WF/AG/73/315

Mr. Ostle.

INSTITUTE OF GEOLOGICAL SCIENCES
GEOCHEMICAL DIVISION

RADIOACTIVE & METALLIFEROUS MINERALS UNIT

REPORT No. 315

A RADIOMETRIC AND GEOCHEMICAL RECONNAISSANCE OF THE PERMIAN OUTCROP AND ADJACENT AREAS IN SOUTH-WEST ENGLAND

by

B C TANDY

Reference
01.42/8/2

THE INSTITUTE OF
GEOLOGICAL SCIENCES
[redacted]
154 CLERKENWELL ROAD
LONDON, EC1R/5DU
Phone No: 01-278 3281

INSTITUTE OF GEOLOGICAL SCIENCES

Geochemical Division

Radioactive and Metalliferous Minerals Unit

Report No 315

A RADIOMETRIC AND GEOCHEMICAL RECONNAISSANCE OF THE PERMIAN OUTCROP AND ADJACENT AREAS IN SOUTH-WEST ENGLAND

by

B C Tandy

Gray's Inn Road

November 1973

CONTENTS

ILLUSTRATIONS (at rear)

SUMMARY

A radiometric and geochemical survey was carried out across the Permian outcrop and adjacent areas in south-west England. It showed an absence of uranium mineralization of any significance except in areas to the north of Exmouth and near Okehampton.

In the Permian near Exmouth, well developed reduction features, with high radiometric values (up to 150 μR/h), are accompanied by high uranium values (up to 34 μg/1) in bicarbonate-rich waters which suggest that uraniferous nodular horizons may be found at points up to 16km north of the previously known occurrence at Littleham.

Localized anomalous radioactivity (up to 60 μR/h) occurs at a number of sites along the line of the Sticklepath-Lustleigh wrench fault zone between South Zeal and Inwardleigh, with up to 150 μR/h being recorded at one excavated site.

Water sampling for uranium in the bicarbonate-rich environment of the Permian is shown to be of great use. Background uranium and radiometric values are controlled by the provenance of the Permian sediments and generally increase in value towards the area nearest the granite source and where reduced bands are best developed.

INTRODUCTION

During the 1971 field season, an applied geochemical and radiometric investigation was carried out in parts of Devon and Somerset comprising the whole of the Permian outcrop together with adjacent areas of the Exe basin above Tiverton, the Tone basin above Wellington (Devonian and Culm) and the Sticklepath-Lustleigh fault zone from north of the Dartmoor granite to the northern end of the Petrockstow basin (traversing Culm, Permian and Tertiary formations). The total area covered was 1600 km^2 and involved seven months intermittent fieldwork by the writer, with periodical assistance from one Scientific Assistant and one Voluntary Worker.

PHYSICAL FEATURES

The area concerned has a vertical interval ranging from sea level to 1700' O.D. (Dunkery Beacon) and it is dominated by the River Exe, flowing from central Exmoor in the extreme north, to the English Channel. The Exe owes its great length to the isostatic uplift of north Devon and Somerset relative to south Devon in Quarternary times.

The east-west grain of Exmoor and the Brendon Hills reflects the strike of the Devonian rocks, with valleys in the softer shales and ridges on the harder grits. A similar, but more subdued pattern is seen on the Carboniferous rocks to the south of Exmoor, as far as the northern margin of the Dartmoor granite.

The Permian rocks occupy generally low-lying but gently rolling countryside between the Brendon, Quantock and Blackdown Hills in the north (Vale of Taunton Dene), down the Culm and Clyst valleys to Exeter, westwards along the partially downfaulted Crediton trough to the north of Dartmoor and around the Exe estuary to Torbay in the south. The coastal section provides high, steep cliffs with sheltered inlets, good beaches and popular holiday resorts, and inland the ground rises to the Eocene gravel and Greensand - capped Haldon Hills overlooking the Teign Valley and Dartmoor to the west. The Tertiary Bovey and Petrockstow Basins (clays, sands) form flat areas interspersed with ball clay workings.

Natural vegetation consists of poor grassland and heather on the ridges of Exmoor. Deciduous woodland occupies the valleys in the Devonian and over most of the Culm where the heavy clay soils support only pastoral agriculture or forestry. Deciduous woodland typifies the Permian areas but much has been cleared to turn the fertile 'Red Devon' soils in to rich pasture, arable and market gardening land. Coniferous and hardwood re-aforestation has been long established around Exeter in the Haldon Hills, the Teign and Taw valleys and in the upper reaches of the River Exe around Dulverton.

GEOLOGY

The age of the rocks in the reconnaissance area ranges from Lower Devonian to Tertiary. The Devonian rocks of north Devon and Somerset are continental, deltaic and marine in origin - sandstones, shales, conglomerates, calcareous beds, and turbidites derived from the newly emerged Old Red continent to the north. The Devonian of south Devon is entirely of marine origin, containing well developed limestones and sub-marine lava flows. Deposition of silts, muds and turbidites, continued into Carboniferous times, along with radiolarian cherts and limestones, and accompanied by outbursts of vulcanicity now represented by lavas, tuffs, ashes and agglomerates. Later, near shore conditions resulted in the deposition of sandstones, mudstones and carbonaceous deposits.

At the end of Carboniferous times, the Armorican orogeny resulted in the formation of a major synclinorium with E-W axes, along with overfolding, faulting, thrusting and slaty cleavages, followed by the intrusion of granites with their accompanying metamorphism.

