIDGE	6698 7052*	46.60	2.40	7.03	0.09	0.15	0.44	1.30	35.80	93.81
UPPER CULLEYHALL FARM, BITTON	6787 7100****	39.00	0.44	6.55	0.11	0.08	0.71	20.00	30.00	96.89
WICK WICK	6659 7835*	51.60	2.20	0.34	0.00	0.28	0.83	3.65	40.70	99.60

Source of samples : + large diameter auger hole
* natural section
*** temporary section
**** surface brash

[1] See section 3.2

Plate 3. Celestite-bearing rock is extracted by the front-end loader, tipped on either side of the track leading to the pit, where it is sorted. Pits rarely exceed 10 m in depth. Former working [6988 8898] south of Cowship Lane, Cromhall, 1971



a. Hand-picked lump celestite
b. Vein celestite
c. Pockets of nodular celestite
d. Coal Measures Shale
e. Coal Measures Sandstone
f. Probe bar

Plate 4. Celestite working north of Yate, about 1920 (For explanation see annotated sketch on opposite page)

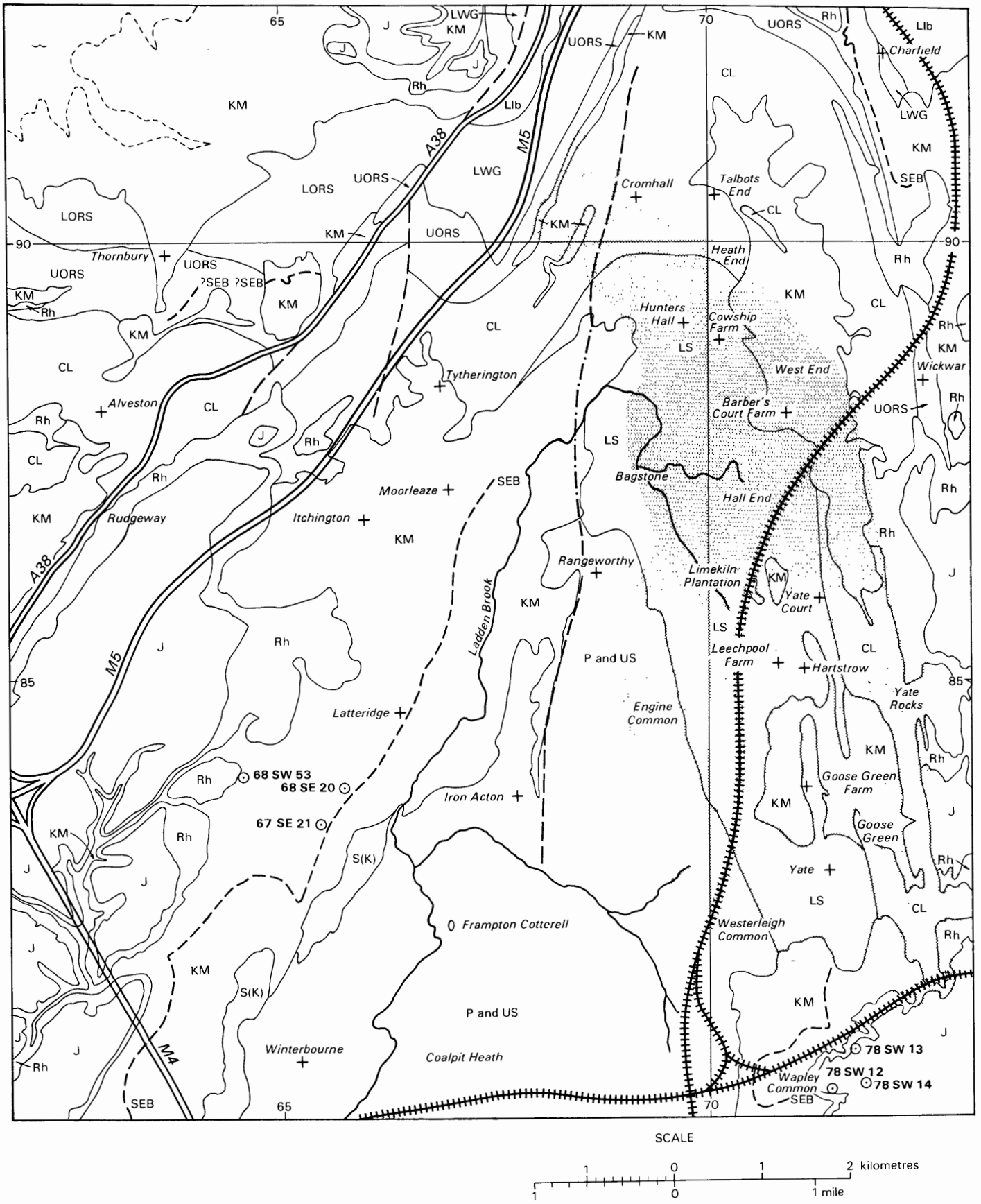


Fig. 12. Yate–Cromhall area
Note: TGM and DCg included in KM. For explanation of symbols see resource sheet (in pocket)

the mineral occurred as veins. No other information on the distribution of vein celestite is available but on the basis of field observations and exploratory work it is thought that the yield from the Cowship Lane workings is not representative, and for the area of Coal Measures as a whole it is more reasonable to assume an average yield of 200 tonnes per hectare, from which a total yield of 62 200 tonnes could be expected.

Because of the haphazard distribution of vein celestite in the Lower Coal Measures it is not possible to demarcate mineral-bearing areas. However, it can be expected that in general higher yields of celestite may be obtained from shales close to Lower Coal Measures sandstones (2.4).

Examination of working pits shows patches, usually less than 100 m^2 in area, with nodular celestite, overlying the Coal Measures. These might be outlined by geological mapping at a larger scale than 1:10 560 which would provide further information on the distribution of the celestite in such situations.

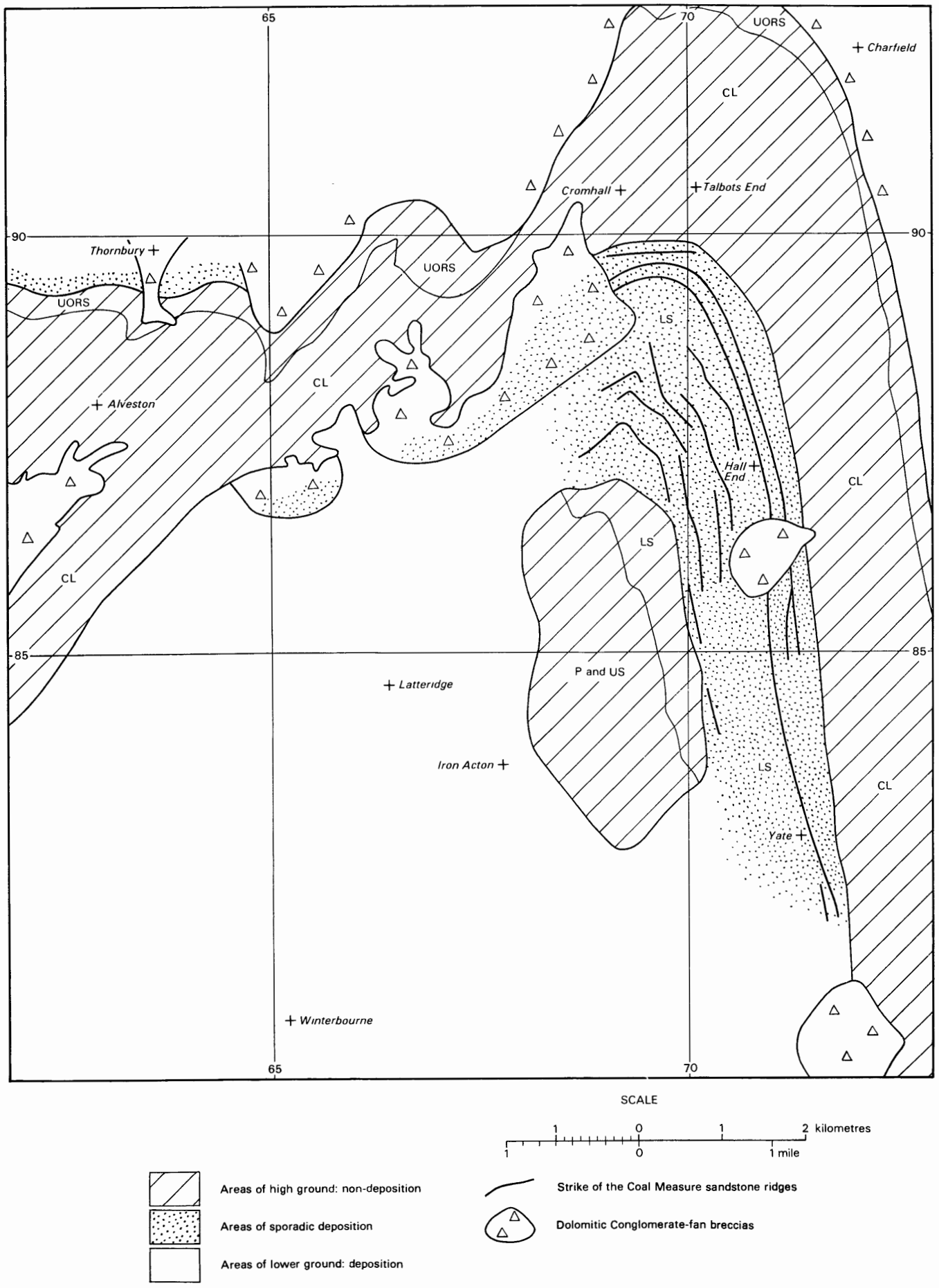


Fig. 13. Yate–Cromhall area: extent of deposition of the Severnside Evaporite Bed
Note: For explanation of symbols see resource sheet (in pocket)

Table 8. Chemical analyses : Yate—Cromhall

Locality	Grid Ref.	SrO	BaO	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Total[1]
WEST END FARM, WICKWAR	7121 8767[x]	55.70	1.30	0.27	0.03	0.11	0.16	0.40	43.70	101.67
	7093 8753[x]	55.90	0.24	0.32	0.05	0.06	0.15	0.42	43.50	100.64
	7097 8765[x]	54.40	1.24	0.94	0.06	0.08	0.18	0.75	43.10	100.75
	Mean	55.33	0.93	0.51	0.05	0.08	0.16	0.52	43.43	101.02
HALL END, WICKWAR	7074 8671[x]	42.60	0.70	2.46	0.12	2.09	3.61	12.20	37.80	101.58
LIMEKILN PLANTATION, WICKWAR	7051 8612[x]	55.30	0.49	0.22	0.00	0.66	0.50	1.20	42.30	100.67
	7049 8701[x]	49.70	2.13	0.17	0.06	1.07	1.84	5.70	40.00	100.67
	7061 8593[x]	50.80	0.04	0.16	0.03	1.61	0.82	4.40	40.90	98.76
	Mean	51.93	0.89	0.18	0.03	1.11	1.05	3.77	41.07	100.03
HUNTER'S HALL, CROMHALL	6964 8903[x]	50.80	2.75	0.26	0.06	0.52	1.14	4.10	41.50	101.13
	6960 8909[x]	54.10	0.54	0.29	0.04	0.42	0.98	1.80	42.30	100.47
	6968 8906[x]	54.50	1.08	0.48	0.02	0.19	0.38	1.02	42.50	100.17
	Mean	53.13	1.46	0.34	0.04	0.38	0.83	2.31	42.10	100.59
COWSHIP COTTAGES, WICKWAR	7068 8876[x]	54.50	0.89	1.39	0.07	0.09	0.21	0.75	42.70	100.60
	7058 8891[x]	55.20	0.55	1.33	0.00	0.03	0.09	0.20	42.50	99.90
	7052 8890[x]	53.20	0.94	0.97	0.06	0.30	0.84	2.10	41.30	99.71
	Mean	54.30	0.79	1.23	0.04	0.14	0.38	1.02	42.17	100.07
LEECHPOOL, YATE	7090 8505[**]	52.80	1.50	0.19	0.00	1.19	0.95	2.35	41.20	100.18
	" "	53.90	1.19	0.23	0.00	2.22	0.46	1.60	42.00	101.60
	Mean	53.35	1.35	0.21	0.00	1.70	0.70	1.98	41.60	100.89

Locality	Grid Ref.	SrO	BaO	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Total[1]
WEST END FARM, WICKWAR	7127 8777*	43.10	1.10	7.62	0.17	0.00	0.50	5.80	34.70	92.99
COWSHIP LANE, CROMHALL	699 889**	54.90	0.48	0.20	0.02	0.05	0.40	0.85	42.60	99.50
TALBOT'S END, CROMHALL	7085 9037****	37.50	0.77	14.00	0.05	0.00	0.39	1.40	30.20	84.31

Source of samples :
* natural section
** working pit
**** surface brash
x trench

[1] See section 3.2

5. Details

5.1 *TYTHERINGTON-WINTERBOURNE*

5.1.1 *Geological Notes*

MOORLEAZE: A stream bank [6695 8719] shows celestite in Keuper Marl. The mineral is associated with quartz and occurs as a broken nodular bed 0.10 m thick above a near-horizontal, thinly bedded greenish grey, calcareous sandstone. Hand specimens and a thin section (E 43 696)[1] show extensive replacement of celestite by quartz. Orthorhombic moulds in quartz indicate the former presence of celestite.

ITCHINGTON: A ditch between [6520 8626] and [6502 8614] exposes Keuper Marl with bedded nodular sugary white celestite. To the east of The Rookery [6540 8666] a ditch section shows celestite at the same stratigraphic level extensively replaced by quartz and calcite. A recent (1974) pipeline excavation [6570 8665] showed massive celestite nodules up to 1 m in diameter free of quartz.

In a ditch section [6709 8640] 500 m north of Lark's Farm [6702 8589] reddish brown Keuper Marl dips 10° to the west and shows:

	Thick-ness m	Depth m
Keuper Marl		
Soil and red calcareous mudstone	0.15	0.15
Severnside Evaporite Bed: celestite nodular, saccharoidal, up to 0.15 m, on mudstone, calcareous, red passing into sandstone, greenish grey, calcareous, flaggy with celestite lined vugs up to 0.05 m at 0.91 m	0.99	1.14
Mudstone, reddish brown, calcareous Base not seen	0.69+	1.83

A temporary section [6654 8495] 160 m north of the Latteridge cross roads showed the following sequence:

	Thick-ness m	Depth m
Soil	0.3	0.3
Keuper Marl		
Severnside Evaporite Bed: mudstone, reddish brown with friable celestite in upper 0.08 m becoming mottled greenish grey with nodules of saccharoidal celestite up to 0.1 m below 0.84 m	0.64	0.94
Mudstone, reddish brown Base not seen	0.05+	0.99

A ditch section [6546 8386] about 50 m west of Lock Lane shows arenaceous Keuper Marl dipping 10° to the north-west:

	Thick-ness m	Depth m
Keuper Marl		
Mudstone, reddish brown mottled greenish grey in places, weathered	0.9	0.9
Severnside Evaporite Bed: sandstone, greenish grey, clayey with celestite nodules up to 0.1 m	0.3	1.2
Mudstone, reddish brown, very sandy mottled greenish grey in places	0.15	1.35
Sandstone, green mottled reddish brown	0.15	1.50
Mudstone, reddish brown, indurated. Base not seen	0.05+	1.55

An old marl pit [6543 8299] 200 m north of Perrinpit Farm [6545 8275] has a weathered east-facing section showing the following sequence:

	Thick-ness m	Depth m
Keuper Marl		
Sandstone, reddish purple, fine to medium grained, broken	0.10	0.10
Severnside Evaporite Bed mudstone, reddish brown with infrequent celestite nodules up to 0.1 m in upper 0.15 m passing into sandstone, greenish grey with vugs up to 0.08 m lined with celestite and calcite, on mudstone, reddish brown mottled greenish grey, becoming sandy towards the base with macrocellular nodular celestite in lower 0.5 m	1.8	1.9
Mudstone, reddish brown, sandy, with abundant discrete crystals of calcite. Base not seen	0.53+	2.43

Thin sections (E 43 693, E 44 604 and E 44 637) show celestite replacing anhydrite.

A disused marl pit [6524 8240] 400 m south-west of Perrinpit Farm [6545 8275] shows:

	Thick-ness m	Depth m
Soil, with fragments of fine grained purplish red sandstone	0.3	0.3
Keuper Marl		
Clay, reddish brown	0.3	0.6

[1] Numbers in parenthesis preceded by the letter 'E' refer to specimens and thin sections in the Petrographic Collections of the Geological Survey and Museum.

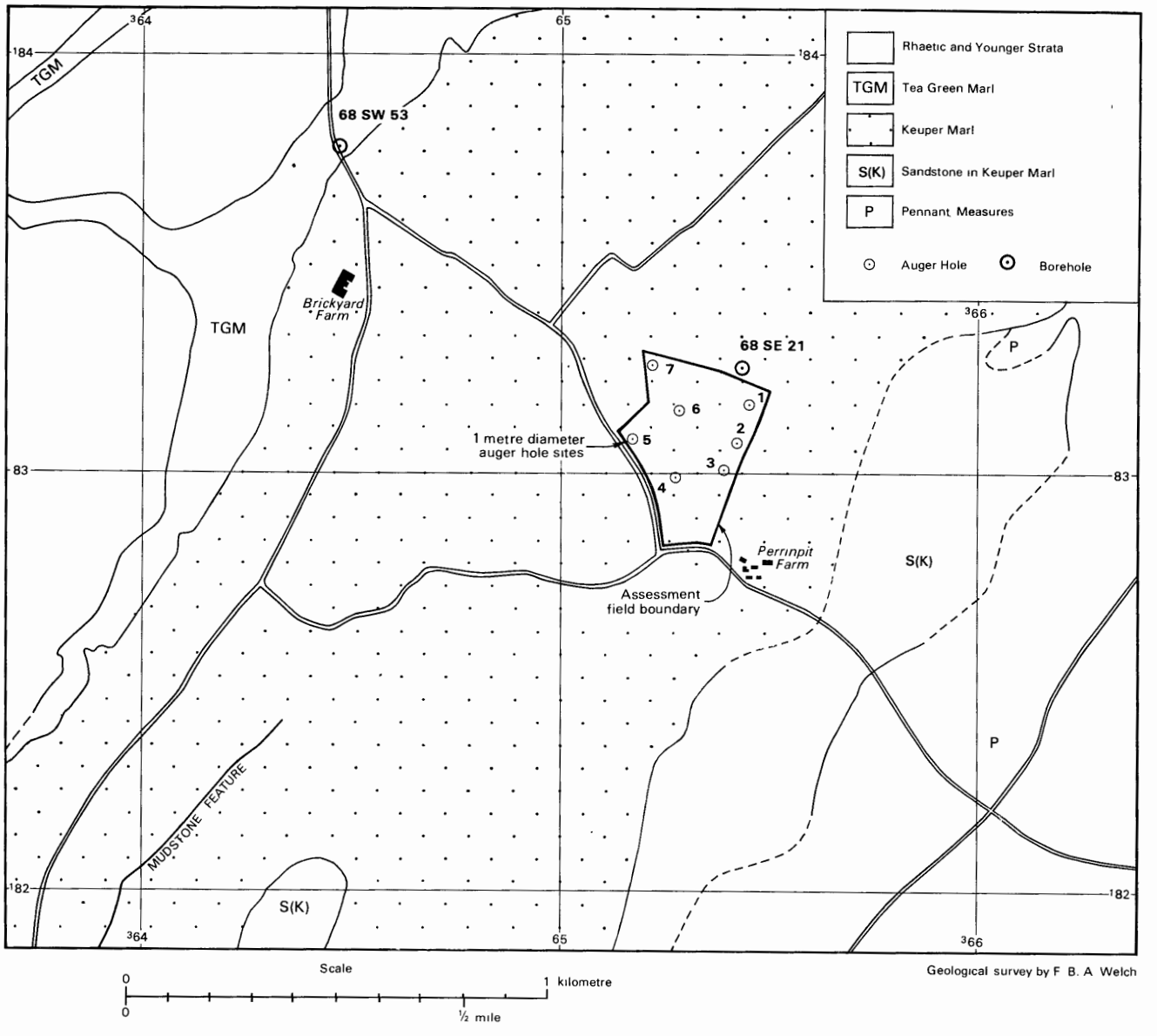


Fig. 14. Geological sketch map of Perrinpit Farm area

	Thick-ness m	Depth m	Auger hole	Final depth m	Yield in kg/m^2	Depths between which celestite occurred m
Severnside Evaporite Bed:			1	2.6	5	2.0 to 2.4
mudstone, reddish brown,			2	3.0	0	-
sandy with seams of celestite			3	4.0	0	-
nodules up to 0.1 m and sand-			4	4.4	trace	3.1 to 3.2
stone alternations containing			5	7.9	19	0.9 to 1.3
vugs lined with celestite and			6	3.0	17	2.0 to 2.4
calcite in lowest 0.1 m			7	4.0	trace	1.2 to 1.4
Base not seen	0.7+	1.3	mean		≃6	

5.1.2 *Perrinpit Farm*

A random scatter of seven 1 m diameter auger holes were sunk over two fields [6525 8315 and 6535 8305] (Fig. 14).

On the basis of this information a yield of 60 tonnes per hectare might be expected.

Celestite either lined cavities in a greenish grey mottled reddish brown sandstone or formed coarsely crystalline infillings in reddish brown mudstone. Analytical data are given in Table 3.