The newly elevated continent underwent rapid flush and desert sub-aerial erosion during Permo-Triassic times, evolving temporally and laterally through all the stages to piedmont old age, with occasional marine incursions. This evolution is reflected in the nature of the 'red bed' sediments ranging from breccias and conglomerates in the Lower Permian to marls and sandstones (with pebble beds) in the Upper Permian and Triassic. There is also a general tendency for the beds to be finer grained in their lateral equivalents to the east (away from the source areas of Dartmoor and the uplifted Culm and Devonian in the west and north). The structural basins of today are the relicts of the cuvettes of New Red times - around the edges of Dartmoor and between Exmoor, the Brendons, the Quantocks and the former position of the sea to the south east. Phenoclast material suggests such provenances. Penecontemporaneous graben-style faulting developed and preserved the Crediton trough, and volcanic activity (of a potash-rich type) especially around Exeter, was extensive.

No deposits of the intervening period till Upper Greensand times are represented. The Upper Greensand sea transgressed westwards depositing the hard sandstone outliers responsible for the Haldon Hills (capped in turn by Eocene gravels). Oligocene and Pliocene deposits (clays, sands, gravels, lignites) are represented along the line of the Sticklepath-Lustleigh fault zone, around Bovey Tracey and Petrockstow, which controlled their deposition. This fault zone is one of a number of largely NW-SE dextral wrench faults of Alpine age affecting SW England[2], and has controlled some of the mineralization.

Mineralization in the Permian is sparse, except for the Littleham nodular horizon discussed below. Manganese wad was worked at the base of the Permian just north of Exeter. The iron lodes (sideritic) in the Devonian of Exmoor, and the Brendon Hills on the watershed forming the boundary of the area studied, are largely strike fault and strata-controlled in fissure veins and are associated with chalcopyrite, and, like the lead vein south of Newton St Cyres and copper-arsenic veins near Sticklepath (in Culm), were worked on a small scale until the First World War.

PREVIOUS WORK

Various authors[1,5,6], have described the Littleham nodular horizon occurring near Exmouth where uranium is associated in nodules with copper, nickel and vanadium in reduction zones of the Lower Marls.

An extensive aeroradiometric survey of SW England in 1958[3] revealed anomalies near Bampton (21.960220) in the Namurian black shales (Dowhills Beds) - 45 μR/h (due mainly to moderate primary concentrations of uranium); in various outcrops of the Exeter Volcanics (especially at Washfield - 21.935154 and Killerton 21.970003) - up to 45 μR/h) but mostly due to potash (K^{40}) and thorium; and in parts of the Permian breccias of the Crediton trough (up to 35 μR/h) where there is some effect due to potash.

The IGS survey of 1970 produced anomalous (> 4μg/1) uranium in stream waters near Paignton, Torquay, south of Exeter and east of Crediton. Analysis by IGS of grab sediment samples collected by Imperial College[4] showed up to 36 ppm from some sites near Crediton.

SELECTION OF AREA STUDIED

The following factors governed the boundaries of the area investigated:-

1. The Permian outcrop and its adjacent areas form a stratigraphically and areally compact unit for prospecting.

2. The possibility of potential uranium sources existing due to:-

a. the maximum crustal mobility was occurring at the time following the granite emplacement and penecontemporaneous with the deposition of the Permian;

b. the Permian has been subjected to a long subsequent history of tectonism and remobilization.

3. A number of potential uranium depositional environments exist in the Permian where precipitation may have taken place - at grain boundaries, along faults and litho-facies boundaries and at contrasting geochemical interfaces. The last of these is the most promising, especially in reduced zones (eg Littleham nodular horizon). Reducing conditions were best developed in the late Permian in SW England.

4. Parallels may be drawn with the uraniferous deposits of the Permian of France (near Nimes), the Madonela deposit in Niger, and the Colorado Plateau, although the reproduction of similar depositional conditions in Devon had to be confirmed by field investigation.

PROCEDURE

The methods adopted in the 1971 fieldwork were as follows:-

1. An orientation survey was carried out in areas of known anomalies, derived from the uranium in water survey carried out by IGS in 1970 and the analyses of selected samples of 'grab' sediments from the Imperial College survey[4] for uranium. Samples were collected in late February 1971 from near Paignton, Torquay, Exeter, and Crediton.

2. Stream water sampling for uranium, copper, zinc and conductivity, was carried out in streams draining the whole of the Permian as well as the Exe basin above Tiverton (21.960130) and the Tone basin above Wellington (31.140210). This work covered 363 sample sites in 1400 km^2 - at a density of approximately 1 site/4 km^2 (April-August 1971).

3. 'Grab' sediment sampling for uranium and multi-element analysis, in streams draining Permian areas only, involved 200 sample sites in 800 km^2 ($\approx$ 1 site/4 km^2), (April-August 1971).

4. Radiometric reconnaissance by hand-held ratemeter in all areas was supplemented by carborne survey in the area south of Tiverton. Effort was concentrated on the target environments mentioned above. This was carried out April-November 1971 but was curtailed owing to lack of time.

All samples underwent pre-analytical preparation at a field laboratory in the Exeter office of IGS. Uranium was analysed by the delayed neutron method (D.N.M.) in waters and sediments at AWRE Aldermaston. Cu and Zn in acidified waters, plus Pb, Ni in sediments were analysed by atomic absorption spectrophotometry (A.A.S.) and other selected elements in sediments were analysed by optical emission spectrometry (O.E.S.) at the Geochemical Division's Analytical and Ceramics Unit.

RESULTS

1. ORIENTATION SURVEY

The objects of this were:-

a. to investigate uranium anomalies from previous geochemical surveys, and to compare 'grab' and sieved sediment sampling at these and other sites;

b. to assess the influence of bicarbonate content of stream waters on uranium values;

c. to assess the relationship between bicarbonate and conductivity values in stream waters.

A total of 18 sites with anomalous and background uranium values from IGS 1970 water and Imperial College sediment surveys were chosen, and were resampled at either the same site and/or upstream according to practicability, resulting in 25 sampling sites. Each of these sites was sampled for uranium (D.N.M.), copper and zinc (A.A.S.), and conductivity in 30 ml water samples, and bicarbonate in 500 ml water samples. 'Grab' samples were taken at 22 sites and sieved sediments were taken at 4 sites. Collecting sieved samples at most sites proved impracticable as the high concentration of fine material in the Permian-derived sediments caused blockage and waterlogging of the sieves and great loss of fine suspended material from the pan. The amount of clay material in the pan also prevented any representative panned concentrates from being collected.

On resampling, the uranium in water results have not reproduced very well (Table 1). Almost all the anomalies have not repeated, with the obvious exceptions of AV 3012, 3013, which have increased tenfold. Bicarbonate values are generally high but do not appear to influence uranium values in water unduly (eg AV 3003 - limestone in catchment, AV 3007, AV3012, AV 3013, AW 3010, AW 2011) at these levels of analytical precision.

A tenuous relationship seems to exist between low uranium values in sediment and high bicarbonate values in the corresponding water (and sometimes high uranium in water) and vice versa. Uranium values in grab sediments are broadly comparable with those in the corresponding sieved sample and 'grab' samples may therefore be collected in place of sieved samples with some degree of confidence. Likewise, bicarbonate and conductivity values are comparable suggesting that the more easily analysed conductivity value will suffice for bicarbonate. The high uranium values (28, 36 p.p.m. —) obtained in grab sediments supplied by Imperial College), from sites AW 3004, 3005, were not reproduced in this sampling.

Table 1

Uranium		Water - U µg/litre)		Sediment - (U ppm)		Bicarb (gms	Conductivity
Site No	Grid Ref	Original	Follow-up	'Grab'	Sieved	$CaCO_3$/litre)	(µmhos)
AV3001	20.859603	4/6	1	3.2	-	0.0285	405
2	" 859604	-	1	3.2	-	0.0285	445
3	" 835650	3	1	2.5	2.2	0.0475	570
4	" 836650	3/2	1	2.5	-	0.0390	535
5	" 864762	2/4	1	2.8	3.0	0.0210	373
6	" 867749	-	1	-	-	0.0255	-
7	" 867748	1	1	-	-	0.0438	-
8	" 933850	2	1	6.4	5.4	0.0155	290
9	" 933851	2	1	4.6	-	0.0210	375
10	" 900867	5/4	2/1	6.3	-	0.0165	335
11	" 898905	3/1	1	3.3	-	0.0245	420
12	" 916887	-	8/5	4.3	-	0.0340	522
13	" 916886	3/1	26/34	3.4	-	0.0330	515
AW3001	20.818974	-	-	2.6	-	0.0115	245
2	" 835896	1	1	3.7	4.1	0.0115	265
3	" 825993	3	1	2.7	-	0.0260	480
4	" 813995	-	1	3.3	-	0.0150	315
5	" 814996	-	1	4.3	-	0.0165	315
6	" 883993	3	1	3.1	-	0.0175	370
7	" 891995	3	1	2.4	-	0.0238	508
8	" 898997	1	1	1.9	-	0.0188	370
9	21.911003	3	1	3.7	-	0.0170	360
10	" 911004	3	2/3	-	-	0.0175	335
11	" 920013	3	2	2.8	-	0.0200	255
12	" 920014	-	1	4.1	-	0.0313	495

The results from sample sites at which both 'grab' and sieved samples were collected are tabulated below:-

Other Metals

Site No	Zn in Water	Zn 'Grab'	Zn Sieved	Cu G	Cu S	Pb G	Pb S	Ni G	Ni S	As G	As S	ppm
AV 3003	0.00	80	70	15	10	40	30	20	20	15	15	
5	-	90	40	10	5	20	20	30	10	30	40	
8	0.00	30	20	5	5	20	30	10	0	20	20	
AW 3002	0.02	150	150	25	25	40	30	60	60	25	20	

Again there is little difference between results for 'grab' sediments and corresponding sieved samples. 'Grab' samples tend to have slightly enhanced values possibly because these metals are somewhat adsorbed on to clay particles which have a tendency to be washed out of the pan as a result of elutriation. Thus 'grab' sediments appear to offer greater sensitivity in detection of the metals tabulated above.

Conclusions

From the results of the orientation survey it was decided that:

a. Water sampling is the most sensitive method for geochemical prospecting for uranium in the Permian, owing to abundant bicarbonate ions from the rock matrix to be expected throughout the whole of the outcrop.

b. Bicarbonate (ie conductivity) values should be determined as a guide, although bicarbonate concentration generally should not give rise to high U values in the absence of soluble uranium.

c. 'Grab' sediment sampling (more practicable than sieving) provides additional information and involves little extra time in collection.