5.1.3 *Borehole Logs*

Borehole ST 68 SW 53
Near Frogland Cross, Frampton Cotterell, Avon
ST 6447 8383
Surface level +65.0 m

	from	Thickness m	Depth m
			1.00
TRIASSIC			
Keuper			
Tea Green Marl			
Mudstone, pale greenish grey, slightly silty, induration variable, occasional nodular argillaceous limestones. Discrete crystals of calcite give a granular texture		1.75	2.75
Keuper Marl			
Mudstone, greyish brown to reddish brown with scattered greenish grey spots, indurated, becoming well indurated with depth, slightly silty locally with disturbed silt partings. Occasional clusters of discrete crystals. Micaceous, scattered listric surfaces		9.03	11.78
Mudstone with evaporite, reddish brown with scattered greenish grey spots, indurated, calcareous with occasional small vugs of calcite. Celestite as pinkish white vug infillings and veins often associated with calcite occurs sporadically throughout		8.75	20.53
Mudstone, reddish brown, locally chocolate brown, greenish grey mottles throughout, silty with occasional silt partings, indurated, locally well indurated. Very calcareous throughout with vugs, veins and discrete crystals of calcite. Sandy towards base		8.77	29.30
Mudstone with Severnside Evaporite Bed, greenish grey mottled reddish brown, indurated to well indurated, silty, often gritty with rounded quartz grains and discrete crystals of calcite. Celestite, pink, finely crystalline forms vugs and macrocells scattered between 30.76 and 32.30 m associated with 'bird's eye' structures and secondary calcite		3.29	32.59
Mudstone, reddish brown mottled greenish grey, some silt partings, indurated, locally well indurated. Calcite veins and discrete crystals throughout with traces of celestite. Micaceous, scattered dolomitised mudstone nodules. Rounded quartz grains more abundant towards base. Calcite veining pseudomorphing fibrous gypsum throughout. Euhedral blue to white celestite crystals in veins at c. 48.0 and at 48.8 m			
	Core seen to	19.00+	51.59

Borehole ST 68 SE 20
Near Forrest Farm, Latteridge, Avon
ST 6578 8368
Surface level +64.9 m

	Thickness m	Depth m
from		0.70
TRIASSIC		
Keuper		
Keuper Marl		
Mudstone, reddish brown mottled greenish grey in parts, very slightly silty, generally poorly indurated, occasional calcareous pellets. Fine calcite veining common. Listric surfaces.		
Core loss from 1.90 to 2.12 m	4.42	5.12
Limestone, argillaceous, nodular with lenses of mudstone	0.16	5.28
Mudstone with sulphate veins, reddish brown mottled greenish grey, slightly silty, indurated throughout. Greenish grey mottles are controlled by the sinuous calcite veins containing rare euhedral celestite laths. Micro veins of calcite due to shearing are developed throughout except through occasional dolomitised silty nodules. Well jointed. Listric surfaces throughout. Disturbed silt laminae towards base		
Core seen to	7.42+	12.70

Severnside Evaporite Bed not identified

Borehole ST 68 SE 21
Near Perrinpit Farm, Frampton Cotterell, Avon
ST 6540 8323
Surface level +60.9 m

	from	Thickness m	Depth m
			1.30
TRIASSIC			
Keuper			
Keuper Marl			
Mudstone, reddish brown with greenish grey bands and mottles, slightly silty to silty, induration variable, brecciated in parts, discrete crystals of calcite common in top 2 m		0.87	2.17
Severnside Evaporite Bed, coarsely crystalline pink celestite as seams of vuggy nodules at 2.42, 2.50 and at 2.55 m in mudstone as above. Celestite nodules greater than 50 mm across between 2.70 and 2.80 m		1.83	4.00
Mudstone, reddish brown, slightly silty, indurated, locally well indurated, with calcite and fibrous gypsum veins, both containing celestite traces. Veining abundant towards base. Listric surfaces and slickensides throughout. Core seen to		2.65+	6.65

5.2 *MICHAELWOOD-WICKWAR*

5.2.1 *Geological Notes*

MICHAELWOOD: A ditch [7100 9673] opposite Wick House reveals a nodular mudstone 0.06 m thick containing 8 per cent $SrSO_4$ (PIF analysis) within a sequence of well indurated reddish brown, mottled greenish grey, mudstone. The mudstones contain abundant discrete crystals of calcite.

The M5 motorway cutting from [7040 9542] to [7090 9577] shows Keuper Marl resting unconformably on Micklewood Shales (Cambrian). Massive nodular gypsum (with secondary alabastrine gypsum) up to 3 m thick is present within the basal Keuper Marl. Near Fern Hill, at [7044 9537] purple-grey micaceous shales (Micklewood Shales) are incorporated in the gypsum, suggesting that in this area the mineral was deposited directly on an extremely irregular Triassic land surface, composed of Cambrian strata.

Behind the buildings of the north-bound service station [7035 9545], Keuper Marl contains massive gypsum averaging 0.5 m thick. Mapping indicates that at least 3 m of Keuper Marl underlies the gypsum. Behind the transformer housing [7039 9550], a lenticular mass of gypsum exhibits 'chicken-wire' structure and displaced mudstone partings.

Mr Nash of Michael Wood Lodge Farm [717 947] reports that prior to 1971, Keuper Marl containing nodules of friable celestite, to 0.1 m in size, could be seen in a stream bank [7130 9440]. Mapping indicates that in the immediate area the Keuper Marl is, on average, only 1 m thick and rests unconformably on Micklewood Shales (Cambrian).

CHARFIELD: A disused brickpit [716 926] at the southern end of the Tortworth Copse, west of Charfield village, shows Keuper Marl and Tea Green Marl dipping gently eastward and resting unconformably on westward dipping Wenlock mudstones, siltstones and fine-grained sandstones. The Severnside Evaporite Bed occurs approximately 12 to 15 m below the base of the overlying Tea Green Marl and consists of an upper impersistent bed of nodular gypsum and three lower beds of nodular celestite in greenish grey mudstone, separated by up to 1 m of reddish brown mudstone. Nodules up to 0.4 by 0.6 m have been noted. The uppermost bed comprises cellular gypsum with trace amounts of celestite and calcite (E 44 621). Nodules from lower levels are 'cauliflower' shaped and are composed of cores of reddish brown to pink, dense, crystalline celestite fringed by large interlocking plates of celestite (E 44 619 and E 44 620), so that in some hand specimens the nodules resemble 'desert roses'. Other nodules show fan-like radiating crystals. In thin sections celestite contains calcite and much relict gypsum. Analytical data is given in Table 4.

Generalised Section	Thickness m	Depth m
Tea Green Marl		
Soil on weathered greenish grey mudstone	1.5	1.5
Keuper Marl		
Mudstone, reddish brown with an indefinite greenish grey band 0.5 m thick at 4.5 m and a continuous greenish grey indurated mudstone 0.3 to 0.5 m thick, containing vugs up to 50 by 20 mm lined with celestite and calcite, at 11.0 m	14.0	15.5
Severnside Evaporite Bed: mudstone, greenish grey mottled reddish brown, sandy, calcareous. An impersistent bed of gypsum nodules in upper metre overlies three beds of dense, finely crystalline, nodular celestite	5.0	20.5
Sandstone, reddish brown argillaceous unconformable on	2.0	22.5
Wenlock Shales		
Shales, yellow-grey variegated weathering to clay, dip about 15° to the west		
Base not seen	18.0+	40.5

LITTLE BRISTOL: Scattered fragments of white nodular gypsum in reddish brown mudstone occur in the fields west of the council houses in Little Bristol Lane [727 913]. No celestite was observed.

5.3 *THORNBURY-OLDBURY*

5.3.1 *Geological Notes*

WHITFIELD: The following section, modified after Reed and Reynolds (1908) was recorded at the Old Brinkmarsh quarry [6745 9131].

	Thickness m	Depth m
SILURIAN		
Wenlock		
Red clay with Hallia mitrata and Orthis basalis	0.46	0.46
Celestite	0.03	0.49
Earthy limestone	0.30	0.79
Celestite	0.04	0.83
Sandy limestone, thinly bedded with grit bands and shale partings	0.91	1.74
Celestite, lenticular	0.08	1.82
Sandstone and shale, thinly bedded	0.10	1.92
Sandy limestone, thickly bedded Base not seen	1.22+	3.14

THORNBURY: The fields [6510 8935] and [6505 8943] are reported to have been worked for celestite in 1914 (Welch and Trotter, 1961). Small nodules of the mineral may still be found along the hedgelines.

An exposure [6548 8941] near Clevewood shows 0.5 m of reddish brown mudstone with small nodules of celestite overlying a sandy breccia (Dolomitic Conglomerate).

Nodules of white sugary celestite were recorded in recently ploughed soil at [6377 8907].

On the western side of the ridge of Dolomitic Conglomerate which extends southwards from Thornbury, scattered nodules of celestite were found in a field [6375 8905] and in a ditch [6325 8945] exposing 0.75 m of Keuper Marl.

A temporary exposure [6398 8929] on the Thornbury Industrial Estate showed:

	Thickness m	Depth m
Keuper Marl		
Soil	0.1	0.1
Mudstone, reddish brown mottled greenish grey sandy, slightly calcareous, weathered	0.4	0.5
Severnside Evaporite Bed: nodular (up to 150 by 200 mm) coarsely crystalline celestite (E 44 641) in greenish grey mudstone	0.5	1.0
Mudstone, pale reddish brown Base not seen	0.5+	1.5

OLDBURY: Scattered nodules of celestite found in the fields west of Stock Lane are associated with a greenish grey sandstone, which forms a slight feature traceable from Lodge Farm [6010 9019] eastwards to Stock Farm [6075 9039], then northwards as far as [6075 9121]. Although gypsum is reported to have been found in a pipeline trench which crossed the feature at [6086 9111], petrographic examination (E 44 618) shows celestite with only trace amounts of gypsum.

A horizontal bed of greenish grey sandy mudstone crops out [6077 9102] on the west-facing slope of a low feature approximately 600 m north-east of Stock Farm [6080 9042] near Titters Hill. In a trench excavation for a water pipeline discrete nodules of pink coarsely crystalline celestite were found within a greenish grey sandy mudstone which also contains isolated 'vuggy' macrocells of celestite. The nodules were commonly composed of many loosely-bound interlocking plates although some were massive. Approximately 200 m south-east of Lodge Farm [6010 9020] the trench again showed greenish grey sandy mudstone with celestite macrocells. In the vicinity of Titters Hill [6094 9021] and Lodge Farm [6010 9020], mapping indicates that Keuper Marl rests unconformably on the Tintern Sandstone Group and oversteps it to the north-east, to rest unconformably on the Quartz Conglomerate.

5.4 *AUST-HENBURY*

5.4.1 *Geological Notes*

AUST: A thin section (E 44 610) shows alabastrine gypsum, probably produced by the hydration of anhydrite (Holliday, 1970), enclosing small (less than 0.3 mm) euhedral celestite laths, which account for up to 0.5 per cent of the rock.

AWKLEY: A section in a new road cutting [5960 8582] near Awkley shows a vein of celestite up to 0.1 m thick, apparently replacing fibrous gypsum, dipping at 10° to 15° towards the north-west. The host rock of reddish brown Keuper mudstone shows extensive greenish grey mottling within 0.5 m of the vein. Thin criss-crossing sheets of gypsum underlie the celestite. In thin section (E 44 608) the vein consists of clear coarsely crystalline celestite laths (80 per cent) with calcite and gypsum in a mudstone matrix. The upper surface of the vein shows disruption of the celestite crystal fabric causing granulation and crystal alignment sub-parallel to the slickensided surface of the vein.

TOCKINGTON: The surface brash in a field [6161 8573] west of Harts Cottage contains corroded gypsum and calcite with traces of celestite in weathered reddish brown mudstone (E 44 614). From Lower Hazel [6262 8740] to Tockington [6086 8656], gypsum nodules are feebly developed and show extensive replacement. Vague 'skins' or 'shells' of gypsum contain cavities lined with finely crystalline calcite and quartz.

ALMONDSBURY: Nodules of celestite up to 0.75 m in diameter occur in dark reddish brown sandy mudstones (Keuper), exposed in a stream section [6060 8474], 450 m west of Ridgewood House. The surfaces of the nodules show typical coalesced macrocell ornament with thin distorted sediment stringers. The Keuper, up to 1 m thick, rests on dark purple-grey coarse sandstones (Middle Coal Measures) which dip to the south-east at approximately 30°. Petrographic examination shows anhydrite relicts within celestite laths. Secondary calcite, replacing both celestite and anhydrite, accounts for up to 2 per cent of the minerals present (E 44 611).

Near Lower Court Farm, Almondsbury, a stream section [6084 8474] exposing Keuper Marl with nodular celestite (E 44 611) resting on Coal Measures Sandstone, demonstrates the association of the mineral with a highly permeable substrate.

LITTLETON-ON-SEVERN: A ditch [5988 8932] shows a bed of nodular gypsum, approximately 0.1 m thick, in sandy Keuper Marl. The gypsum exhibits 'chicken-wire' structure with displaced reddish brown sandy mudstone partings (E 44 640). Mapping indicates that in the immediate area Keuper Marl about 1 m thick rests on Dolomitic Conglomerate which fringes Black Rock Dolomite.

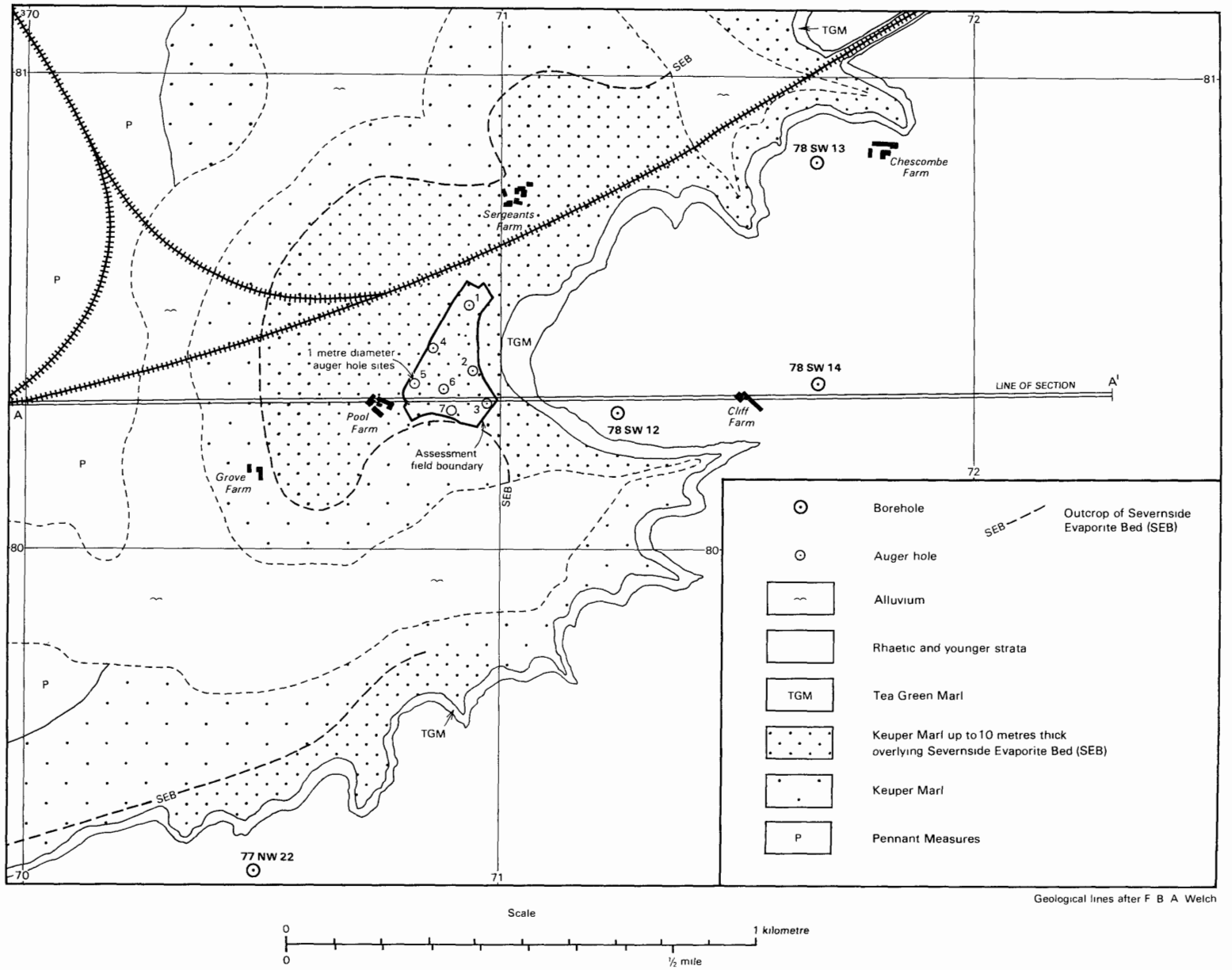


Fig. 15a. Geological sketch map of Wapley Common

5.5 *WAPLEY-BITTON*

5.5.1 *Geological Notes*

WAPLEY COMMON-WESTERLEIGH: Two pits dug in connection with housing development on the site of Sargeant's Farm south of Yate showed the following sections:

Pit 1 [7107 8074]

	Thickness m	Depth m
Keuper Marl		
Soil on weathered reddish brown slightly silty mudstone	1.90	1.90
Severnside Evaporite Bed: celestite pink, vuggy and nodular in upper 0.2 m becoming massive with calcite below and interpenetrating greenish grey and reddish brown mudstones (E 44 615)	0.40	2.30
Mudstone, reddish brown, rarely mottled greenish grey towards base	0.50	2.80
Limestone, argillaceous, greenish grey, recrystallised, nodular with interpenetrating green mudstone (E 44 639)	0.13	2.93
Mudstone, reddish brown, well indurated, blocky, with discrete crystals of calcite giving granular appearance	1.00	3.93
Mudstone, slightly silty, greenish grey, well indurated, calcareous in parts Base not seen	0.20+	4.13

Pit 2 [7105 8076]

	Thickness m	Depth m
Made ground: concrete	0.20	0.20
Keuper Marl		
Mudstone, reddish brown, rarely mottled, greenish grey blocky, weathered	1.40	1.60
Severnside Evaporite Bed: mudstone, greenish grey containing nodular white and pale blue sugary celestite. Nodules often vuggy. Celestite with calcite becomes massive towards base	0.75	2.35
Mudstone, slightly silty, reddish brown, well indurated blocky with discrete crystals of calcite giving granular appearance Base not seen	0.50+	2.85

Along the valley sides of the Wapley Common Brook and in the scarp feature of Westerleigh Hill, nodular and vuggy celestite, often impregnated with quartz, occurs in a greenish grey mudstone.

Massive pink, platy celestite crops out in a roadside verge at [7038 7950].

FOLLY BROOK: A stream section, immediately north of the M4 motorway at [692 779] shows well indurated reddish brown, mottled greenish grey, mudstone with gypsum veins, on average 10 mm thick.

SISTON: On a track north of Shortwood Clay Pit [631 765] nodular celestite replacing gypsum and overlying a hard mudstone in the Keuper Marl, is exposed at [6822 7661]. Within Shortwood Pit gypsum with some celestite is disseminated through Keuper Marl mudstones and occurs at approximately the same level.

A ditch section [6713 7500] shows fibrous celestite 'stringers' or veins discordant to dip in reddish brown Keuper Marl. It is thought that the celestite at this locality replaces vein gypsum.

Temporary exposures in a ploughed field [672 751] north of the track to Lodge Farm [6770 7528] showed two types of celestite: towards the crest of the hill [672 752] large nodules of celestite; downslope [671 751] veins of calcite, gypsum and some celestite associated with a green mudstone.

In a ditch [6740 7500] near Lodge Farm weathered brown to reddish brown Keuper Marl displays many small irregularly shaped, greenish grey patches of clay, some of which contain coarsely friable celestite. Occasionally the clay-celestite contact has a yellowish green discolouration.

The ditch section shows:

	Thickness m	Depth m
Soil	0.1	0.1
Made ground-tabular, fine grained, dark grey limestone	0.3	0.4
Keuper Marl		
Severnside Evaporite Bed: mudstone reddish brown, with irregular patches of greenish grey clay, some filled with saccharoidal celestite	0.5	0.9
Mudstone, greenish grey Base not seen	0.1+	1.0

To the west of St Anne's Bridge [6870 7494] the outcrop of the Severnside Evaporite Bed on the hill side is partially obscured by stoney clay hillwash. Abundant quartz is found associated with nodular vuggy celestite.

HOLBROOK COMMON: In a stream section [6930 7407] south-east of Blue Lodge, well indurated mudstone with nodular gypsum and calcite is exposed.

BITTON: In a ditch section [6840 7129] greenish grey mudstone contains irregular masses of calcite and gypsum.

WILLSBRIDGE: At [6696 7053], about 3 m above the floor of the Cherrygarden Hill railway cutting, greenish grey mudstone with coarsely crystalline sugary celestite and varying amounts of gypsum and calcite occur within reddish brown

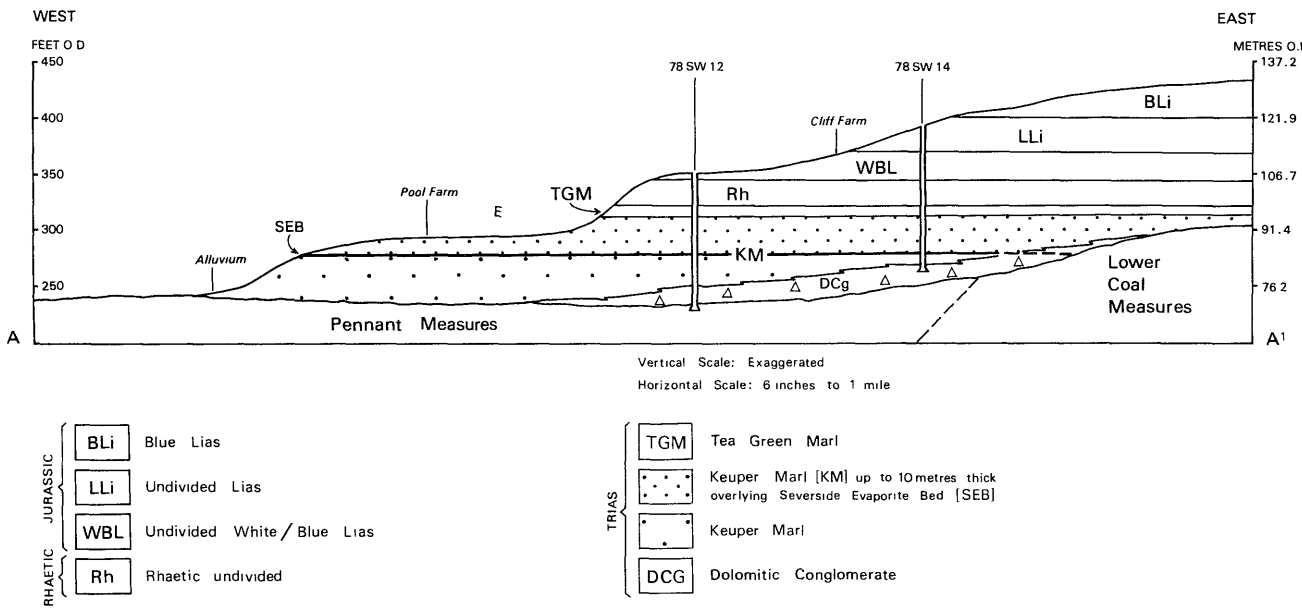


Fig. 15b. Conjectural section of Wapley Common

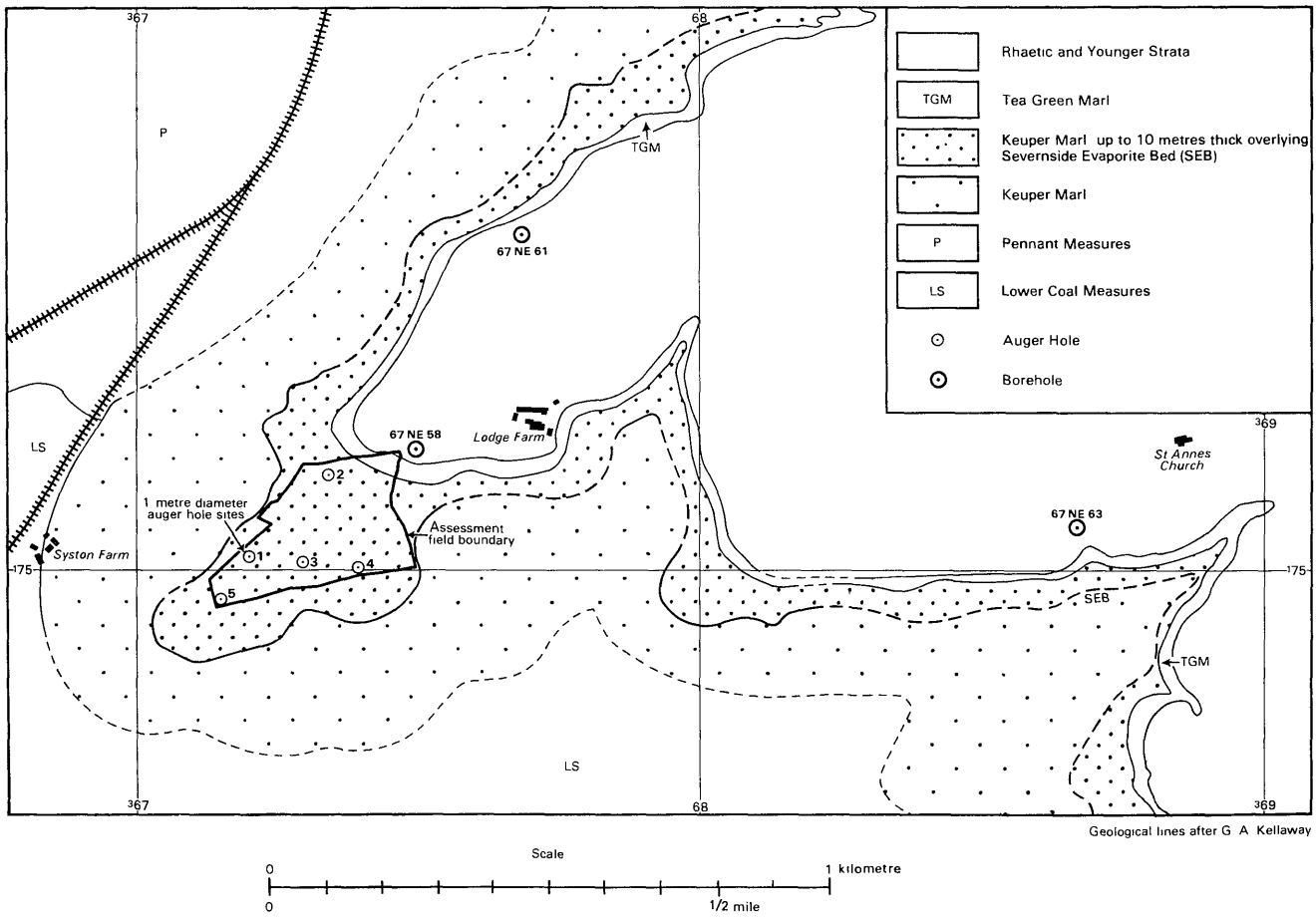


Fig. 16. Geological sketch map of Lodge Farm area

Keuper Marl. On the west-facing slope of the cutting [6698 7053] Tea Green Marl overlies Keuper Marl.

WEST WICK: A stream section from [6644 7860] to [6658 7850], west-north-west of Folly Bridge [6688 7829] shows thin alluvium overlying some 2 m of weathered Keuper Marl, which rests on Coal Measures Shales. Pink stained coarsely crystalline, celestite nodules up to 0.2 m across, occur throughout the reddish brown mudstones and clays of the stream bank where they are often associated with greenish grey mottles and as a lag deposit on the stream bed. Mr I.A. Thomas (personal communication) noted large nodules up to 0.5 m in shale bottomed hollows of the stream bed.

5.5.2 *Wapley Common, Lodge Farm, Redfield Hill*

Large diameter auger holes at three sites provided the following information.

WAPLEY COMMON: [710 804] The Severnside Evaporite Bed was seen to consist of massive coarsely crystalline celestite with stringers of greenish grey mudstone distributed through up to a metre of greenish grey mudstone, though the aggregate mineral thickness did not usually exceed 0.5 m. The celestite yields from boreholes on the eastern part of Wapley Common, adjacent to Wapley Bushes, fall below the mean value for the area as a whole and it is possible that these boreholes failed to penetrate the full thickness of mineral-bearing mudstone (Fig. 15).

Auger hole	Final depth m	Yield in kg/m^2	Depths between which celestite occurred m
1	4.5	12	1.5 2.5 to 4.1
2	3.1	29	0.6 2.1 to 2.7
3	6.8	9	0.8 to 1.3 6.1 to 6.8
4	6.0	196	1.2 to 1.3 2.2 to 3.1
5	6.1	270	1.0 to 2.1
6	4.7	40	2.9 to 3.5
7	3.8	211	1.2 1.6 to 2.8
mean	5.0	≃110	

From these results a yield of 1100 tonnes per hectare might be expected. In addition minor amounts of redistributed vein celestite may be present beneath the Severnside Evaporite Bed.

Analysis of samples shows that SrO varies from 24.00 to 54.10 per cent with a mean value of 45.16 per cent (see Table 7). Nodules with cores of quartz have been noted (see 4.6); the determined values of SiO_2 vary from 0.6 to 27.0 per cent with a mean of 7.32 per cent. CaO values are less than 10 per cent in these samples having a mean of 3.47 per cent, which is significantly lower than values from other areas, for example, 9.75 per cent at Redfield Hill.

LODGE FARM: Drilling in a field [673 751] (Fig. 16) proved the Severnside Evaporite Bed. It comprised two seams of celestite within greenish grey mudstone. The upper seam, less than 60 mm thick, was largely weathered to sand-grade celestite and contained nodules with quartz cores. The lower seam, although less weathered and up to 200 mm thick, comprised nodules containing considerable quantities of interstitial green mudstone. Celestite and gypsum veins, in part replaced by quartz and calcite, underlay the seams.

Auger hole	Final depth m	Yield in kg/m^2	Depths between which celestite occurred m
1	4.0	57	1.2 to 2.0
2	4.3	118	3.0 to 3.8
3	3.0	8	2.7 to 2.8
4	5.0	18	1.3 to 1.4
5	3.9	68	1.4 to 2.0
mean	4.0	≃54	

Assuming that these results are typical, a yield of 540 tonnes per hectare might be expected.

Analysis of six samples shows the SrO content to vary from 9.0 to 52.8 per cent with a mean of 35.2 per cent. Determined values of SiO_2 range from 4.45 to 19.0 per cent with a mean of 10.56 per cent. CaO values show a large variation from 0.54 to 20.0 per cent with a mean of 6.55 per cent (Table 7).

REDFIELD HILL FARM: Drilling in a field [6840 7145] (Fig. 17) proved up to four seams of white sugary celestite with gypsum or calcite, usually less than 200 mm thick, distributed through some 2 m of reddish brown mottled greenish grey mudstone. Near the surface the mineral weathers to a coarse celestite 'sand'.

Auger hole	Final depth m	Yield in kg/m^2	Depths between which celestite occurred m
1	5.0	19	0.5 to 0.8
2	2.3	70	0.3 to 1.4
3	2.9	134	0.2 to 1.8
4	4.0	26	0.5 to 1.4
5	4.8	78	0.1 to 2.0
mean	3.8	≃65	

On the basis of this information, a yield of 650 tonnes per hectare might be expected.

Analysis of eleven samples shows the SrO content to vary from 13.0 to 53.5 per cent with a mean of 36.49 per cent. SiO_2 values are all less than 7.5 per cent with a mean of 3.74 per cent. Determinations of CaO vary from 0.33 to 20.0 per cent with a mean of 9.75 per cent (Table 7).

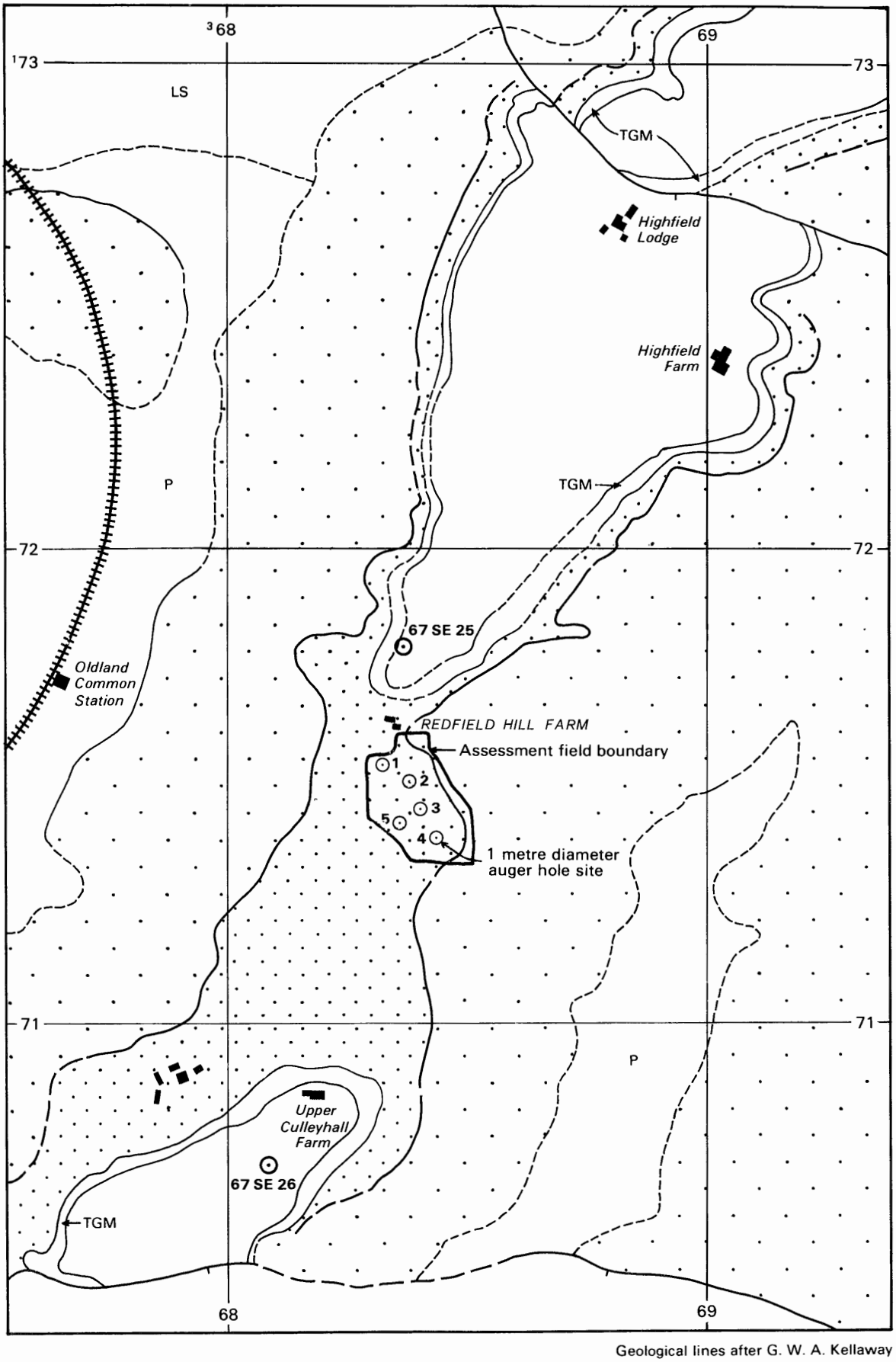


Fig. 17. Geological sketch map of Redfield Hill Farm area

5.5.3 *Borehole Logs*

Borehole ST 67 NE 56
Cliff Farm, Westerleigh, Avon
ST 6968 7876
Surface level +97.8 m

	Thickness m	Depth m
from		1.00
JURASSIC		
Blue Lias		
Clay with limestone and mudstone alternations, grey clay as squeezed partings with pale grey to dark grey muddy limestones, nodular and massive with abundant fossil impressions.		
Core loss from 3.93 to 5.14 m	4.14	5.14
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstone, greyish brown, poorly indurated with some core loss from 5.14 to 7.15 m. Silty laminae with cross bedding from 7.35 to 7.50 m Chlamys ratoniensis and Tutcheria cloacina	2.36	7.50
Westbury Beds		
Mudstone, medium to dark grey, silty, calcareous in parts, fissile, occasional mudstone pellets, listric surfaces, micaceous below 10.00 m. Rhaetavicula contorta and Protocardia sp.		
Core losses from 9.22 to 10.11 m	2.89	10.39
Sandstone, greenish grey, fine grained, calcareous, pyritic with black phosphatised vertebrate remains	0.01	10.40
Keuper		
Tea Green Marl		
Mudstone, greenish grey rare reddish brown mottles, slightly silty, indurated, calcareous with argillaceous limestone nodules towards base. Manganese stains on joints, pyritic in parts, slickensides and listric surfaces common	3.89	14.29
Keuper Marl		
Mudstone, reddish brown with occasional greenish grey mottles, very slightly silty, indurated, locally well indurated. Manganese stains on joints. Calcareous with argillaceous limestone nodules especially between 15.60 and 15.68 m and from 15.92 to 15.98 m. Greenish grey mottles associated with discrete crystals of calcite giving a granular texture. Silt partings, greenish grey from 22.16 to 22.30 m. Slickensides and listric surfaces throughout	8.37	22.66
Severnside Evaporite Bed with mudstone, gypsum as large globular masses associated with greenish grey mottled mudstone from 22.82 to 22.86 m, from 22.90 to 23.15 m and from 23.62 to 23.77 m. Celestite partially replaces gypsum throughout. Fibrous gypsum veins from 22.66 to 22.73 m		
Core seen to	2.70 +	25.36

Borehole ST 67 NE 57
Coxgrove Hill, Pucklechurch, Avon
ST 6867 7698
Surface level +100.9 m

	Thickness m	Depth m
from		0.90
JURASSIC		
White Lias		
Clay, khaki with brown streaks, some disturbed calcareous silt partings	0.72	1.62
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstone, pale grey to greenish grey, slightly silty, calcareous throughout. Dark grey towards base with fish scales and impression of Chlamys sp. and Protocardia sp. Clay band from 2.30 to 3.60 m Core loss from 1.85 to 2.07 m	2.94	4.56
Westbury Beds		
Mudstone, dark grey to black, with buff silt partings, some micaceous and with mudstone pellets. Pyritised impressions of Rhaetavicula contorta and Protocardia sp., fish remains common. Core loss, rubble and cavings of Cotham Beds from 5.05 to 5.90 m. Mudstone becomes calcareous and silty with a fissured base	2.19	6.75
Keuper		
Tea Green Marl		
Mudstone, greenish grey, slightly silty with occasional disturbed silt partings and wisps. Argillaceous limestone nodules throughout. Pyrite as discrete crystals. Listric surfaces	3.52	10.27
Keuper Marl		
Mudstone, reddish brown mottled greenish grey, indurated, locally well indurated, silty, calcareous in parts with argillaceous limestone nodules from 11.72 to 11.80 m. Discrete crystals of calcite give a granular texture in parts. Becoming silty with rounded quartz grains towards an irregular base	7.82	18.09
Severnside Evaporite Bed, gypsum, alabastrine with nodular mosaic fabric. Replaced in part by euhedral celestite laths passes into	0.11	18.20
Mudstone, reddish brown with sedimentary dykes infilled with pale brown slightly silty mudstone. Gypsum nodules are preferentially developed in these dykes and are partially replaced by euhedral celestite crystals. Fibrous gypsum veins common	0.55	18.75
Mudstone, reddish brown mottled greenish grey in parts, disturbed silt partings at 21.0, 21.5, and 22.75 m. Indurated, many fibrous gypsum veins, listric surfaces	6.02	24.77
Mudstone, reddish brown, greenish grey mottles locally developed, indurated, in parts well indurated, micaceous. Calcite lined solution holes and vugs are sporadically developed. Becoming very silty with scattered rounded quartz grains; manganese and hematite on joints with scattered gypsum nodules from 34.5 to 36.6 m. Very sandy at base	13.73	38.50
CARBONIFEROUS		
Upper Coal Measures		
Sandstone, purple-grey, very fine grained, apparent dip c. 30°, micaceous, hematised, indurated, thinly bedded with amorphous and specular hematite and platy gypsum on joints. Occasional pale purple-grey mudstone partings, well indurated with listric surfaces at 39.20 and 39.40 m. Becomes a finely laminated sandstone with disturbed silt horizons containing nodular gypsum at 40.5 m. Core seen to	2.82+	41.32

Borehole ST 67 NE 58
Lodge Farm, Siston, Avon
ST 6750 7523
Surface level +93.4 m

	Thickness m	Depth m
from		1.00
TRIASSIC		
Rhaetic		
Cotham Beds		
Clays with mudstone and limestone alternations, khaki, slightly silty clays with mudstone pellets. Muddy nodular limestones throughout with alternations of pale grey to buff well indurated mudstone with occasional fossil impressions	1.73	2.73
Westbury Beds		
Mudstone with limestone alternations, dark grey mudstone with calcareous silt partings, indurated, locally poorly indurated and fissile, micaceous below 4.48 m, pyritic, Chlamys sp. and Protocardia sp. in parts. Nodular limestones between 3.00 and 3.04 m and from 3.73 to 3.84 m; pale to dark grey, fine grained	3.07	5.80
Keuper		
Tea Green Marl		
Mudstone greenish grey mottled reddish brown with depth. Induration variable, silt partings. Argillaceous limestone nodules throughout; slickensides	3.00	8.80
Keuper Marl		
Mudstone with argillaceous limestone nodules, reddish brown mottled greenish grey mudstone; slightly indurated, locally indurated. Discrete crystals of calcite give a granular texture throughout. Pale brown argillaceous limestone nodules from 10.23 to 10.45 m and from 10.81 to 11.03 m. Listric surfaces and slickensides throughout	5.82	14.62
Mudstone with Severnside Evaporite Bed, reddish brown mottled greenish grey. Induration variable, scattered calcite grains throughout locally as 'trails'. Celestite and calcite as small, occasionally vuggy nodules at 15.05, 15.15, 15.35 and at 16.85 m and as diffuse macrocells partially restricted to brecciated mudstone dykes from 19.70 to c. 20.6 m. Irregularly banded ? dolomitised limestone from c. 17.95 to 18.30 m. Some greenish grey spots have dark nucleii. Listric surfaces sporadically developed. Veins of celestite and calcite from 20.90 to 21.00 m	6.89	21.51
Mudstone, dark reddish brown mottled greenish grey throughout, indurated to well indurated, slightly silty, many discrete calcite crystals locally giving a granular texture. Rare sinuous celestite veins and cavity infillings		
Core seen to	7.23+	28.74