2. WATER SAMPLING

Uranium - The results of this survey are shown in Figure 1. In the environment investigated, this appears to be the most sensitive geochemical medium for uranium detection showing a great range in values (from 1 to 36 µg/litre U). The mean value lies below the limit of detection and the population falls into four different classes:

Eighty-four per cent of the values are < 2 µg/litre and approximately 23% are 2 and 3 µg/litre. These occur in areas underlain by Devonian and Carboniferous rocks, and Permian rocks with Devonian and Carboniferous provenances. The Carboniferous and Devonian areas have low conductivity values (as a result of low bicarbonate concentrations) in water (50-250 µ mhos) which may explain the low values of uranium in water. However the conductivity values in the Permian north and south west of Cullompton (31.020070) are quite high, which, coupled with the low tenor of uranium, indicates a general lack of available uranium in these areas. Likewise, low uranium in streams draining the Teign valley and the Tertiary deposits around Newton Abbot, with moderate to high conductivity values, suggests an absence of available uranium to be taken up by the high bicarbonate streams.

Exceptions in these areas include sites AW 3235 (31.096223) - 4 μg/litre (617 μ mhos), and AW 3383 (21.907147 - 6 μg/litre (271 μ mhos).

All the remaining anomalous values (> 3 ug/litre) fall into two areas near Exeter (20.920920). An area to the north of Exmouth (30.010800) contains a number of extremely high values over a distance of about 15 km (Fig 2). Uranium is known in this area (Littleham nodular horizon) and the occurrence of reduction features in the rocks is common. Streams sampled run across the NW to NE strike of the beds and this suggests a strike or strike-fault-controlled uranium source between the sampling sites and the base of the Pebble Beds (forming a watershed). Sample sites in streams draining to the east of the watershed have little uranium in water. A small amount of follow-up sampling has confirmed some higher results, and radiometric readings are generally higher (up to 100μR/h) in this area. To the south of Exeter a number of high uranium values correspond with an area of high radiometric background (up to 25 μR/h). The rocks show some reduction features and have a generally granitic provenance.

The effect of conductivity values on uranium concentrations in water has been computed by a least squares best fit model and the anomalies still stand as the water contains more uranium than can be accounted for by conductivity (and hence bicarbonate) alone, hence suggesting anomalous sources of uranium in the drainage basins.

3. SEDIMENT SAMPLING

Uranium - Although found to be a less sensitive method than uranium in water, the 'grab' sediment sampling results reflect a broadly similar pattern of uranium distribution. Values (mean = 2.9 ppm) fall into four classes and tend to show a general increase towards the south where the provenance of the Permian rocks becomes more granitic.

A few anomalies stand out. Site AW 3214 (21.979216) has 6.3 ppm U where the stream drains an exposure of the radiometrically anomalous Dowhills Beds (Namurian black shales) reading 40 μR/h. Although the uranium in water value at this site is low (1 μg/litre), and the sediment uranium value high, the conductivity is also low (252 μ mhos), a reciprocal relationship that holds for most of the sites sampled. Site AW 3057 (21.593016 - 8.4 ppm U, 100 μ mhos and 1 μg/litre U in water, the highest sediment value recorded, is probably influenced by having granite in its catchment, although it does also drain a radiometrically anomalous area in the Carboniferous to the south (see below). Other anomalous sites are in the Permian and are associated with the areas of anomalous uranium in water:-

Site No	Grid ref	Sediment U ppm	Water U μg/l	Conductivity μ mhos
AW 3084	31.053041	5.1	2	652
AV 3008	20.934849	6.4	1	290
AV 3010	20.900866	6.3	2	335
AV 3067	20.896866	6.7	2	480
AV 3101	30.836045	5.5	1	193
AV 3103	20.987865	4.9	8	710
AV 3114	30.070896	5.3	1	180

Copper, Lead and Zinc - The values for these metals in sediments tend to be low and within narrow ranges. They bear little relation to the distribution of uranium in sediment and water, although a vague pattern of increase in values towards the south is seen. Highest values are tabulated below:-

Site No	Grid ref.	Cu	Pb	Zn	Comments
		ppm	ppm	ppm	
		10	15	60	= Mean values
AW 3001	20.820974	30	70*	180	Pb vein in area
3007	20.891996	5	80*	40	"
3051	20.864965	25	40	200*	Drains Pb vein
3052	20.876964	30	50	250*	Granite and mineralized
3057	21.593016	60*	100*	250*	catchment
3208	21.967148	15	80*	80*	
3221	31.094274	40	80*	140	
3225	31.089258	20	80*	130	
AV 3011	20.899907	40	110*	190*	Contamination possible
3056	20.881821	25	90*	180	
3058	20.866854	50*	60	130	
3059	20.858846	50*	50	140	
3062	20.883878	25	30	230*	
3068	20.896853	65*	60	210*	
3082	20.870905	30	50	220*	
3091	30.015811	20	80*	100	
3102	20.987864	10	70*	60	
3105	20.986897	50*	30	70	
3106	20.985893	10	70*	40	
3111	30.059887	20	40	280*	

* = anomalous values

Although agricultural and other contamination is possible in all cases, the anomalous values draw attention to the possibility of mineralization in the northern part of the Haldon Hills, to the south of Crediton, near Tiverton and near Wellington. Sites AV 3091 to 3111 may be related to the uranium anomalies in the area north of Exmouth, as the Littleham nodular horizon contains Cu, Ni and V mineralization.