Borehole ST 67 NE 59
Park Farm, Pucklechurch, Avon
ST 6904 7763
Surface level +84.1 m

	Thickness m	Depth m
from		1.00
JURASSIC		
White and Blue Lias		
Clay with limestones, pale khaki brown, silty clays with pale grey, silty fossiliferous limestones	1.22	2.22
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstones with limestone alternations, pale grey, silty, poorly indurated, calcareous throughout locally with nodular muddy limestones. Fossiliferous	3.27	5.49
Westbury Beds		
Mudstone, dark grey to black, silty partings friable locally indurated. Pyritised fossil impressions, micaceous throughout. Fine grained calcareous sandstone with phosphatised vertebrate remains at base	2.53	8.02
Keuper		
Tea Green Marl		
Mudstone, greenish grey, silty indurated locally well indurated. Calcareous throughout with discrete crystals of calcite giving a 'gritty' texture with argillaceous limestone nodules from 9.99 to 11.73 m. Listric surfaces common	3.71	11.73
Keuper Marl		
Mudstone, reddish brown extensively mottled greenish grey, slightly silty, induration variable. Calcareous throughout with scattered discrete crystals of calcite. Nodular calcareous mudstone at c. 13.8 m. Rare halite pseudomorphs at 15.15 m. Micaceous, scattered rounded quartz grains increase towards base, listric surfaces	6.79	18.52
Mudstone, chocolate brown, silty, indurated with nodular alabastrine gypsum showing faint relict sediment stringers	0.33	18.85
Mudstone, reddish brown mottled greenish grey, gritty texture due to discrete calcite crystals and rounded quartz grains. Indurated, locally well indurated. 'Birds eye' structure common. Micaceous. Erosion surface at base	1.95	20.80
Severnside Evaporite Bed, gypsum nodules with cores of subhedral celestite crystals. Mudstone stringers separate nodules and contain much rounded quartz grains. Passes into brecciated mudstone with sedimentary dyke structures, chocolate brown mottled pale reddish brown, very silty with nodules of gypsum (containing rare cores of celestite) developed preferentially in mudstone infilled dykes. Gypsum veins towards base	1.00	21.80
Mudstone, reddish brown locally chocolate brown with greenish grey reduction spots, silty, indurated, locally well indurated with scattered veins and vugs of calcite and celestite. Brecciated in parts		
Core seen to	2.84+	24.64

Borehole ST 67 NE 60
Leigh Farm, Pucklechurch, Avon
ST 6949 7827
Surface level +99.8 m

	Thickness m	Depth m
from		1.00
JURASSIC		
Core loss, clay with limestone	1.50	2.50
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstone with clay and limestone alternations, pale grey, dark grey with depth, silty partings, poorly indurated becoming indurated. Thin clay seams and argillaceous nodular limestones	3.50	6.00
Westbury Beds		
Mudstone, dark grey to black, silt partings, indurated, Rhaetavicula contorta, Protocardia sp., fish scales and phosphate nodules in fine grained calcareous sandstone at base	2.18	8.18
Keuper		
Tea Green Marl		
Mudstone, pale greenish grey silty, indurated. Argillaceous limestone nodules throughout. Occasional discrete crystals of calcite and pyrite throughout. Listric surfaces	3.34	11.52
Keuper Marl		
Mudstone, reddish brown with green reduction spots containing dark nuclei below 16.00 m. Silt partings in parts. Indurated, locally well indurated with calcareous nodular mudstones. Manganese on joints. Calcite lined vugs and scattered discrete crystals throughout. Listric surfaces, micaceous	9.78	21.30
Mudstone, dark reddish brown, slightly silty, indurated, scattered small gypsum nodules and fibrous veins with traces of celestite, becoming 'gritty' towards base with rounded quartz grains	3.20	24.50
Mudstone with Severnside Evaporite Bed, reddish brown mottled greenish grey, silty, indurated with scattered nodules of gypsum with traces of celestite sometimes having fibrous gypsum inter-connecting veins. Arcurate fibrous gypsum veins at c. 25.0 m. Abraded grains of gypsum and quartz common in mudstone infilled dykes		
Core seen to	4.50+	29.00

Borehole ST 67 NE 61
Near Gingells Farm, Shortwood Hill, Avon
ST 6769 7560
Surface level +95.3 m

	Thickness m	Depth m
from		1.00
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstone with clay alternations, pale grey to greenish grey mottled brown in top 0.8 m, silty, indurated. Occasional argillaceous nodular limestones. Thin clay bands throughout. Fossiliferous with fish scales throughout		
Core loss from 2.30 to 3.05 m	2.05	3.05
Westbury Beds		
Mudstone with clay alternations, dark grey to black, scattered disturbed, silt partings, indurated to well indurated, locally fissile. Occasional argillaceous limestone nodules. Pyritised Rhaetavicula contorta and Chlamys sp. Fine grained calcareous sandstone with phosphatised vertebrate remains at base	2.25	5.30
Keuper		
Tea Green Marl		
Mudstone, dark greenish grey, slightly silty with silt partings throughout. Discrete crystals of calcite give a gritty texture. Calcareous throughout with argillaceous limestone nodules. Traces of pyrite	2.31	7.61
Keuper Marl		
Mudstone, chocolate brown mottled greenish grey, slightly silty, indurated locally well indurated, calcareous throughout with discrete crystals with rare calcite lined vugs and argillaceous limestone nodules. Micaceous; joints with pyrite and manganese staining. Brecciated with slump structures at c. 11.8 m. Listric surfaces, slickensides throughout	5.39	13.00
Mudstone with Severnside Evaporite Bed, greenish grey mottled reddish brown, indurated, locally well indurated. Calcareous throughout, with discrete crystals giving a gritty texture and calcite lined vugs with traces of celestite. White to pale pink celestite and gypsum, vuggy with the occasional euhedral celestite laths projecting into cavities at c. 14.5 m. Mudstone shows flow structures around the celestite. Veins of celestite and calcite throughout. to base	2.80	15.80
Mudstone, chocolate brown mottled greenish grey, silty indurated, very well indurated from 17.5 to 20.0 m. Calcareous throughout with calcite veins common below 20.0 m. Listric surfaces	8.34	24.14
Mudstone, greenish grey becoming reddish brown with depth, slightly silty, indurated. Fractured, calcareous throughout with discrete crystals of calcite giving a gritty texture. Veins of celestite and calcite up to 40 mm c. 24.5 m; coarsely crystalline	1.10	25.24
Mudstone grades locally to fine grained sandstone, reddish brown, indurated locally very well indurated, abundant rounded quartz grains and discrete calcite give a gritty texture. Celestite as coarsely crystalline pink nodules at 29.0 and c. 33 m	7.96	33.20
Sandstone, reddish brown with purple-blue below 36.00, fine grained, very well indurated, micaceous. With coarse quartz sand partings stained, dark purple-red below 36.9 m. Brecciated and impregnated with hematite towards base	4.30	37.5
CARBONIFEROUS		
Coal Measures		
Pennant Measures		
Sandstone, dark purplish grey, fine to medium, well indurated, cemented in parts by hematite. Micaceous below 38.10 m with dips of 10° to 15°. Passes into coarse quartz sand impregnated with hematite at base		
Core seen to	1.15+	38.65

Borehole ST 67 NE 62
Gingells Farm, Shortwood Hill, Avon
ST 6838 7595
Surface level +110.9 m

	Thickness m	Depth m
from		1.25
JURASSIC		
Lower Lias		
Clay, yellowish grey, calcareous with nodules of argillaceous limestones	1.25	2.50
TRIASSIC		
Rhaetic		
Cotham Beds		
Clay with limestone alternations, pale khaki, mottled throughout, many calcareous pellets. Silt partings locally micaceous	1.50	4.00
Westbury Beds		
Mudstone, dark grey, slightly silty, scattered disturbed silt partings, poorly indurated, fissile in parts. Clay bands, pyritised fine grained calcareous sandstone at base. *Protocardia* sp. Fish scales common	3.20	7.20
Keuper		
Tea Green Marl		
Mudstone with argillaceous limestone nodules greenish grey, slightly silty, gritty locally with rounded quartz grains. Induration variable. Nodular and bedded argillaceous limestones from 7.78 m to base. Joints stained with pyrite and manganese. Slickensides	3.16	10.36
Keuper Marl		
Mudstone, reddish brown. Mottled greenish grey. Locally silt partings and patches, indurated to well indurated. Scattered celestite nodules associated with calcite between 15.68 and 15.91 m, up to 100 mm across. Mudstone is jointed with much purple staining and traces of platy gypsum developed. Listric surfaces throughout. Slickensides. Many rounded quartz grains towards base	7.98	18.34
Severnside Evaporite Bed, pinkish white coarsely crystalline globules and nodules of celestite up to 50 mm in diameter, forming trails in a matrix of dark reddish brown, very silty mudstone with lighter brown mudstone infilled dykes	0.66	19.00
Mudstone, dark reddish brown dykes of paler brown infillings, slightly silty, occasional disturbed silt partings, induration variable, locally brecciated. Calcareous with discrete crystals of calcite giving a granular texture and locally as accumulations within vugs and along veins with traces of celestite at about 20.00 m. Pseudomorphs after halite at c. 24.6 m. Joints coated with some celestite and manganese stains. Micaceous, slickensides, listric surfaces throughout		
Core seen to	7.21+	26.21

Borehole ST 67 NE 63
Saint Anne's Well, Siston, Avon
ST 6867 7508
Surface level +75.3 m

	Thickness m	Depth m
Clay wash	2.30	2.30
TRIASSIC		
Keuper		
Keuper Marl		
Mudstone, reddish brown locally dark reddish brown mottled greenish grey. Silty, locally very silty. Induration variable. Calcareous throughout with discrete crystals of calcite giving a gritty texture. Argillaceous limestone nodules up to 0.1 m from 2.3 to 4.5 m. Some thin clay bands less than 0.1 m thick with mudstone pellets throughout	5.80	8.10
Mudstone, greenish grey becoming reddish brown with depth mottled throughout. Slightly silty, well indurated, locally very well indurated, micaceous, gritty in parts with discrete crystals of calcite. Scattered small vuggy nodules of calcite and celestite, with veins of same from 12.0 to 13.0 m	5.44	13.54
Severnside Evaporite Bed, coarsely crystalline celestite nodule lined with quartz crystals, surrounded by celestite impregnated mudstone passes into mudstone, dark reddish brown with macrocellular celestite and fragmentary calcite throughout. Celestite laths in nodule shows relict anhydrite. Mudstone matrix contains angular gypsum fragments Rounded quartz grains with hematite coating are well developed in dykes infilled with sandy mudstone	0.96	14.50
Mudstone, reddish brown, locally dark chocolate brown with rare greenish grey mottles, very slightly silty, well indurated. Fine veins of celestite, calcite and fibrous gypsum. Gritty calcite grains throughout sometimes removed by solution leaving pits. Nodular buff pellet mudstone at 20.0 and at 22.5 m. Slickensides, listric surfaces throughout. Pseudomorphs after halite at 30.5 m	19.5	34.0
Mudstone, dark reddish brown rare buff and greenish grey mottles, very silty, gritty in parts with an abundance of rounded quartz grains increasing with depth. Very well indurated with dark pink nodules of platy celestite c. 30 mm across between 34.5 and 35.3 m, associated with extensive mottling. Slickensides and listric surfaces throughout	4.70	38.70
CARBONIFEROUS		
Lower Coal Measures		
Mudstone, dark purplish brown, very silty, well indurated, iron stained and cemented with sintery ironstone from 39.0 to 39.2 m. Large, up to c. 3 mm, rounded quartz grains throughout. Passes into	0.55	39.25
Sandstone, dark purple locally dark reddish brown on joints, medium to coarse, argillaceous, cemented in part with hematite, heavily stained with manganese throughout. Core seen to	1.32+	40.57

Borehole ST 67 NE 64
Adjacent to M4 Coal Sack Farm, Westerleigh, Avon
ST 6682 7862
Surface level +47.5 m

	Thickness m	Depth m
from	2.15	2.15
TRIASSIC		
Keuper		
Keuper Marl		
Mudstone, reddish brown, slightly silty, induration variable, well jointed and blocky. Thin calcareous silt partings at c. 2.8 m. Friable, small, less than 20 mm, calcite and celestite lined vugs at c. 3.0 m.	1.21	3.36
Sandstone, pale greenish grey, fine grained, poorly cemented, silt partings below 3.5 m. Scattered small vugs of calcite and celestite.	0.29	3.65
Mudstone, reddish brown streaky greenish grey mottles, very slightly silty, indurated, locally well indurated, micaceous, gritty with discrete crystals of calcite throughout. Small nodules and vugs of celestite and calcite throughout often abundantly developed in sandy accumulations and partings. Occasionally coarsely crystalline laths of celestite occur within these nodules	2.90	6.55
CARBONIFEROUS		
Pennant Measures		
Mudstone, pale grey, shaly, finely laminated, silty, micaceous partings throughout dips at c. 10°	0.16	6.71
Sandstone, dark purplish grey, some clay and silt partings, finely laminated with cross bedding, indurated, fissile. Joints stained with ochre and ? manganese. Dips at 10°. Core seen to	10.73+	17.44
Severnside Evaporite Bed not identified		

Borehole ST 67 SE 24
Blue Lodge, Wick, Avon
ST 6943 7393
Surface level +71.5 m

	Thickness m	Depth m
from		1.46
JURASSIC		
White and Blue Lias		
Clay, khaki mottled pale, grey, silty laminations. Thin rubbly pale grey limestones throughout	1.13	2.59
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstone, buff to greenish grey, silty, well indurated. Silt laminae throughout. Fish scales common and associated with stained Chlamys sp. impressions. Thin, 10 to 20 mm calcareous sandstones become common towards base	1.50	4.09
Westbury Beds		
Mudstone with clay alternations, dark greenish grey to black, disturbed silt laminae with limestone pellets throughout. Micaceous, fissile in parts. Pyritic staining on impressions of Rhaetavicula contorta and Protocardia sp.	2.74	6.83
Keuper		
Tea Green Marl		
Mudstone, with thin limestones, greenish grey with buff mottles. Argillaceous limestone nodules throughout, more abundant from 8.10 to 8.35 m. Listric surfaces in top 0.5 m	2.67	9.50
Keuper Marl		
Mudstone, reddish brown mottled greenish grey, very slightly silty, micaceous throughout. Argillaceous limestone nodules throughout. Greenish grey toward base	3.27	12.77
Mudstone, reddish brown, rare greenish grey mottles. Discrete crystals of calcite give a granular texture and are associated with mottling. Variably indurated, becomes greenish grey towards base	2.91	15.68
Mudstone, reddish brown mottled greenish grey, slightly silty, indurated, well indurated below 16.50 m. Calcite veins and vugs at 16.20 m. Well jointed throughout, slickensides	2.51	18.19
Mudstone, greenish grey, silty, well indurated, micaceous. Macrocells of pink gypsum from 18.63 to 18.66 m	1.13	19.32
Mudstone, pale reddish brown with rare greenish grey mottles, indurated. Veins of calcite and gypsum throughout with calcite on joints and fracture surfaces	1.18	20.50
Severnside Evaporite Bed, gypsum nodules, globular, white polycrystalline, partially replaced by euhedral celestite laths. Mudstone stringers separating nodules contain rounded quartz grains. Occasional solution cavities are lined with calcite and are common from 20.84 to 20.88 m	0.38	20.88
Mudstone, reddish brown, rare greenish grey mottles very slightly silty, brecciated from 20.88 to 21.17 m, possibly due to solution collapse, induration variable, highly fractured with cross-cutting calcite and gypsum veins throughout. Pale grey silt partings from 22.27 to 22.42 m. Slickensides with calcite developed and listric surfaces throughout		
Core seen to	3.18+	24.06

Borehole ST 67 SE 25
Redfield Hill, Oldland Common, Avon
ST 6839 7180
Surface level +86.3 m

	Thickness m	Depth m
from		1.00
TRIASSIC		
Rhaetic		
Cotham Beds		
Clay, khaki mottled olive, weathered, slightly silty to silty, fissured with ochre staining	0.60	1.60
Mudstone, medium grey with ochreous staining, weathered silty laminae in parts; fissured, slightly micaceous	0.25	1.85
Core loss from 1.85 to 2.11 m	0.26	2.11
Westbury Beds		
Clay, dark grey, weathered, slightly silty with poorly developed laminae. Limonite specks throughout. Protocardia sp.	0.13	2.24
Mudstone, dark grey, rare grey silt laminae, induration variable, fissile in parts. Limonite specks and gypsum crystals on some joints		
Core loss from 3.00 to 3.53 m	1.29	3.53
Keuper		
Tea Green Marl		
Mudstone, greenish grey, very slightly silty, induration variable. Argillaceous limestone nodules from 4.67 to 4.72 m. Becomes mottled reddish brown with depth with calcareous silt laminae in parts. Irregular calcite veins towards base. Listric surfaces below 5.10 m	2.93	6.46
Keuper Marl		
Mudstone, reddish brown with scattered greenish grey mottles, silty with some disturbed laminae, induration variable. Brecciated from 8.00 to 8.06 m. Discrete crystals of calcite, mica flakes throughout. Calcite veins common. Listric surfaces and slickensides. Well indurated and chocolate brown towards base	6.27	12.73
Mudstone, greenish grey with rare reddish brown mottles, slightly silty, well indurated, locally very well indurated, sub-conchoidal fracture. Listric surfaces	2.11	14.84
Severnside Evaporite Bed, pink finely crystalline celestite partially replaces nodular mosaic gypsum/anhydrite from 14.95 to 15.05 m. Passes into mudstone, reddish brown with scattered nodules of gypsum partially replaced by euhedral celestite laths. Small, less than 10 mm nodules of gypsum are developed within mudstone dykes and are often connected by fibrous gypsum veins. Celestite nodules up to 15 mm across occur between 16.25 and 16.42 m in a green mudstone with calcite veining. Calcite replaces both celestite and gypsum in the lower part of bed	1.63	16.47
Mudstone, reddish brown mottled greenish grey, very slightly silty, indurated, locally poorly indurated, calcite veins throughout. Brecciated in part with occasional yellow calcite crystals and pink gypsum as veins and lining cavities. Core seen to	2.97+	19.44

Borehole ST 67 SE 26
Upper Cullyhall Farm, Oldland, Avon
ST 6806 7067
Surface level +89.13 m

	Thickness m	Depth m
from		1.00
JURASSIC		
White and Blue Lias		
Clay with limestone, pale greenish grey with buff limestone fragments, silty wisps and partings. Broken recovery from 1.00 to 3.75 m. Fish scales, Chlamys sp. Protocardia sp. in bituminous limestone from 4.19 to 4.34 m	3.34	4.34
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstone with clay, dark grey, silty with scattered wisps and partings, poorly indurated. Fine grained pyritic sandstone at base	1.58	5.92
Westbury Beds		
Mudstone, dark grey, silty, induration variable. Micaceous and shaly in parts. Occasional silt partings with mudstone pellets, and fine grained sandstone partings. Pyritised impressions of Chlamys sp. Rhaetavicula contorta and Gyrolepis sp. scales. Dark grey limestone at c. 6.5 m. Broken recovery towards base	1.81	7.73
Keuper		
Tea Green Marl		
Mudstone, greenish grey, mottled reddish brown, slightly silty becoming silty with depth. Indurated locally well indurated. Gritty texture due to discrete crystals of calcite throughout. Argillaceous limestone nodules at 8.9 and 9.9 m. Network of calcite veins towards base	2.77	10.50
Keuper Marl		
Mudstone, reddish brown, rare mottles greyish buff and greenish grey, silty, indurated, locally well indurated. Scattered grains of calcite locally give a gritty texture. Micaceous listric surfaces. Cavities lined with calcite and celestite at c. 15.0 m	6.00	16.50
Severnside Evaporite Bed, reddish brown mudstone mottled greenish grey, containing seams of vuggy nodules of pink and white coarsely crystalline celestite, usually less than 80 mm across at c. 17.5, 18.5 and 19.0 m with traces of calcite throughout. Mudstone, silty, indurated with a gritty texture due to discrete crystals of calcite, well indurated from 18.5 to 19.5 m. Micaceous, slickensides throughout, locally coarse rounded quartz grains abundant. Passing into mudstone, greenish grey, laminated with sandy intercalations and 'dykes' throughout. Celestite as nodules up to 20 mm across at 19.9 m and at c. 20.8 m. Mudstone dolomitised, with mudflake conglomerates and nodules of celestite and gypsum below 20.85 m.	4.45	20.95
Mudstone, reddish brown, mottled greenish grey, silty, rounded quartz grains in lensoid accumulations. Discrete crystals of calcite give a gritty texture locally. Variably indurated. Calcite veining with celestite traces throughout. Mudstone inhomogenous, with patches of mudflake conglomerate and dolomitised nodular calcrete. Listric surfaces throughout		
Core seen to	10.21+	31.16

Borehole ST 77 NW 22
Westerleigh Hill, Avon
ST 7048 7932
Surface level +110.3 m

	Thickness m	Depth m
from		4.00
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstone, pale greenish grey mottled dark greenish grey, silty, poorly indurated with occasional nodular muddy limestones from 5.41 to 5.53 m. Occasional pyritised fossil impressions throughout, abundant in lower 0.6 m. Core loss from 4.36 to 5.41 m	2.57	6.57
Westbury Beds		
Mudstone, olive black with thin silt laminae below 6.70 m. Poorly indurated, fissile. Ostrea, Chlamys, Rhaetavicula contorta fragments throughout. Silt partings disturbed near base. Listric surfaces and slickensides throughout. Occasional pyritised partings Core losses 50 per cent from 6.85 to 10.29 m	3.72	10.29
Keuper		
Tea Green Marl		
Mudstone, pale greenish grey becoming grey with depth, slightly silty, calcareous with calcite crystals giving a granular texture, manganese and pyrite on joint surfaces. Micaceous, listric surfaces and slickensides	2.57	12.86
Keuper Marl		
Mudstone, reddish brown mottled greenish grey below 13.50 m, indurated to well indurated, silty partings. Green mottles and manganese associated with joints. Micaceous with listric surfaces and slickensides throughout. Passes into muddy reddish brown limestone at 14.06 m	1.33	14.19
Mudstone, greenish grey mottled reddish brown, slightly silty, indurated, well indurated in places. Joints with manganese stains. Micaceous, listric surfaces throughout. Calcareous in parts passing into argillaceous nodular limestone at 15.44 m	1.38	15.57
Mudstone, reddish brown with rare greenish grey mottles, some spherical with dark nucleii, induration variable. Manganese on some joints. Granular patches of discrete calcite crystals, calcareous with argillaceous limestone nodules and calcite veining along joints. Mudstone conglomerates and breccias from 20.85 to 21.00 m. Slickensides and listric surfaces throughout	6.18	21.75
Mudstone, greenish grey containing a vuggy nodule of celestite lined with dogtooth calcite	0.05	21.80
Mudstone, reddish brown with chocolate brown, rare greenish grey mottles, well indurated in places with conchoidal fracture. Calcite crystals line cavities from 22.85 to 23.50 m and from 25.15 to 25.20 m with calcite veins following joints. Discrete calcite crystals give granular texture from 25.00 to 26.40 m. Micaceous, listric surfaces, slickensides throughout	4.60	26.40
Mudstone with Severnside Evaporite Bed, greenish grey, very slightly silty, indurated but locally friable. Nodular celestite up to 50 mm in diameter with coarse crystalline orthorhombic celestite lined with amethystine quartz at 27.05 m	0.70	27.10
Mudstone, dark reddish brown with rare greenish grey mottles associated with calcite veins from 27.97 to 28.42 m, indurated, listric surfaces throughout. Core seen to	1.90+	29.00

Borehole ST 78 SW 12
Cliff Farm, Wapley, Avon
ST 7125 8029
Surface level +108.0 m

	Thickness m	Depth m
from		1.00
JURASSIC		
White and Blue Lias		
Clay with a calcareous mudstone band, pale greenish grey to brown, mottled in parts, laminated, calcareous, silty	0.90	1.90
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstone with occasional clay bands, pale greenish grey becoming darker grey towards base, calcareous, slightly silty with silty partings. Fossil impressions including Chlamys sp. Clay bands, generally rubbly with limestone pellets, laminated in parts	2.04	3.94
Westbury Beds		
Mudstone with occasional clay bands and a sandstone band, black to dark grey, slightly silty, laminated and shaly in parts, with silty horizons, abundant gypsum crystals along some laminated surfaces, micaceous throughout, fossiliferous throughout, includes Protocardia and Chlamys sp., with a nodular, pyritised band with lamellibranch impressions at base	3.23	7.17
Keuper		
Tea Green Marl		
Mudstone with a clay band, greenish grey, very slightly silty, indurated, blocky in parts, calcareous throughout, locally pyritised, scattered flakes of mica, irregular joints with slickensides	2.32	9.49
Keuper Marl		
Mudstone with argillaceous limestone nodules dark reddish brown, mottled greenish grey in parts, slightly silty, indurated to well indurated, scattered flakes of mica, iron staining along some joint surfaces, listric surfaces and slickensides, calcilutite bands from 13.00 m to base, pale greenish grey to brown, up to 0.13 m thick, alternating with mudstone. Rare calcite veining at base	6.87	16.36
Mudstone, dark reddish brown mottled greenish grey in parts, slightly indurated becoming progressively well indurated, calcareous throughout with thin veins of calcite, scattered flakes of mica throughout, jointed with slickensides and listric surfaces	7.09	23.45
Severnside Evaporite Bed with mudstone, dark greenish grey mottled reddish brown, indurated, slightly silty, porcellanous texture in places. Horizontal coarsely crystalline vein celestite at 23.45 m. Well defined bed of finely crystalline, in parts amorphous, celestite with some calcite and gypsum between 23.95 and 24.36 m, locally with intercalations of greenish grey mudstone containing many small sand grade grains of gypsum	0.90	24.35
Mudstone, reddish brown mottled greenish grey in parts, mottles, sometimes calcite-filled vugs, a few scattered reduction spots some with dark nucleii, calcareous in parts, with discrete crystals of calcite giving a granular texture, indurated to well indurated, vesicular in places, especially between 24.35 and 24.60 m suggesting 'bird's eye' structure, well jointed with numerous slickensides and listric surfaces, brecciated in parts, occasional nodules of dolomite, rare galena with some pyrite at c. 29.58 m, pseudomorphs after halite common below 29.90 m	7.20	31.55
Dolomitic Conglomerate		
Sandstone and breccia alternations		
Sandstones, pale yellowish green to reddish brown, fine grained, micaceous in part cemented in upper band between 31.55 and 32.00 m with celestite, otherwise by hematite. Breccia, generally yellowish red, with many angular fragments of quartzite, recrystallised limestone and fine grained sandstone, set in matrix of poorly sorted quartz and limestone grains cemented with quartz and dolomite	4.53	36.08
CARBONIFEROUS		
Lower Coal Measures		
Quartzite, purple, with angular contact with sandstone and breccias above		
Core seen to	0.07+	36.15

Borehole ST 78 SW 13
Chescombe Farm, Wapley, Avon
ST 7167 8082
Surface level +106.4 m

	Thickness m	Depth m
from		1.00
TRIASSIC		
Rhaetic		
Cotham Beds		
Clay, weathered, pale brown to yellowish brown mottled grey in places, calcareous with silty partings, occasional thin muddy limestone bands	2.06	3.06
Mudstone, olive grey to brownish grey, slightly silty, calcareous with dense manganese stains on fractures, interbedded limestones with shell fragments	1.74	4.80
Core loss from 4.80 to 4.90	0.10	4.90
Westbury Beds		
Mudstone with clays, very dark grey, laminated with silty wisps, micaceous and fissile, abundant fragments of Rhaetavicula contorta, pyritised between 7.49 and 7.63 m. Medium grained calcareous sandstone with bone fragments and phosphatic nodules at base	2.77	7.67
Keuper		
Tea Green Marl		
Mudstone, greenish grey mottled reddish brown, indurated to well indurated, slightly silty becoming silty with disturbed silt partings. Manganese stains on joints, slickensides and listric surfaces	3.52	11.19
Keuper Marl		
Mudstone, reddish brown mottled greenish grey, indurated, slightly silty, silt partings show slump structures. Calcareous in parts with discrete crystals of calcite giving a granular texture. Occasional argillaceous limestone nodules. Micaceous in parts, manganese stained joints, slickensides	13.01	24.20
Dolomitic Conglomerate		
Mudstone and conglomerate, greenish grey mottled reddish brown, indurated to well indurated, sandy throughout especially from 26.0 to 26.3 m with occasional porcellanous limestone, and angular sandstone clasts. Micaceous and cemented with celestite throughout. Celestite present as fine laths and small (less than 50 mm) nodules. Coarsely crystalline celestite as veins at c. 25.7 and 25.9 m. Masses of celestite up to 100 mm across at 26.0 m abundant towards base. Passes into	2.30	26.50
Sandstone, reddish brown, fine grained, cemented in parts by celestite. Occasional pale buff, calcareous areas. Becomes conglomeratic	0.50	27.00
dark reddish brown sandstone with sub-angular to rounded clasts of greenish grey sandstone. Impregnated with fine laths of celestite throughout. Less conglomeratic towards base	1.25	28.25
CARBONIFEROUS		
Lower Coal Measures		
Mudstone, reddish purple mottled ochre, impregnated with hematite. Laminated micaceous with a dip of c. 30° below 32.92 m. Well jointed with slickensides		
Core seen to	6.94+	35.19
Severnside Evaporite Bed from 24.20 to 26.50 m		

Borehole ST 78 SW 14
Cliff Farm, Wapley, Avon
ST 7167 8035
Surface level +119.4 m

	Thickness m	Depth m
from		1.00
JURASSIC		
White and Blue Lias		
Clay with limestone bands and nodules, variegated bluish grey with brown, slightly silty with pockets of selenite crystals and calcite grains. Pyritised fossil impressions. Occasional mudstone pellets throughout. Grades into calcareous mudstone bands, pale grey, very well indurated, well jointed with abundant pyritised fossil impressions. Occasional nodular muddy limestones, fine grained with lamellibranch and brachiopod impressions	14.00	15.00
TRIASSIC		
Rhaetic		
Cotham Beds		
Mudstone, pale grey to greenish grey, well indurated, calcareous with limestone at base. Silt laminae in parts, blocky fracture, well jointed, fossiliferous, listric surfaces	2.40	17.40
Westbury Beds		
Mudstone, dark grey with pale grey silt laminae, calcareous, fissile in parts, blocky in parts. Micaceous and pyritic throughout. Protocardia sp., and fish remains abundant on some bedding planes	4.02	21.42
Keuper		
Tea Green Marl		
Mudstone with limestone nodules, greenish grey, indurated, occasionally well indurated with silt partings. Argillaceous limestone nodules between 23.11 and 23.54 m. Discrete crystals of calcite as local patches with a granular texture. Manganese stained joints, some listric surfaces	2.84	24.26
Keuper Marl		
Mudstone, reddish brown mottled greenish grey, slightly silty, indurated to well indurated, with occasional argillaceous limestone nodules between 24.72 and 25.65 m and from 28.62 to 28.72 m, some partially recrystallised. Discrete crystals of calcite giving a granular texture, micaceous, well jointed with manganese on joints, listric surfaces and slickensides	10.98	35.24
Mudstone with Severnside Evaporite Bed, greenish grey, slightly mottled reddish brown, well indurated and jointed. Celestite between 35.96 and 36.33 m. Disseminated passing into more massive finely crystalline celestite with many vugs towards the base of bed. Isolated irregular nodule of celestite in reddish brown mottle at 36.78 m	1.82	37.06
Dolomitic Conglomerate		
Conglomerate, angular to subrounded fragments of grey limestone, red-purple quartzite, red cherty limestones with a pink-buff fine to coarse quartz sand matrix partially cemented by celestite at the top.		
Core seen to	1.66+	38.72

5.6 *YATE-CROMHALL*

5.6.1 *Geological Notes*

TALBOTS' END: Scattered nodules of celestite with calcite (E 44 616 and E 44 617) occur in fields [709 903] and [705 906]. No celestite has been observed at outcrop although it was augered south of Fox Hole Lane [709 901].

CROMHALL COMMON: A pit [703 887] off Cowship Lane, backfilled in 1973, showed dark purplish red shales and thin sandstones (Lower Coal Measures shales) generally dipping southwards at 30° to 35° though dips as high as 60° were observed. The shales were deeply weathered giving rise to a superficial yellowish red clay, often 2 m or more in thickness. The shales often displayed an open joint pattern and fracture surfaces were common. The celestite occurred as veins, concordant and discordant with respect to the bedding of the shales and as isolated blocks up to 1 m in size in the weathered zone.

WEST END-YATE: Many of the fields of Barber's Court Farm [707 881] to the south of Cowship Lane have been worked for mineral. In a pit [703 877], backfilled late in 1973, large celestite 'mumblers' (doggers or boulders) up to 0.7 m diameter, were present in weathered reddish yellow clay, probably residual Keuper Marl, which overlay purplish grey Lower Coal Measures shales, dipping at 20° to the west. Celestite also occurred in the shales as veins, concordant and discordant with respect to bedding. The mineral was particularly common in shales adjacent to interbedded sandstones and quartzitic conglomerates.

South of Tanhouse Lane, ground on both sides of a mudtrack which runs north-south, has been dug for celestite. A pit [712 851] showed weathered purplish grey shales with interbedded quartzitic sandstones dipping at 25° to the west.

Celestite occurred in the shales as veins concordant and discordant with respect to bedding and was more frequent immediately adjacent to arenaceous strata. A weathered mantle up to 2 m thick contained angular blocks of celestite, up to 0.5 m in size. The long axis of several blocks was orientated vertically.

The fields south of Broad Lane, [710 837 and 711 835], were worked and backfilled in 1972. Over parts of the fields river terrace deposits occur; they consist of red-brown sandy clay with angular fragments of quartzitic sandstone, chert and celestite, overlying Keuper Marl. A section [7104 8365] exposed red-brown sandy clay containing angular blocks of sandstone, chert and celestite (shown as terrace on the geological map) overlying nearly horizontal weathered Keuper Marl which rested in turn unconformably on Lower Coal Measures shales dipping at 30° to the west. Celestite also occurred at the unconformity as isolated masses, up to 1 m across and in the shales as veins, often disturbed by superficial movements.

STIDCOT: In the banks of the Ladden Brook south from Summer Bridge [6870 8820] to [6805 8760], 'mumblers' of coarsely crystalline celestite are embedded in orange-red clays (weathered Lower Coal Measures shales). Locally reddish brown weathered Keuper Marl overlies Coal Measures.

5.6.2 *Bristol Cottages and Rose Garden*

Trenches in the Lower Coal Measures at two sites provided the following information.

BRISTOL COTTAGES: [698 894] The site is underlain by Lower Coal Measures dipping south-south-west at 20°. The trenches showed alternating shales, thin sandstones and rarely, coals. Six trenches were dug but none encountered celestite (Fig. 18).

ROSE GARDEN: [695 885] Yellow and grey weathered Coal Measures material with included red clays (? residual Keuper Marl) up to 1.1 m, rest on blocky sandy purplish red mudstones (Fig. 18). None of the six trenches yielded celestite, although the mineral was formerly worked 500 m to the north-west [699 889].

5.6.3 *West End Farm, Hall End, Limekiln Plantation, Hunter's Hall and Cowship Cottages*

Trenching to investigate the distribution of celestite at, or near, the Triassic/Carboniferous unconformity provided the following information.

WEST END FARM: [711 875] Keuper Marl, up to 2.7 m thick, rests on Lower Coal Measures shales. Scattered nodules of celestite were observed in the weathered, near-surface clays, but additionally a massive bed of mineral, at or just above the unconformity, was proved in three of six trenches. No celestite was observed in the Carboniferous strata.

Trench	Final depth m	Yield in kg/m^2	Depths between which celestite occurred m
1	4.4	trace	0.1 to 0.6
2	3.8	nil	-
3	4.1	179	1.6 to 1.9
4	3.5	442	1.4 to 1.8
5	3.2	235	2.4 to 2.7
6	3.6	trace	c. 0.6
mean	3.8	≃143	

Only trenches 3, 4 and 5 situated on low ground adjacent to the stream yielded mineral in appreciable quantities (Fig. 19). Taking account of the variability of the yields from the trenches, it is thought that the outlined area (Fig. 19) might contain 1430 tonnes per hectare.

HALL END: [708 867] Yellow and brown variegated clays up to 0.35 m thick overlie red clay (? Keuper Marl) up to 2.3 m in thickness containing disseminated and sporadically nodular celestite, which in turn, rests on blocky shales and mudstone with thin coals and sandstones (Lower Coal Measures). Six trenches were excavated, three in each field (Fig. 19). Because of the disturbed appearance of the ground, it is thought that the western field has been already worked for celestite; two of the trenches yielded measurable quantities of mineral, nevertheless. No celestite was recorded in the eastern field