4. RADIOMETRIC RECONNAISSANCE

The frequency distribution of a random sample (400) of radiometric readings, (ie those taken at geochemical sampling sites) has been computed and a selected distribution of all radiometric readings, in three classes, is shown on Fig 3, from which great variation in background values is seen:-

Radiometric Readings (in µR/h (2 π solid angle) Ratemeter 1413a, at hip height)

	On Exposure		On Superficial Cover		
	Range	App. Mean	Range	App. Mean	
Eocene	5-8	6.5	5-8	6.5	loosely consolidated sands, gravels and clays
Permian:-					
Devonian-derived	8-15	10	7-10	8	Area NW of Wellington
Culm-derived	7-16	8	5-12	6	Wellington-Tiverton-Cullompton
Granite-derived	10-30	14	6-18	10	S of Cullompton, highest where rocks reduced
Exeter Volcanics	20-45	30	15-30	22	Mostly K_2O and Th
Carboniferous (Culm)	15-20	16	9-14	12	
Devonian (Exmoor)	17-23	20	10-18	14	
Dartmoor Granite		30			

The mean radiometric readings of the Permian rocks vary according to the provenance and are related to the mean readings of source rocks by a ratio of about 1:2.

Anomalies in Permian rocks

a. Stogumber Station (31.114373) 15 µR/h ($1\frac{1}{2}$ x background) - in e^2 Lower Sandstones over 3 metre length.

b. Fitzhead (31.1140294) to 331.130293). 10 µR/h ($1\frac{1}{2}$ x background) - along line of fault covered by superficial material.

c. Holywell Lake (31.114206) 20 µR/h (2 x background) - in Triassic Upper Sandstones (just above contact with Permian Lower Marls), 3 metres thick by 2 metres long exposure of red friable sands with white reduced bands (giving highest readings).

d. White Ball (31.102194) 18 μR/h - 500 metres long roadside exposure same horizon as c., but no reduced bands.

e. Chevithorne (21.972150) and for 3 km to the east, 16 μR/h - a series of exposures along the roadside with small white reduction spots in the red sandstones, parallel to E-W strike of rock. Near unconformity.

f. Silverton (21.955024) 16 μR/h 4m x 10m exposure of red sandstones with tourmalinized quartz boulders.

g. Shobrooke (21.856010) to Raddon (21.905027) - 16-20 μR/h on sandstones with well developed reduction features.

h. Newton St. Cyres area (21.880980) - Max. 24 μR/h, coarse breccias containing K feldspar crystals (hence activity), but finer sandstones in places show reduction spots. Large number of anomalous exposures within 3 km radius.

i. Western Crediton Trough - a great number of sites with activity up to 30 μR/h on coarse red sandstones and breccias with frequent occurrences of green reduction spots, eg Stairhill Farm - 20.808993, 20.815994, North Tawton 21.664020, Exbourne 21. 604022, Neopardy 20.795990, Nichols Nymet Cross 21.700016, Slade 21.670020, Langmead 21.640020, Redpost Cross 21.630020 etc.

j. Peamore (20.020880) to Dawlish (20.960760) - an area of high formational background (> 18 μR/hr) elongated along the line of strike (see Fig 3). Generally fine red sandstones with reduction spots. Max 25 μR/h. Isolated anomalies of up to 20 μR/h occur at Holloway Barton (20.896853) and between Clapham (20.900870) and Dunchideok House (20.880878).

k. South of Newton Abbot - a few isolated anomalies of 20 μR/h occur at 20.835655 (faulted unconformity with Culm) 20.891648, 20893642 and 20.870622 in coarse red sandstones with some reduction spots.

l. Littleham area - in red e^3 Lower Marls along the cliff section west of Budleigh Salterton (30.060815) a number of grey-green reduced horizons (up to 10 cm thick) read between 25-60 μR/h, including nodular horizon at Littleham Cove (30.039803). Much of the nodular horizon is now obscured by landslip. Attempts to trace these active horizons inland resulted only in background readings being found except at Carter's Brickpit (30.022822) - 40 μR/h. A reading of 19 μR/h over superficial material was recorded over the extrapolated line of the nodular horizon in the field behind Littleham Church (30.030813). 24 μR/h was recorded at 30.0102865 during the course of follow-up of anomalous water samples (AV 3096) on fine red sandstones with reduction spots, 18 μR/h at 30.011851 and 16 μR/h at 30.010854 over superficial material are indicative of the moderately high activity encountered in this area. Such activity may suggest some extension of the uraniferous reduced zone to the north of Littleham and is related to the area of high uranium in water.