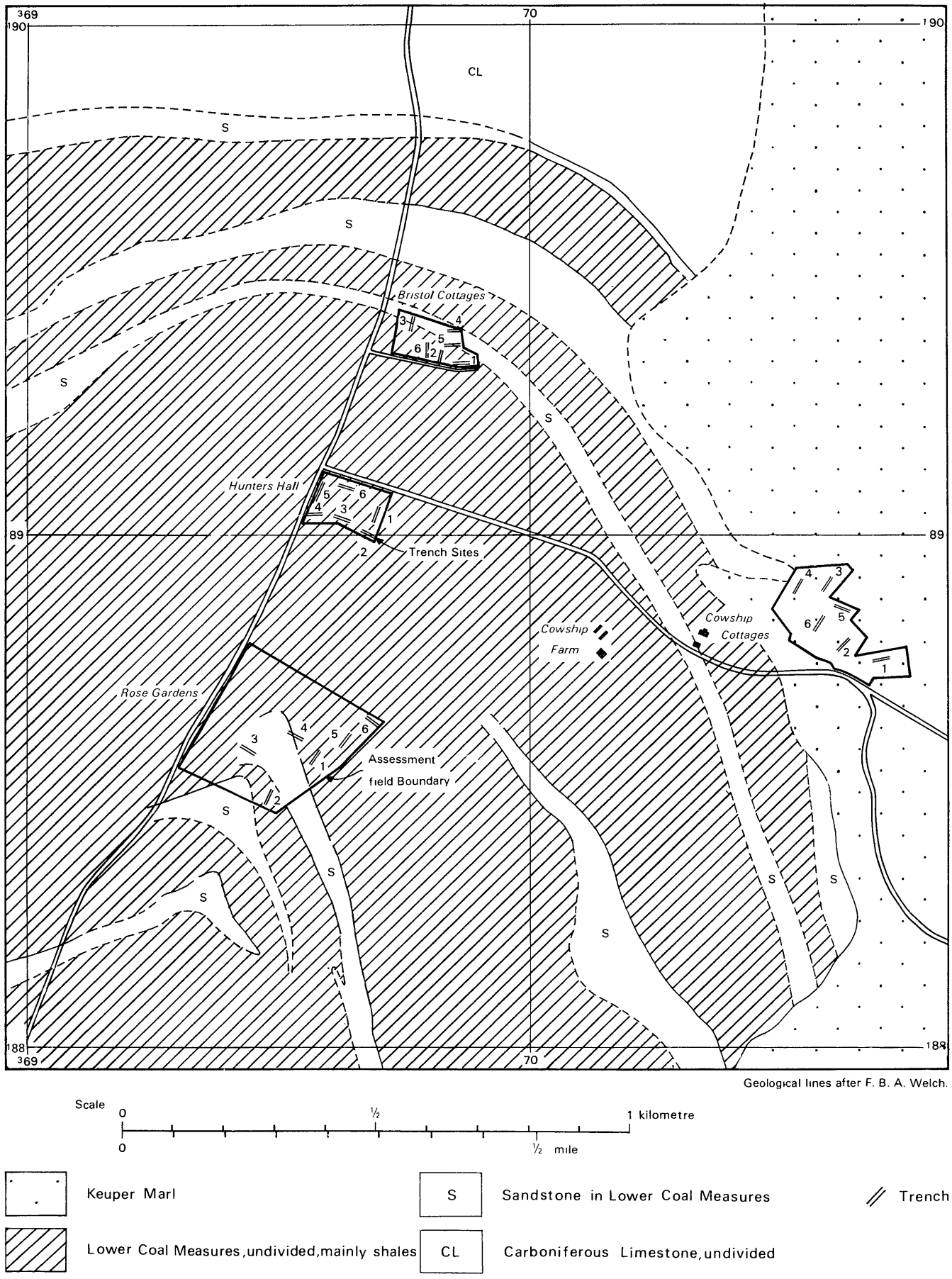


Fig. 18. Geological sketch map of Cromhall Common area

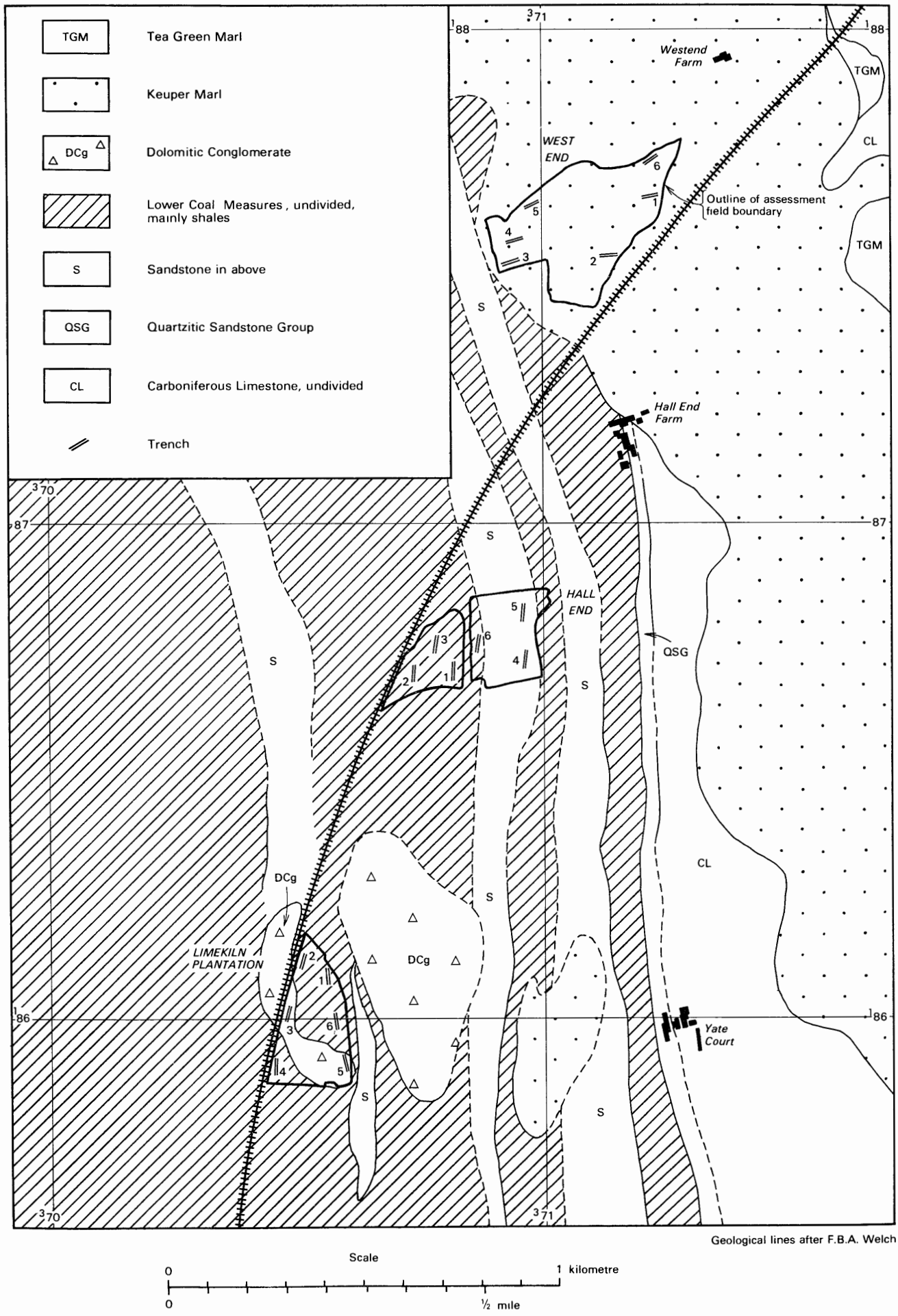


Fig. 19. Geological sketch map of Hall End area

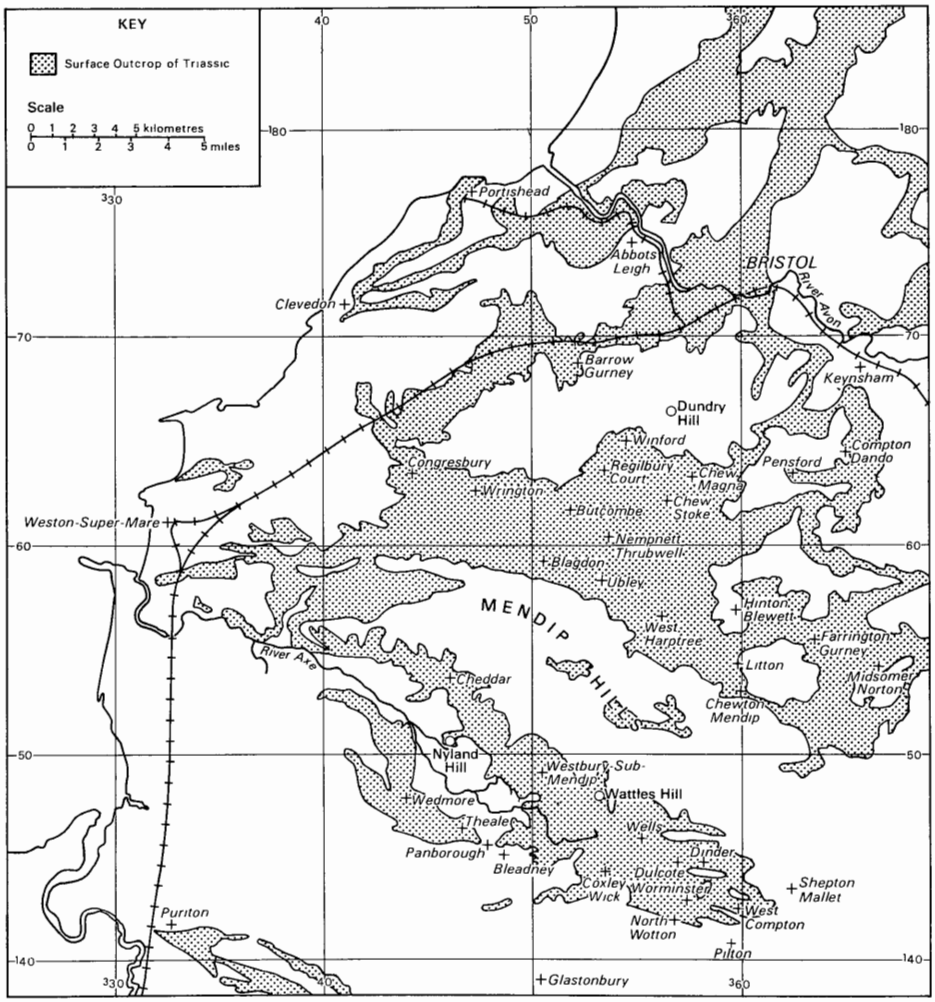


Fig. 20.
The area south of Bristol

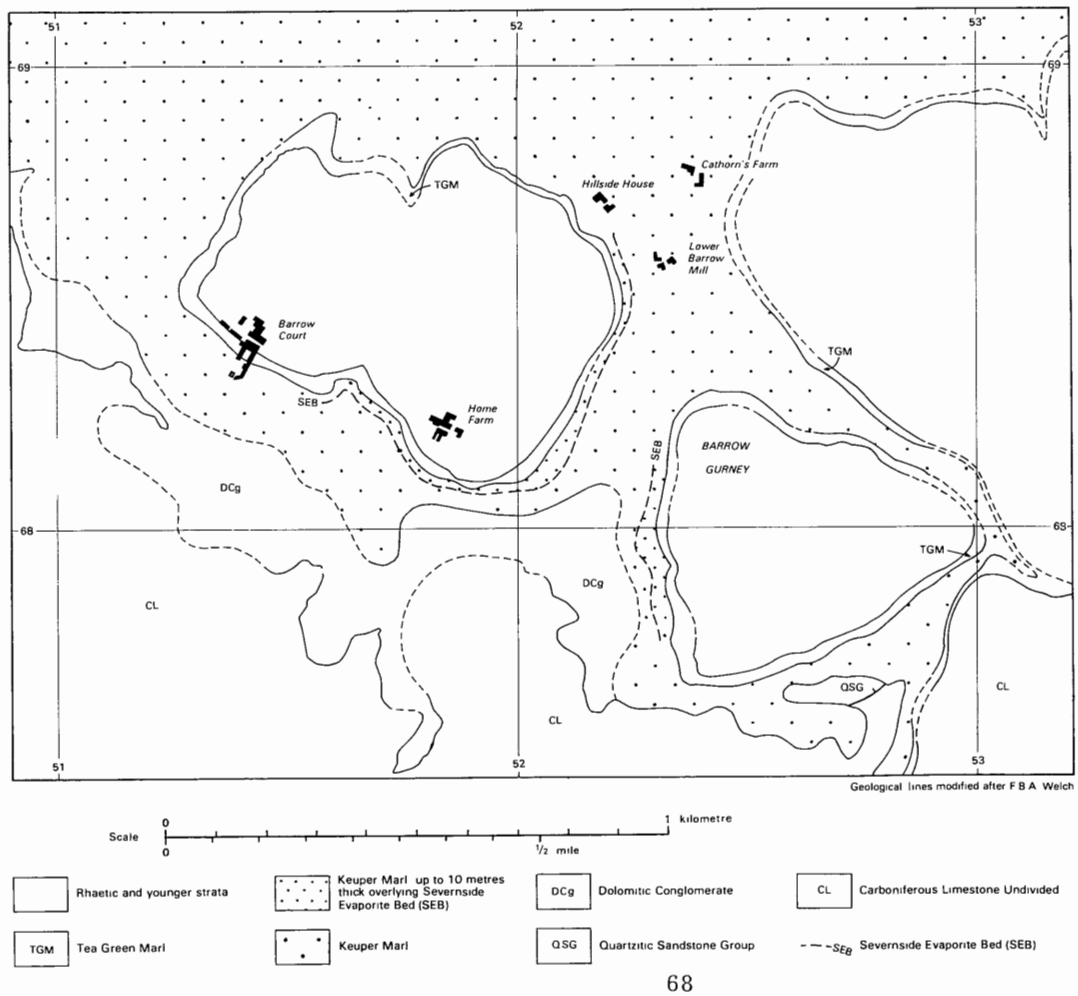


Fig. 21.
Geological sketch map of Barrow Gurney area

where up to 2 m of variegated clays overlie conglomeratic sandstone. On the basis of the available information an average yield of no more than 70 tonnes per hectare might be expected.

Trench	Final depth m	Yield in kg/m^2	Depths between which celestite occurred m
1	3.3	nil	-
2	4.5	30	c. 1.5
3	4.7	10	0.3 to 1.8
4	5.0	nil	-
5	5.0	nil	-
6	1.8	nil	-
mean	4.1	≃7	

It is not known whether this estimated yield is applicable to ground already dug for celestite; certainly areas worked before 1950 are not likely to have been systematically developed and may retain considerable quantities of mineral.

LIMEKILN PLANTATION: [705 860] The site is underlain by Keuper Marl and Lower Coal Measures which weather to stiff, yellow, grey and red variegated clays up to 1.2 m thick (Fig. 19). Small nodules of celestite were found usually randomly distributed within this weathered horizon, but in three of the six trenches, blocks of mineral up to 50 kg in weight and enclosed in greenish grey clay rested on the irregular surface of unweathered purplish grey blocky shales (Coal Measures).

Trench	Final depth m	Yield in kg/m^2	Depths between which celestite occurred m
1	5.2	149	2.3 to 2.5
2	4.0	663	1.7 to 2.4
3	5.0	92	1.8 to 2.2
4	5.0	trace	c. 2.1
5	3.5	4	c. 2.2
6	3.9	nil	-
mean	4.4	≃151	

On the basis of this information the mineral appears to be restricted to the northern part of the field and a yield of 1510 tonnes per hectare might be expected.

HUNTER'S HALL: [697 891] Weathered, stiff, yellow, grey and red variegated clays up to 1.2 m thick overlie purplish red, blocky shales and thin sandstones (Lower Coal Measures) (Fig. 18). In three of the seven trenches dug, celestite occurred at the junction of the weathered and unweathered material. There is no apparent systematic pattern in the distribution of the mineral.

Trench	Final depth m	Yield in kg/m^2	Depths between which celestite occurred m
1	4.2	nil	-
2	4.5	nil	-
3	4.7	145	2.8 to 3.1
4	4.1	nil	-
5	4.6	5	c. 1.8
6	5.0	nil	-
7	4.7	34	1.7 to 2.0
mean	5.3	≃26	

A yield of 260 tonnes per hectare might be expected, taking the area trenched as a whole.

COWSHIP COTTAGES: [705 888] Clayey gravel (First Terrace) up to 1.1 m thick, rests on up to 1.5 m of sandy reddish brown Keuper Marl which, in turn, overlies purplish red mudstones and thin sandstones of Lower Coal Measures age (Fig. 18). The upper weathered reddish brown Keuper Marl containing scattered nodules of celestite, passes down into blocky greenish grey mudstone with massive celestite developed near the base of the Keuper Marl. No celestite was recorded from the Palaeozoic strata.

Trench	Final depth m	Yield in kg/m^2	Depths between which celestite occurred m
1	3.4	231	2.2 to 2.5
2	4.2	nil	-
3	3.5	51	2.2 to 2.3
4	5.0	3	c. 1.5
5	3.0	nil	-
6	2.6	266	1.6 to 2.1
mean	3.6	≃92	

Although mineral was not found in two of the six trenches, no distributive pattern may be inferred. A yield of some 920 tonnes per hectare might be expected from the area investigated.

5.7 *OTHER AREAS*

Thomas (1973) listed known celestite occurrences in the United Kingdom. The only currently workable deposits occur in the Coal Measures and Keuper Marl of the Yate area, but the mineral was formerly worked south of Bristol where it occurs sporadically in the Keuper Marl and Tea Green Marl and locally contains substantial quantities of gypsum, quartz and calcite.

Although rapid reconnaissance surveys undertaken mainly during the summer of 1974 have provided the following information in addition to that given by Green and Welch (1965) and Thomas (1973) it is inadequate for resource estimates. Locations south of Bristol and around the Mendips mentioned below are shown on Fig. 20.

General

North of the Mendips, Green and Welch (1965, p. 167) recorded nodular celestite in Keuper Marl 'at about the level of the Woodford Hill Sandstone although one case is also known from the Butcombe Sandstone'. These sandstones lie respectively about 8 and 20 m below the base of the Tea Green Marl.

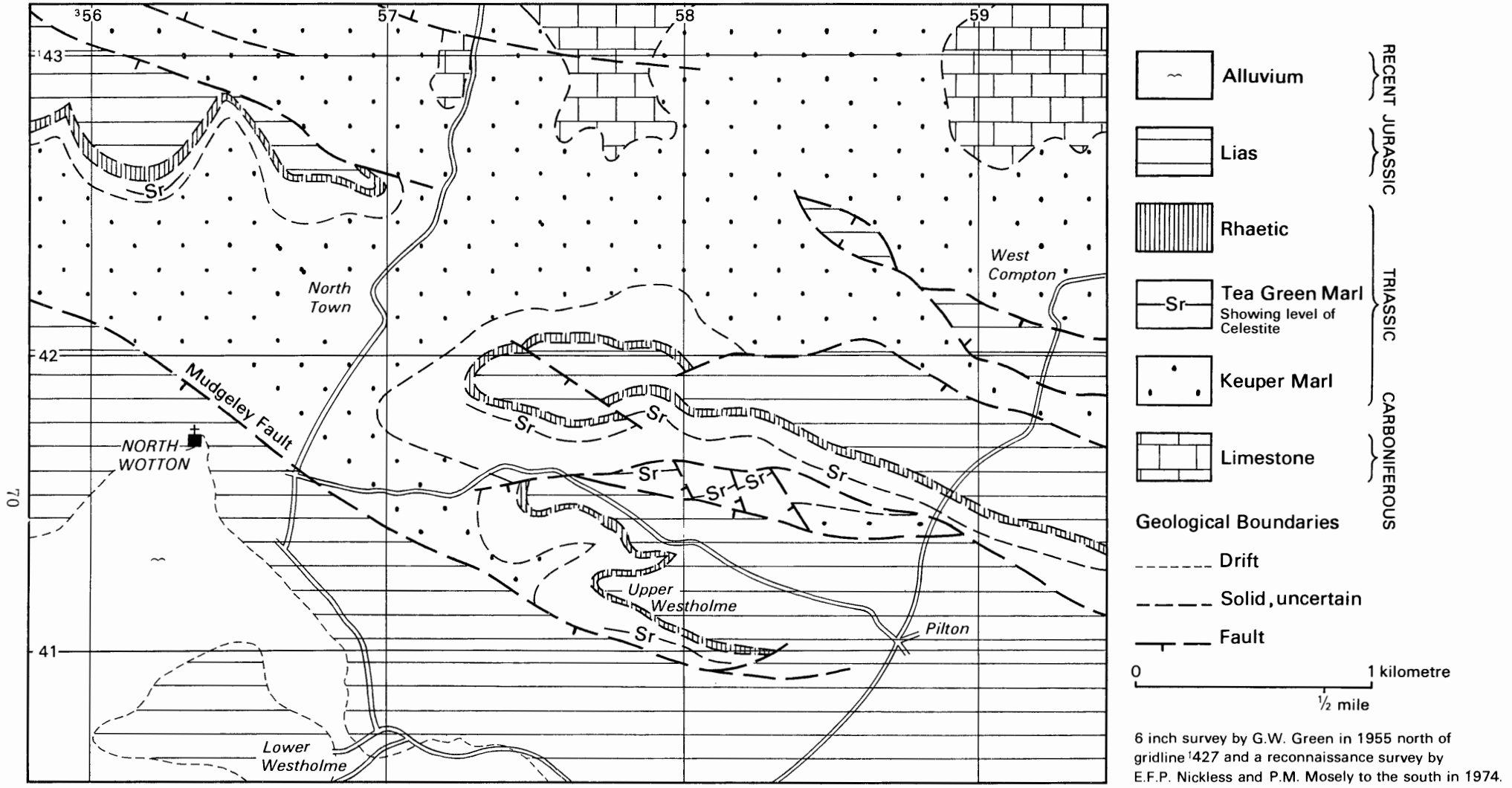


Fig. 22. Geological sketch map of North Wootton area

Although only eight of 27 soil traverses undertaken during this survey demonstrated anomalous amounts of strontium in the soil, surface evidence indicates that within the Keuper Marl celestite and gypsum form a laterally discontinuous bed 3 to 10 m below the base of the Tea Green Marl, that is, about the level of the Woodford Hill Sandstone, although the present authors have not found any new evaporite occurrences associated with the Woodford Hill Sandstone sensu stricto. At Winford [5423 6495] and Regilbury Court [5267 6285] the celestite occurs on an irregular surface of Dolomitic Conglomerate.

South of the Mendips (Green and Welch, 1965) the mineral occurs at about 'the level of the Westclose Hill Conglomerate, and at about the middle of the Tea Green Marl'. The Westclose Hill Conglomerate lies approximately 30 to 40 m below the base of the Tea Green Marl and is tentatively correlated by Green with the Butcombe Sandstone to the north of the Mendips. Recent investigations by the present authors in the neighbourhood of Wells have shown celestite to be present 10 to 15 m below the base of the Tea Green Marl and such occurrences are tentatively correlated with the celestite which occurs at or about the level of the Woodford Hill Sandstone to the north of the Mendips. In the area of North Wootton [5638 4180] the authors have found celestite, with varying amounts of gypsum, in the Keuper Marl immediately beneath the overlying Tea Green Marl. The latter attenuates locally reflecting elevations in the Palaeozoic surface (G.W. Green, personal communication).

Celestite and associated coarsely crystalline calcite nodules were found by G.W. Green (personal communication) during the 6-inch survey of the Weston-Super-Mare (279) Sheet and the adjacent area to the north [south-eastern corner of the Cardiff (263) Sheet]. The stratigraphical position of the occurrences is either at the base of the Tea Green Marl or in the red marls immediately below.

5.7.1 *South Bristol*

BARROW GURNEY: Welch (1952) reported nodular celestite in spoil tips from old mineral workings approximately 700 m south of Lower Barrow Hill at [5232 6856]. The nodules, up to 200 mm in diameter, showed a finely foliated exterior, and he was able to trace a bed of nodular celestite for 200 m along the strike. Recent field investigations have shown an extension of this outcrop of the Severnside Evaporite Bed, which occurs in the Keuper Marl approximately 5 to 7 m below the base of the overlying Tea Green Marl (Fig. 21). Additionally, sampling in the fields below Home Farm [5184 6822], about 100 m south of the Lodge [5165 6835], proved up to 0.25 m of friable coarsely crystalline celestite and gypsum (the former replacing the latter) at 0.8 m depth over 40 m along a traverse.

A thin section (E 44 633) of celestite sampled from the old workings shows finely crystalline celestite laths, some badly corroded and partially replaced by sparry calcite.

There is no evidence of large-scale celestite extraction in the area. To the east of the old workings and beneath Home Farm the mineral is probably present beneath a cover of Triassic and Jurassic rocks but in both areas the thickness of overburden, which increases rapidly away from the line of outcrop, may inhibit the extent of future workings.

5.7.2 *North of the Mendips*

WESTON-SUPER-MARE DISTRICT: Celestite-calcite and coarsely crystalline calcite nodules up to 300 mm across are commonly present at the base, or within 1 m of the base, of the Tea Green Marl in the Hutton-Uphill area on the north side of the Mendip Hills [for example, 3424 5883 and 3230 5824] (G.W. Green, personal communication, 1976). Similar nodules were found in the Kewstoke area, north-east of Weston, at Horne Farm, Norton [3419 6371] just below the base of the Tea Green Marl although celestite was not confirmed.

WINFORD: About the turn of the century, celestite was worked [5424 6460] 350 m south of Winford Church (G.A. Kellaway, personal communication). Field boundary walls in the vicinity contain blocks of finely crystalline, sugary, white celestite.

REGILBURY: Fields west and north-west of Regilbury Court [5270 6290] were worked for celestite between 1893 and 1909. These workings have been filled in and the ground returned to agriculture but some loose surface celestite fragments were noted. To the north-east, traverses from [5282 6317] to [5312 6318] and from [5335 6332] to [5370 6347] show small, though significant, strontium anomalies at [5307 6318, 5335 6332, 6341 6332 and 5354 6334]. Surface fragments show celestite locally with considerable amounts of calcite and as a result of augering it is thought that the evaporite is restricted to hollows in the Dolomitic Conglomerate.