Sticklepath Fault Zone

The most extensive area of high activity, discovered during the carborne survey, occurs between South Zeal (20.6530 9320) and Hill Farm (20.5950 9840) (Fig 4.). Peaks were detected at 20. 6070 9640, 20.6130 9570, 20.6220 9580, and

20.6250 9550 and investigation in the immediate areas showed radiometric readings, mostly on embankments, of up to 30 μR/h (3 x background). These sites fall on a line running WNW, approximately corresponding with the fault direction for a distance of about $2\frac{1}{2}$ km. Examination of sites along the projection of this line revealed 60 μR/h in fault-shattered ochreous-stained black Culm shales (Crackington Formation) at South Zeal (206450 9400 and 20.6530 9360) and 18 μR/h in Meldon Cherts at 20.6530 9320. To the north west 20 μR/h is recorded in black Crackington shales at 20.6010 9760 and 16 μR/h over superficial material at 20.5960.9820. These indications extend the length of the anomalous area to 8 km and there may be a further continuation WNW to the small anomalies (14-20 μR/h) in the Culm near Inwardleigh (fig 4), although restricted investigations failed to reveal any trace of the anomalies over superficial cover in the fields between the anomalous sites. The anomalies seem to be best detected in the embankments of road cuttings. Excavation at one of these sites (at 20.6250 9550) exposed black Culm (Crackington) shales with ochreous staining, jasperization, yellow clay gouge and relict ?sulphide structures reading up to 150 μR/h. Another site (20.6130 9570) revealed black shales reading 60 μR/h. Only a limited amount of time could be spent on these sites and further detailed investigation is required.

CONCLUSIONS AND RECOMMENDATIONS

With the scattered minor exceptions mentioned in the text, evidence of uranium mineralization of potential economic significance in the Permian outcrop and adjacent areas of south-west England is lacking.

Only the uranium anomalies in water, with scattered radiometric anomalies, in the area north of Exmouth, and the radioactive anomalies along the Sticklepath-Lustleigh fault zone near Okehampton are promising indications.

The former is an area where reduction features in the Permian are developed to their maximum and uranium mineralization is known in the Littleham nodular horizon. This area is recommended for follow-up in the form of intensified water sampling and radiometric reconnaissance along the stream courses above the anomalous points. It seems that whilst the uranium anomalies in water may be due in part to effective leaching of the plentiful active reduced bands (up to 30 μR/h) by the bicarbonate rich water, there is evidence for the extension of the Littleham nodular horizon as far north as near Whimple (at 30.060 978) 16 km north of its previously recorded northernmost occurrence at Carter's Brick Pit. Active nodules and reduced bands (up to 100 μR/h) are plentiful and well scattered in the stream sections examined.

Likewise the area of radiometric anomalies near Okehampton seems favourable for uranium mineralization. The Alpine wrench fault (Sticklepath - Lustleigh Fault) is resolved as it passes through the rapidly alternating competent and incompetent layers of the Crackington Formation into a large number of minor shears, many of which show solution features where exposed. A possible uranium source in the granite is nearby, and copper and arsenic have been worked in the area. Further work has also been carried out in this area (March 1972) and a number of other small anomalies (up to 60 μR/h) have been revealed in fault clay gouges and black shales. However, these anomalies cannot be traced outside of the sunken road or railway cuttings in which they occur. Most of the road cuttings have been examined and probably only radon traverses will detect any extensions of activity beneath the thick soil cover outside of the cuttings.

Conclusions from the remainder of the survey suggest that background values of uranium and, to some extent, other metals, increase towards the southern part of the Permian outcrop - nearest the granite source and where reduced bands are best developed. Further work, for example gamma spectrometry in slightly active areas, would be of academic interest.

The value of water sampling for uranium in a hard water area has been vindicated, and, although bicarbonate values influence uranium values, plots of uranium against conductivity distinguish real and spurious anomalies. The value of 'grab' sediment sampling, especially for metals other than uranium, has also been shown. Although the copper, lead and zinc values in sediment are limited, the slightly anomalous values recorded near Wellington, Tiverton, Crediton, and the northern Haldon Hills and Exmouth are of interest.

REFERENCES

1. CARTER, G E L An Occurrence of Vanadiferous Nodules in the Permian Beds of South Devon. Mineralogical Mag. 22, 1931.

2. DEARMAN, W R Wrench-Faulting in Cornwall and South Devon. Proc. Geol. Ass. 74, pt 3 1963.

3. MILLER, J M Provisional Interpretation of Aeroradiometric Surveys in South-West England. Inst. Geol. Sci. G.B. Geochem. Div. R.M.M.U. Report 1971.

4. NICHOL, I et al Regional Geochemical Reconnaissance of Part of Devon and North Cornwall. Inst. Geol. Sci. G.B. Report No 71/2 1971.

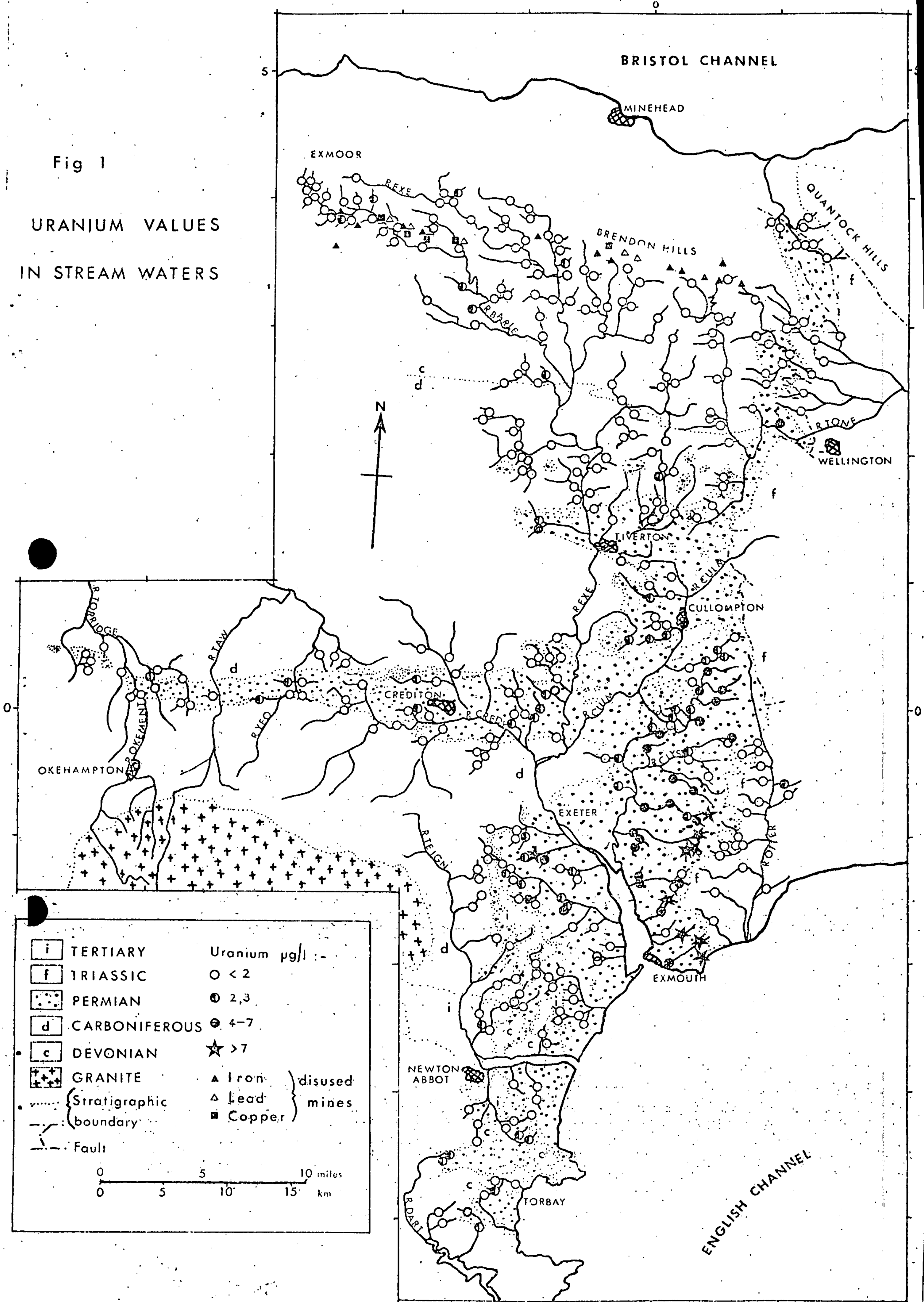
5. PERUTZ, M Radioactive Nodules from Devonshire, England. Miner. Petrogr. Mitt. 51 1940.