BUTCOMBE: South of Bicknell Farm [5172 6278] traversing detected strontium anomalies [5163 6253 and 5162 6250] in Keuper Marl, approximately 3 to 5 m below the base of the Tea Green Marl.

In his geological survey of the area south-west of Butcombe in 1948-9, Green noted the presence of celestite nodules between Round Wood [504 611] and Long Wood [506 611]. Traversing near Hanging Wood [502 616] showed celestite in Keuper Marl, approximately 5 m below the base of the Tea Green Marl at [5032 6108].

NEMPNETT THRUBWELL: Green (in Green and Welch, 1965, p. 73) noted nodular celestite 'at the level of the Woodford Hill Sandstone, in a silage pit [521 606] near West Town', although its presence was not reflected in three soil sampling traverses in the immediate area. At Rookery Farm [5457 6034] he records nodular celestite. Traversing in the immediate area and to the north-west near Southmead Farm [5384 6093] detected strontium anomalies [5379 6080, 5379 6077, 5377 6071 and 5378 6067] at about the level of the Woodford Hill Sandstone.

Traverses east and south of The Knoll

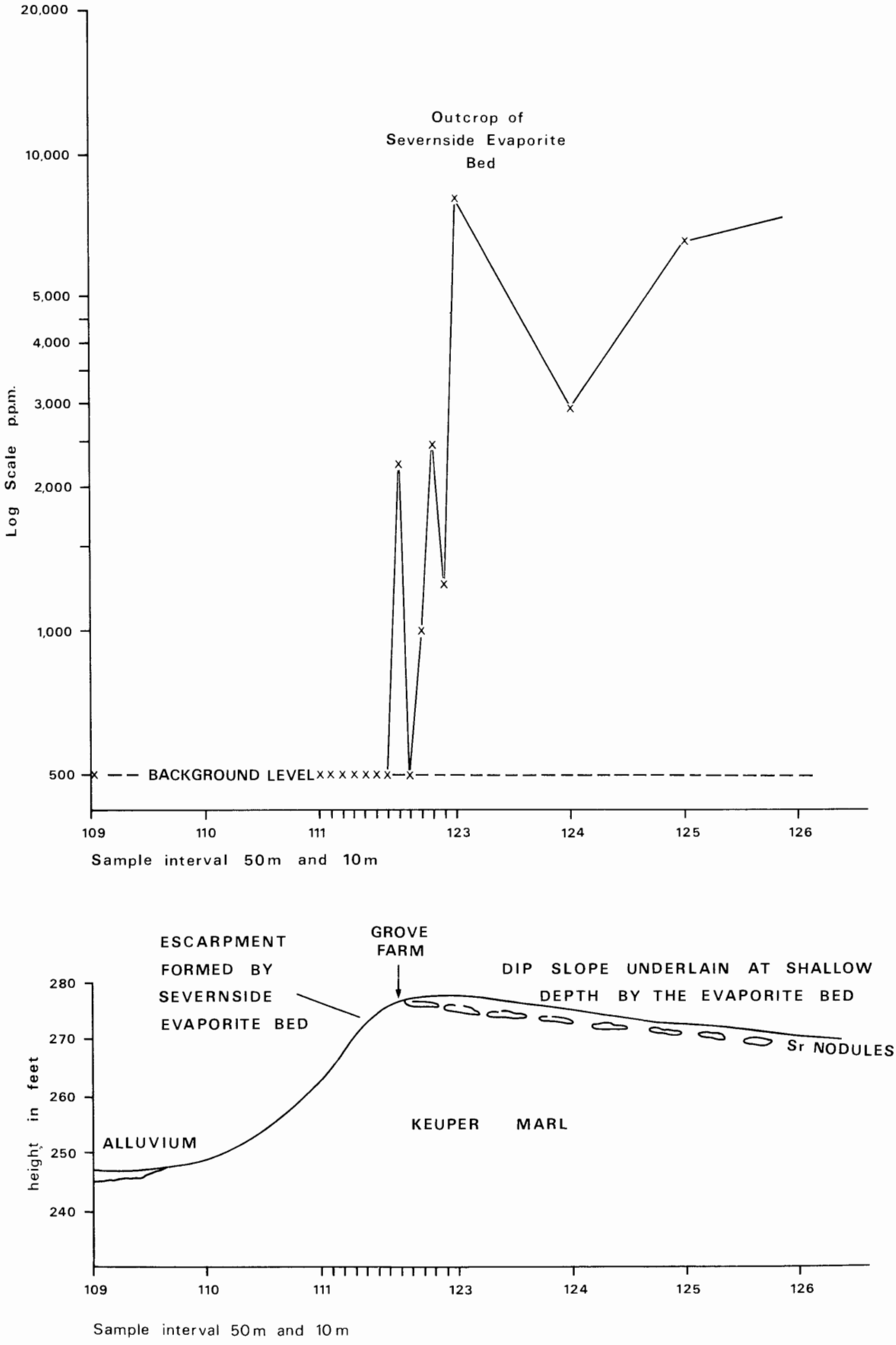


Fig. 23. Cross-section of Wapley Common with geochemical plot of a traverse across the Severnside Evaporite Bed feature

[542 618] found strontium anomalies [5433 6181 and 5441 6194] overlying a sandstone feature (? Woodford Hill Sandstone).

CHEW MAGNA: A strontium anomaly [5820 6128] was detected, at a level approximately 12 to 15 m below the base of the Tea Green Marl, at Knowle Hill [583 613] where a fault-bounded block of sandy Keuper Marl is capped by Tea Green Marl. The stratigraphical interpretation of the anomaly, which may indicate the presence of a bed of celestite hereabouts, is unknown.

On the Triassic scarp from Upper Littleton [5524 6456] to Norton Hawkfield [5932 6472] an anomalous concentration of strontium was found in the soil 170 m north of Halfway Farm [5942 6377], stratigraphically approximately 15 m below the base of the Tea Green Marl.

5.7.3 *South of the Mendips*

CHEDDAR TO WESTBURY SUB MENDIP: A series of hills often with exposed Carboniferous Limestone cores fringed with Dolomitic Conglomerate and Keuper Marl fringe the Mendips between [457 504] and [497 483]. Near Nyland Hill [458 504] traversing proved strontium anomalies at [4593 5035] and [4606 5016] but no celestite was observed. Although Green and Welch (1965) record celestite in the Westclose Hill Conglomerate, traversing did not find any strontium anomalies around Westclose Hill [469 495].

Nodules of celestite with varying proportions of calcite and quartz are present in the Keuper Marl, for example, at [4914 4803] and [4885 4834] on the southern flank of Lodge Hill. However, the stratigraphical level of the evaporite is uncertain as Tea Green Marl is absent on Lodge Hill.

On Windmill Hill [497 482] Tea Green Marl caps Keuper Marl within which at about the level of the 30 m contour, that is, some 10 to 12 m below the base of the Tea Green Marl, there is a greenish grey mudstone containing traces of celestite with some calcite: small nodules of celestite occur in an old hedge line [4937 4840].

No trace of celestite was found at Chalcroft Hill [494 475].

WESTBURY SUB MENDIP: It is understood that celestite was worked in the Westbury [502 487] area before 1914 but no records of the extent of worked ground are known. Green and Welch (1965, p. 167) noted that 'celestite was dug from a small field [5082 4824]... at the base of the Dolomitic Conglomerate (Westclose Hill Conglomerate)'.

Nodular, coarsely crystalline celestite with minor amounts of calcite and quartz is generally found within a broad belt between 24 and 34 m above OD. Near Furlong Farm the thin Keuper Marl cover on Westclose Hill Conglomerate contains nodules of celestite [5029 4859]. Between [5063 4839] and [5083 4820] the Conglomerate itself contains celestite. Scattered nodules of celestite occur on the soil of fields [5080 4820] and [5083 4810] reputedly worked for mineral.

To the south, nodules of celestite in Keuper Marl were found at [5069 4801, 5079 4798, 5075 4759 and 5099 4775].

There is no evidence of celestite between Easton [512 478] and Shortwood Farm [5180 4674].

WATTLES HILL: Nodules of celestite with quartz and calcite occur on the southern slopes of Wattles Hill [525 476]. A stream section [5250 4722] shows vuggy nodules of quartz and calcite at a level about 15 m below the base of the Tea Green Marl. Soil traversing [5258 4711] found a trace of strontium. Nodules of celestite occur at [5192 4738] and [5260 4690] in wash on the lower slopes of the hill.

WELLS: Between [5376 4689] and [5397 4664] the Keuper Marl contains nodules of vuggy quartz and calcite which crop out at about 91 m above OD, that is, about 15 m below the base of the Tea Green Marl. Green and Welch (1965) report impure celestite in Dolomitic Conglomerate below Underwood Quarry at [539 467]. Eastwards scattered quartz and calcite concretions occur around the hillside to [5430 4661]. Coarsely crystalline, sugary celestite with little or no quartz or calcite crops out as a nodular bed, about 15 m below the base of the Tea Green Marl, in a brook section [5435 4729] near Milton Farm, and was traced laterally by augering along the foot of Cold Nose Plantation to a road section [5440 4684] where nodules of vuggy quartz and calcite are exposed. Eastwards scattered quartz and calcite nodules overlying sandstone occur in the fields below Milton Lodge [5460 4702]. No evidence of these minerals was found east of the nearby road section [5491 4715].

DULCOTE: A section [5669 4420] in Dulcote Quarry shows gently dipping Keuper mudstones with thin interbedded sandstones resting on massively bedded sandstones with angular limestone debris, which infill a Triassic valley 10 m wide and 5 m deep cut into Carboniferous Limestone. Ovate nodules, up to 200 mm across, of quartz and calcite are scattered through the Keuper. Jobbins (in Green and Welch, 1965, p. 168) has described similar quartz-calcite nodules from the quarry as pseudomorphs after baryte or celestite.

DINDER: Green and Welch (1965, p. 168) record a report that bedded 'strontia' (celestite) 1.2 m thick was worked from two fields 1100 m south-south-east of Dinder Church [5751 4460] approximately 15 to 20 m below the base of the Tea Green Marl, that is, at a level intermediate between the upper celestite horizon in the Keuper Marl and the Westclose Hill Conglomerate. The workings have been filled in but nodules of gypsum with traces of celestite may be found in fragments of well indurated green sandy mudstone which litter the fields. Soil traversing at The Roundabout [5845 4353] and at Knowle Hill [5910 4280] failed to detect any lateral extension of the evaporite.

WORMINSTER: During the primary six-inch geological survey in 1955 Green noted that on Worminster Down the Tea Green Marl has a surface brash which includes celestite-calcite masses and hard whitish marl with rare speckles of galena and cavities probably after halite (Green and Welch, 1965, p. 81). Celestite was found by

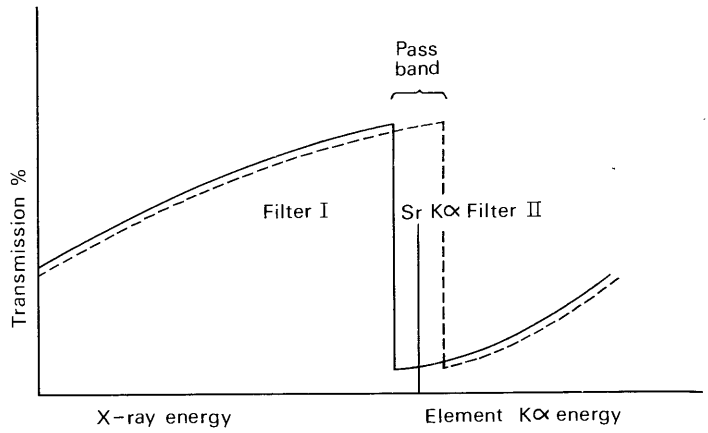
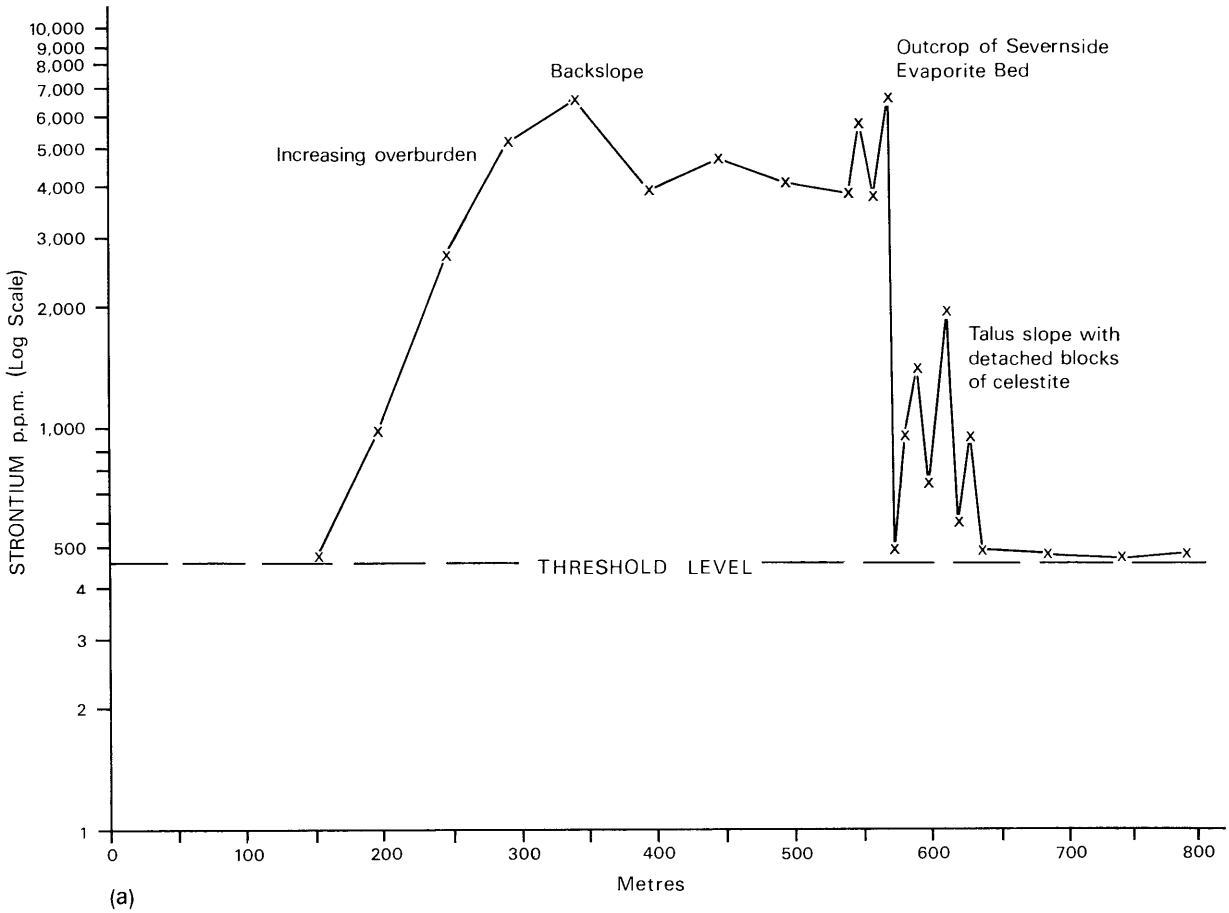


Fig. 24. X-ray transmission through balanced filters of rubidium and bromine



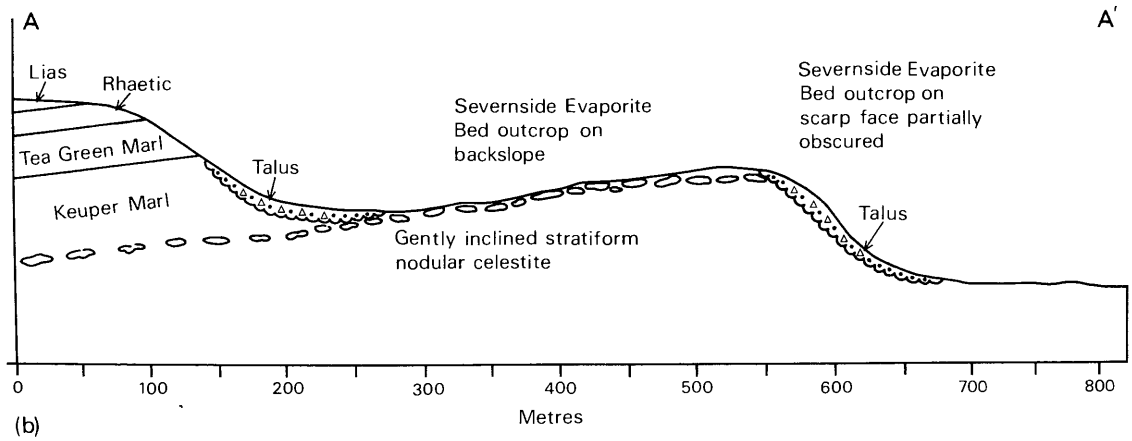


Fig. 25a Generalised plot of a traverse across the Severnside Evaporite Bed with geological interpretation

Fig. 25b Generalised geological cross-section showing the relationship of the Severnside Evaporite Bed to topography

P. N. Mosley on the north side of Worminster Sleight, at about 12 m below the base of the Tea Green Marl, near a degraded pit [5810 4348], and at [5763 4355] where thin sandy Keuper Marl with pink white coarsely crystalline celestite rests on Dolomitic Conglomerate. Investigations show a gently eastwardly dipping greenish grey mudstone containing nodules of celestite (with only trace amounts of calcite) up to 0.5 m diameter, and with a macrocellular habit. A bed of nodular celestite occurring at about the middle of the Tea Green Marl and traceable for 200 m along the strike, crops out [5620 4256] on the south facing scarp slope of Launcherly Hill.

NORTH WOOTTON TO PILTON: Between North Wootton [5638 4180] and Pilton [5885 4083] bedded celestite with gypsum and calcite occurs at the top of the Keuper Marl and within the Tea Green Marl which north-east of North Wootton is estimated to reach 30 m in thickness (Fig. 22). Nodules, up to 0.5 m diameter, of coarsely crystalline vuggy celestite occur [5812 4213] about 2 m below the base of the Tea Green Marl and [5804 4203] at about the middle of the Tea Green Marl.

WEDMORE-PANBOROUGH: Keuper and Tea Green Marls crop out, but traversing and a rapid geological and geochemical reconnaissance failed to detect any celestite.

BLEADNEY-COXLEY WICK: Exposures [4845 4527] and [4878 4515] show celestite and gypsum at a level approximately 5 m above the base of the Tea Green Marl. To the east in exposures [4934 4515] and [4961 4514] the minerals occur some 15 m above the same datum (P. N. Mosley). These exposures are at the same stratigraphic level as the occurrences listed by Green (1965) at Callow Hill, Ben Knowle Hill and Hay Hill. Celestite with gypsum and calcite can be traced as a more or less continuous bed within the Keuper Marl from [5280 4438] to [5247 4441] approximately 15 m below the base of the Tea Green Marl on the southern slopes of Hay Hill (S. J. Booth).

5.7.4 *South Wales*

Welch and Trotter (1961), Thomas (1968) and Thomas (1973) report isolated occurrences of celestite in the Vale of Glamorgan. A brief reconnaissance revealed the following additional information.

PENARTH TO BARRY: Along the coastal section from [132 670] to [189 714] gypsum beds crop out within both the Keuper Marl and the Tea Green Marl. No celestite was observed but traces of strontium were detected in a vuggy bed just below the Tea Green Marl-Keuper Marl junction near Lavernock Point and on the wavecut platform at [188 683].

LLANTRISANT-LLANHARAN: Fieldwork and geochemical sampling of the vug mineral previously identified as celestite in the Dolomitic Conglomerate exposed in a road cutting [052 520] near Llantrisant suggests that the mineral occurrence is not as extensive as thought by Thomas (1968) and that much of it is barite ($BaSO_4$).

6. Geochemistry

6.1 *SAMPLING PROCEDURE*

Soil sampling procedures were tested in the Wapley Common-Sargeant's Farm area, Yate, where geological mapping and trenching show that a bed of celestite underlies a small plateau. Two traverses were made, a half-inch diameter soil auger being used to collect samples. Sampling intervals of 50 to 100 ft were arbitrarily selected for the first and second traverses respectively.

Analysis of the samples showed close agreement (to within ±10 per cent) between near surface (0.1 m depth) and subsurface (0.5 to 1.0 m depth) values which varied strongly along the lines of traverse. As pH measurements made at each sampling station show no great variation it is unlikely that pH values control the present-day distribution of celestite. Where the mineral crops out strontium values of 5000 to 10 000 ppm were recorded (Fig. 23). Downslope of the outcrop of the Severnside Evaporite Bed detached blocks of celestite gave rise to a multiple peak (Fig. 23). At the back of the plateau where celestite occurs 5 to 8 m below the surface, the amount of strontium in the soil is low, usually about 500 ppm (not shown on Fig. 23).

The systematic survey of potential celestite-bearing areas was based on the results of these initial studies. To minimise possible effects due to application of fertilisers and to discount possible contamination attributable to hillwash, soil samples were taken from a depth of 0.5 to 1.0 m from the surface at spacings of 10, 20 or 50 m, dependent on the slope of the ground, along traverse lines 200 to 400 m apart and 10 m from any hedge-line.

6.2 *ANALYTICAL PROCEDURE*

6.2.1 *Introduction*

Although X-ray fluorescence (XRF) offers a quick and reliable method of elemental analysis, the equipment is extremely heavy, expensive, delicate and mechanically complicated and, as it normally requires a source of mains electricity and a supply of cooling water, is not suitable for field use. In contrast, the Portable Isotope Fluorescence Analyser (PIF) weighs approximately 8 kg, is relatively cheap, robust, battery powered and easy to operate.

The basic theory of the XRF and PIF methods of analysis is the same. Each element has a characteristic fluorescent X-ray spectrum which bears a simple relationship to its atomic number, namely $1/\lambda$ is proportional to Z^2 where λ is the wavelength and Z is the atomic number. Primary X-rays are projected onto the sample, resulting in excitation of particles and release of energy in the form of secondary X-rays (fluorescent X-rays). These rays, which are unique to each element, are dispersed by a crystal spectrometer. Only one wavelength is detected at each spectrometer setting and its intensity is measured using a scintillation counter. Thus the operator is able to identify elements and

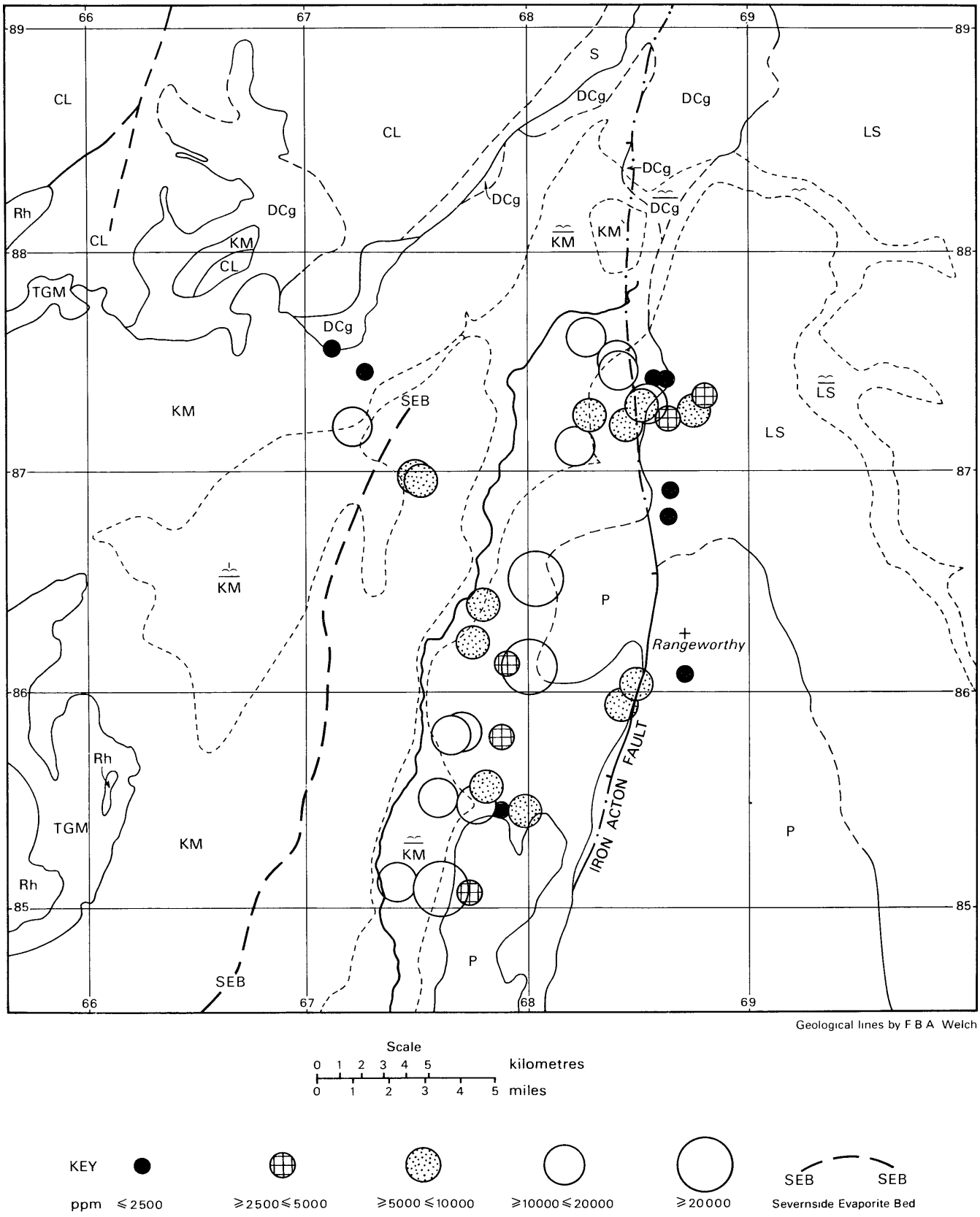


Fig. 26. Strontium (ppm) distribution based on analysis of oak leaves and twigs

to determine their relative quantities. The measurements only indicate the elemental response and chemical values must be determined by calculation.

The XRF uses electronically generated X-rays to excite secondary fluorescent radiation, characteristic of the element sought, which is selected and measured with a crystal spectrometer. In contrast, the PIF uses a radioisotope as an X-ray source and a pair of absorption filters substitute for the diffraction crystals. The use of filters to isolate the secondary radiation unique to strontium, is dependent upon the characteristic breaks (known as absorption edges) in the mass absorption coefficients of elements, a function of the X-ray energy.

By carefully selecting the materials used to make the filters, and their individual thicknesses, absorption can be achieved over a range of energies except for the region of the strontium pass band (Fig. 24).

6.2.2 *The Portable Isotope Fluorescence Analyser* (PIF)

The PIF consists of a hand-held probe which houses the source and energy selection filters, and a scintillation detector with photomultiplier tube.

The filters are mounted in a spring-loaded tray and their position alternated by a lever. The source is normally sealed at the sides and back with dense metal and the 'active' front is screened by a safety shutter which is maintained in the closed position when the instrument is not in use.

The analyser is provided with a bi-directional digital read-out which permits the difference reading to be displayed as a net count over preset intervals of 10 or 100 seconds. Power is supplied by rechargeable nickel-alkali batteries or by a mains transformer unit.

Although the instrument is designed for semi-quantitative assays on ores and rocks in situ, it may be used on powdered samples to give relatively precise quantitative results.

In order to achieve a degree of homogeneity the samples are dried and finely ground in a mortar and pestle. The 'prepared' sample is then placed in a plastic cup on the probe face. The plastic cup incorporates a mylar window which is renewed after each sample has been analysed. (Mylar is a transparent organic foil, about 2μm in thickness which allows the passage of both the primary and secondary X-rays with very little absorption).

With the safety shutter open the instrument will count the response through each filter and automatically compute and display the difference reading which is proportional to the abundance of the element. Ideally each filter should give the same reading when no strontium is present, but because of practical difficulties in 'balancing' filters accurately, there may be small discrepancies which must be taken into account in calibrating the machine. Calibration is effected by determining the difference readings of a series of chemically analysed standards similar in composition to the 'unknown' samples. All determinations are expressed as percentages of strontium.

6.2.3 *Sources of Error*

The main errors inherent in isotope analysis are due to variation in matrix composition and particle size. The latter can be minimised by fine grinding, but this may increase matrix absorption. Variations in matrix composition, especially with respect to elements such as iron, are not as easily overcome, but the effects may be reduced by calibrating the PIF using standard samples with a similar matrix composition to the samples to be analysed.

Bowie and others (1965) working in Cornwall found that the difference readings for a known amount of tin fall as the content of iron in the matrix rises. It is likely that the matrix iron content influences strontium analysis in a similar fashion, but as the PIF has been used to gain an indication rather than a precise measurement of strontium content, no attempt has been made to quantify this effect. However, the ferric oxide content of soil samples from north-east Bristol is similar to published analyses of Keuper Marl from other areas (Sherwood and Hollis, 1966).

Determinations made using the XRF and PIF have been plotted graphically and show good agreement above 0.5 per cent (5000 ppm) strontium. Below this value the plots are similar but the PIF determinations tend to be higher because of the inability of the instrument to filter out background and matrix effects, which at low concentrations 'swamp' the strontium response.

6.2.4 *Interpretation of Results*

The background value for strontium in the Keuper Marl of the area usually varies between 150 and 400 ppm but exceptionally values of 600 ppm have been recorded. For practical purposes a value of 470 ppm, which coincides with the limit of detectability of the PIF, has been used to define the regional threshold of strontium.

The distribution of strontium in the Latteridge-Tytherington [664 846 - 669 884] area has been plotted and the isochemical pattern agrees closely with field observations. The high values for the backslope area of the Marle Hills may be attributed to the scattered celestite nodules which are a feature of the area (Figs. 7 and 25).

Boreholes in the Pucklechurch area [669 765] show that the Severnside Evaporite Bed contains gypsum with only trace amounts of celestite and calcite. Geochemical traverses have demonstrated that there is nevertheless enough strontium present to determine the outcrop of the Bed.

The geochemical technique fails in areas of deeply weathered Coal Measures, for example, around Ashworthy Farm [687 885] where celestite may be observed in the river section near Summer Bridge [6870 8820]. Celestite occurs as randomly distributed veins in the Coal Measures and it is thought that the dispersion of strontium through the host rock is low.

6.3 *BIOGEOCHEMISTRY*

A biogeochemical study of the Rangeworthy-Cromhall area was undertaken in May 1971, with

a view to establishing the relationship between the strontium content of the flora and celestite distribution.

A rapid reconnaissance of the study area showed that although few species of tree were present, the sessile oak (Quercus petraea) grows in most hedgerows. Consequently, leaves and twigs were collected from forty oaks randomly distributed across the area and to assist interpretation of the results, trees situated on known celestite-bearing areas of the Keuper Marl and Lower Coal Measures shales were included. The sampling was undertaken on two consecutive days during a period of dry weather, and an attempt was made to collect specimens showing the same degree of leaf development.

6.3.1 *Analytical Method**

After drying, the samples were ashed in porcelain dishes at 500° C in an electric muffle furnace.

For the analysis a weight of 0.20 g was used and samples were attacked using a $HNO_3/HClO_4$ mixture. Solutions were made up to 20 ml and aliquots taken. To the final solution was added 0.25 per cent lanthanum to overcome interference by aluminium and phosphorous. Strontium was determined by atomic absorption spectrophotometry.

6.3.2 *Results*

The results are summarised in Table 9, and illustrated on Fig. 26.

The strontium content decreases eastwards reflecting the change of bedrock from Keuper Marl to Lower Coal Measures shales. The results range from 0.07 to 2.6 per cent strontium, with a mean value of 0.89 per cent. High strontium values were recorded in known celestite-bearing areas, for example 2.6 per cent strontium at Q20, but also at Q34 (2.08 per cent) where no celestite has been proved. Apart from the nature of the bedrock, the proximity of the sampling point to drainage systems may influence the strontium content of the leaves. Soil sampling has shown alluvium to be richer in strontium and consequently the results obtained from trees growing on alluvium have to be interpreted cautiously.

Although forty trees were sampled in a small area the results do not form a consistent and readily interpretable pattern. Greater sample density might overcome this problem but the analytical procedure is time-consuming and uses sophisticated laboratory-based equipment. It is thought that a biogeochemical study of the kind described may provide a useful indication of celestite distribution on a wider, regional scale but is not readily useful to delimit the extent of celestite deposits.

6.4 *ANALYSIS OF CELESTITE SAMPLES***

A tungsten carbide Tema vibratory disc mill was used to provide finely ground (100 to 300 g) samples of fifty representative celestite specimens, collected from exposures and trenches.

6.4.1 *Experimental*

After mixing with 20 per cent by weight of graphite and pressing the mixture into lead discs, samples and standards were analysed for strontium, calcium, silicon, aluminium, iron magnesium and sulphur by direct electron-excitation X-ray spectrometry using a Telsec B.200 Betaprobe instrument. Three samples of celestite, previously analysed by combined wet chemical and instrumental methods, ranging in composition from 53.9 to 55.6 per cent of SrO ($SrSO_4$ is 56.4 per cent SrO) were used to calibrate the instrument, and to extend the range of standard materials. $SrSO_4$ was prepared from Johnson Matthey High Purity (Grade 2) $SrCO_3$, then spiked with similarly pure materials to cover the range 0 to 10 per cent of CaO, SiO_2, Al_2O_3, Fe_2O_3 and MgO.

Further sub-samples were mixed with Dupont Elvacite, pressed into pellets and analysed for barium by conventional X-ray spectrometry using a Phillips 1220C instrument.

6.4.2 *Results*

Results of single determinations are given in Tables 3 to 8. For some samples with 50 per cent or more of SrO, duplicate, or in one case, triplicate, determinations were made on fresh sub-samples of the mixture with graphite. The ranges thus obtained are shown in Table 10.

*by Mrs L.M. Rundle. Geochemical Division Report 74, 1971. [Unpublished]

**Analysis by J.L. Roberts, A.E. Davies and T.K. Smith with a contribution by M. Davis. Geochemical Division Report 97, 1974. [Unpublished]

Table 9. Strontium content of oak leaves and twigs

Sample No.	Per cent strontium	Sample No.	Per cent strontium
Q 1	0.16	Q 21	1.41
2	0.16	22	0.83
3	0.62	23	0.59
4	0.85	24	0.28
5	1.49	25	2.09
6	1.66	26	1.85
7	0.96	27	1.65
8	1.43	28	1.34
9	0.17	29	1.65
10	0.16	30	0.64
11	1.04	31	0.23
12	0.54	32	0.72
13	0.40	33	0.38
14	0.94	34	2.08
15	0.24	35	1.09
16	0.21	36	0.07
17	0.65	37	0.15
18	0.86	38	1.56
19	0.29	39	0.77
20	2.60	40	0.89

Table 10. Range of results for celestite samples containing 50 per cent or more SrO

Constituent	Approximate level per cent	Range of results (per cent absolute)
SrO	50	± 1.2
BaO	1	± 0.1
CaO	1	± 0.1
MgO	0.05	± 0.02
Fe_2O_3	0.1	± 0.02
Al_2O_3	0.5	± 0.02
SO_3	40	± 0.7
SiO_2	1	± 0.03

Where samples contain less than 50 per cent of SrO the accuracy of the results is unknown. Such deviations from a celestite matrix affect the measured background and peak X-ray intensities.

Glossary

Anticline	An arch fold, the core of which contains the stratigraphically older rocks.
Arenaceous	Predominantly sandy.
Argillaceous	Predominantly clayey.
Armorican orogeny	A period of mountain building, mainly Permo-Carboniferous in age.
Bird's eye structure	A spot, bleb, tube or cavity resulting from localised disturbances such as algal or burrowing activity, escaping gas bubbles, shrinkage cracking, soft sediment slumping, reworking of sediments, or plant roots.
Chicken-wire structure	A term applied to the chicken-wire mesh mosaic of light and dark shades of colour observed in nodular evaporite accumulations.
Desert rose	A radially symmetric group of crystals with a resemblance to a rose, formed in sand, soft sandstone or clay. The crystals are usually of calcite, less commonly of barite, gypsum or celestite.
Diagenesis	Post-depositional physical and chemical changes of minerals and sediments.
Druse	A cavity in a rock lined with crystals of the same composition as the rock.
Euhedral	A term used to describe crystals which have well developed crystal boundaries or facies.
Facies	The sum of all the primary lithological and palaeontological characteristics exhibited by a sedimentary rock and from which its origin and environment of formation may be inferred.
Indurated	A term applied to a compact rock or soil hardened by the action of pressure, cementation and/or heat.
Inlier	An area or group of rocks surrounded by outcrops of rocks of younger age.
Listric surface	A curvilinear surface of fracture, usually concave upwards. They often form wedge-shaped masses appearing to be thrust against or along each other.
Lithostratigraphical unit	A practical unit of general geology, comprising a geographic name (derived from an appropriate feature of the type area) combined with a descriptive lithologic term (usually the dominant rock type).
Macrocell	Usually ovate globule of evaporite minerals, often packed together to give a nodular structure.
Overlap	The relationship among conformable strata such that each successively younger stratum extends beyond the boundaries of the stratum lying immediately beneath.
Overstep	A stratum resting unconformably on an inclined series of older rocks is said to "overstep" each of them in turn.
Pericline	An elongate dome structure.
Rudaceous	Containing pebbles and boulders.
Sabhka	Flat, low lying areas often encrusted with salt and mushy evaporite minerals, usually formed on desert coasts above the high water mark (supratidal) but sometimes found around temporary desert lakes.
Substrate	Rocks and soil material lying near but not exposed at the surface.

Supratidal	See Sabhka
Slickensides	Observed on joint and fault surfaces as the result of movement between the surfaces in close contact under pressure, the striations being parallel to the direction of movement
Syncline	A trough fold, the core of which contains the stratigraphically younger rocks.
Unconformity	A substantial break or gap in the geological record where a rock unit is overlain by another that is not next in stratigraphic succession.
Vug	A cavity lined with crystals differing in composition from the host rock.

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Assessment of British Sand and Gravel Resources

No. 1 The sand and gravel resources of the country south-east of Norwich, Norfolk: Description of 1 : 25 000 resource sheet TG 20. By E. F. P. Nickless. Price £1.15. Report No. 71/20

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GLOUCESTERSHIRE

THE CELESTITE RESOURCES OF THE AREA NORTH-EAST OF BRISTOL

25

ORDNANCE SURVEY PROVISIONAL EDITION

Scale 1:25 000 or about 2½ Inches to 1 Mile

SHEET ST 68 & PARTS OF ST 59,69,79,58,78,67,77

EXPLANATION OF SYMBOLS AND ABBREVIATIONS

DRIFT

- Alluvium
- 1st Terrace
- Estuarine Alluvium
- Head

(RECENT AND PLEISTOCENE)

SOLID

- J — Jurassic (undivided) (JURASSIC)
- Rh — Rhaetic
- TGM — Tea Green Marl
- KM — Keuper Marl including Sandstone - S(K) and Severnside Evaporite Bed - SEB
- DCg — Dolomitic Conglomerate

(TRIASSIC)

- US — Upper Coal Measures (undivided)
- P — Pennant Measures
- LS — Lower Coal Measures with Sandstone - S
- QSG — Quartzitic Sandstone Group
- CL — Carboniferous Limestone (undivided)

(CARBONIFEROUS)

- UORS — Tintern Sandstone Group / Quartz Conglomerate
- LORS — Thornbury Beds

(OLD RED SANDSTONE)

- LWG — Lower Ludlow and Wenlock Group
- Llb — Llandovery Group

(SILURIAN)

- TrS — Tremadoc Beds

(CAMBRIAN)

- Landslip
- Worked Ground WG-1
- Made Ground
- Exposure

BOUNDARY LINES

- Geological boundary, Drift
- Geological boundary, Solid
- Severnside Evaporite Bed, abbreviations indicate the dominant mineral. Sr = celestite, Ca = calcite
- Fault at surface, crossmark indicates downthrow side
- Fault on sub-Triassic surface (assumed position)
- Inferred boundary between Resource Categories

Broken lines denote uncertainty

* Where Resource Category has no boundary line use "celestite polygon closure"

BOREHOLE DATA

ST 67 NE 63 — Borehole Registration Number
240.6 75.4 — Surface Level in feet and metres above O.D. (Newlyn)
Borehole site
2.30 Clay wash
13.54 Severnside Evaporite Bed
Geological classification (KM) / (LS)
38.70 / 40.57 — Final depth
The depth and nature of the lithologies encountered in the borehole are shown. The length of the graphic log is proportional to the depth of the borehole in metres

TGM Mudstone · Mudstone · Conglomerate · Sandstone

Note: The figures *in italics* are conversions to metres of measurements recorded in feet

BOREHOLE REGISTRATION NUMBER

Each borehole is identified by a Registration Number, e.g. ST 67 NE 63. The initial letters and numbers refer to the O.S. 1:25 000 sheet, the succeeding letters to the quarter sheet, and the last numbers to the I.G.S. serial number for that quarter

RESOURCE CATEGORIES

(See section 3.2 of Report)

- CEL-1 — INDICATED
- CEL-2 — INFERRED
- CEL-3 — HYPOTHETICAL
- CEL-4 — CELESTITE EITHER PRESENT BENEATH MORE THAN 10 METRES OF OVERBURDEN OR GENERALLY ABSENT

This map should be read in conjunction with the accompanying Report which contains details of the assessment of resources

Original one-inch geological survey published on Old Series Sheets 19 and 35
Survey on the six-inch scale in 1938–1939 and 1943–1952 by F. B. A. Welch, G. A. Kellaway and R. W. Pocock. R. W. Pocock and H. G. Dines, District Geologists.
Minor amendments and outcrops of the Severnside Evaporite Bed by E. F. P. Nickless, S. J. Booth and P. N. Mosley in 1971–1974.
Celestite Survey by E. F. P. Nickless, S. J. Booth and P. N. Mosley in 1971–1974. R. G. Thurrell, Head, Mineral Assessment Unit
1:25 000 Celestite Resource sheet published 1976. Austin W. Woodland, CBE., *Director, Institute of Geological Sciences*
I3307b

Compiled from 6" sheets last fully revised 1903–57. Other partial systematic revision 1939–53 has been incorporated. Some tidal lines revised 1956. Major roads revised 1967–72. The Grid lines on this sheet are at 1 Kilometre interval. Heights are in feet above Mean Sea Level at Newlyn. 1 square inch on this map represents 99.638 acres on the ground. The representation on this map of a road, track, or footpath, is not evidence of the existence of a right of way. Contour Values are in feet.