6. PONSFORD, D R A Radioactivity Studies of Some British Sedimentary Rocks. Bull. Geol. Surv. G.B. No.10 1955.

Fig 1

URANIUM VALUES

IN STREAM WATERS



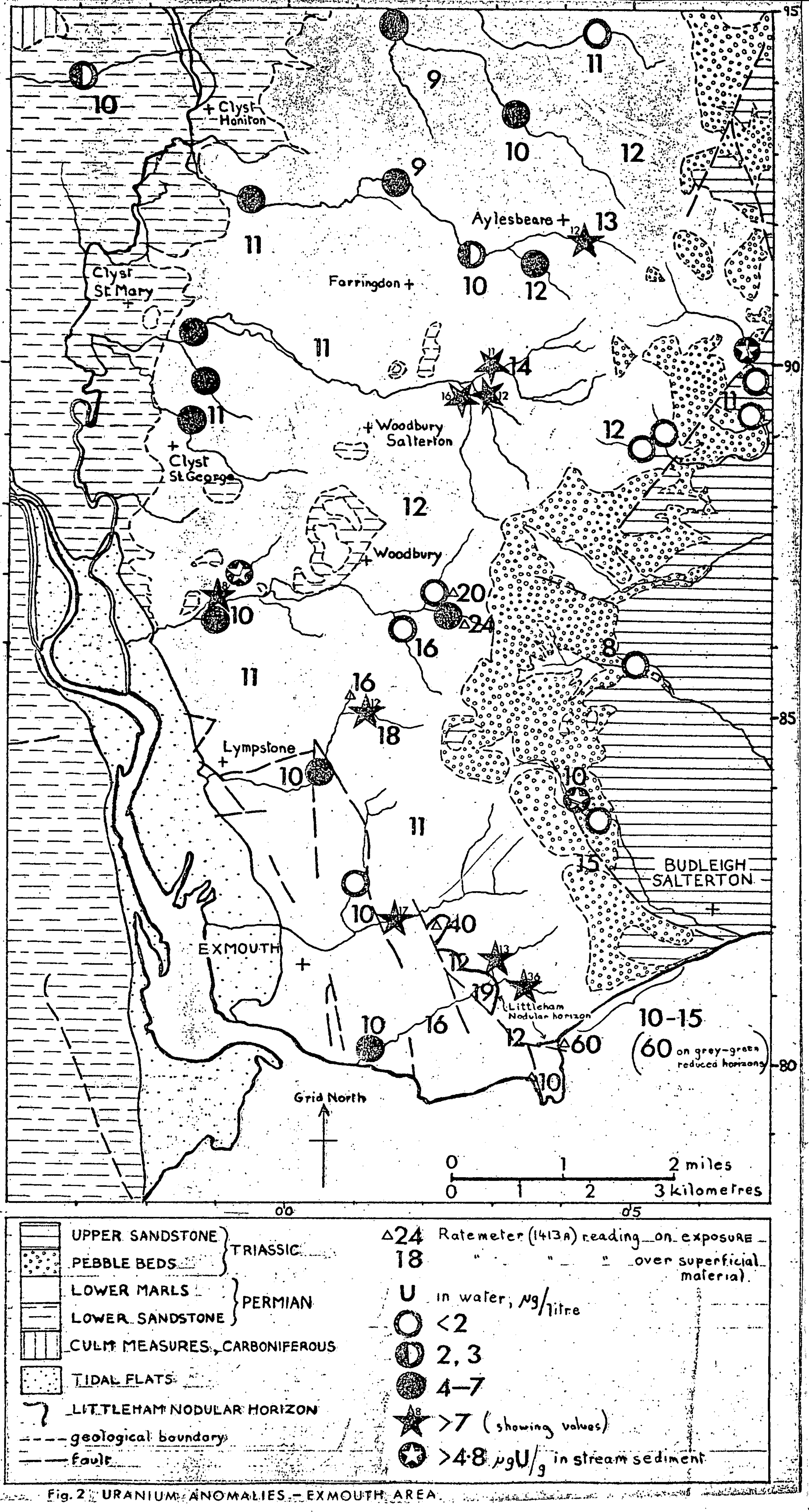
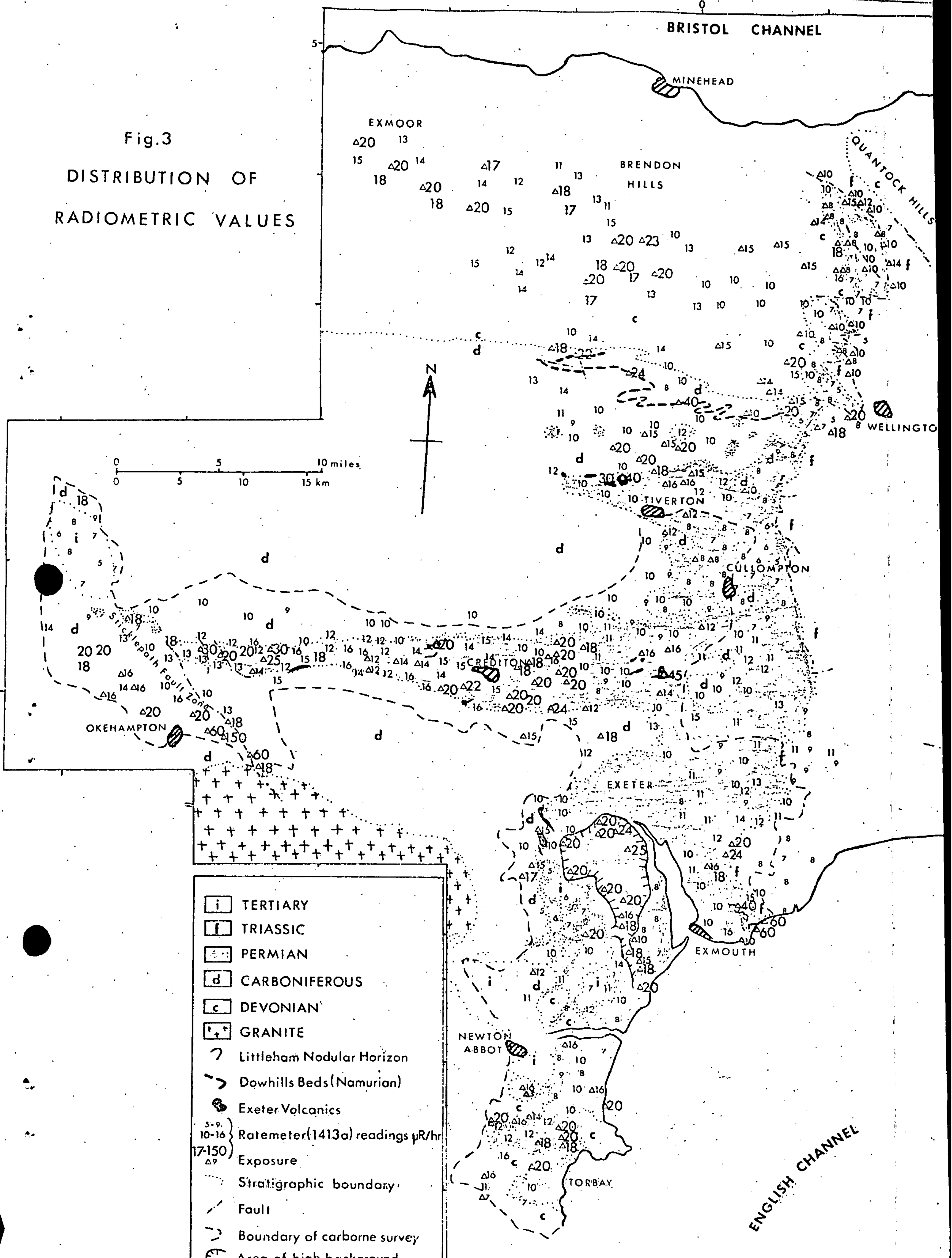


Fig. 2 URANIUM ANOMALIES – EXMOUTH AREA

Fig.3

DISTRIBUTION OF RADIOMETRIC VALUES



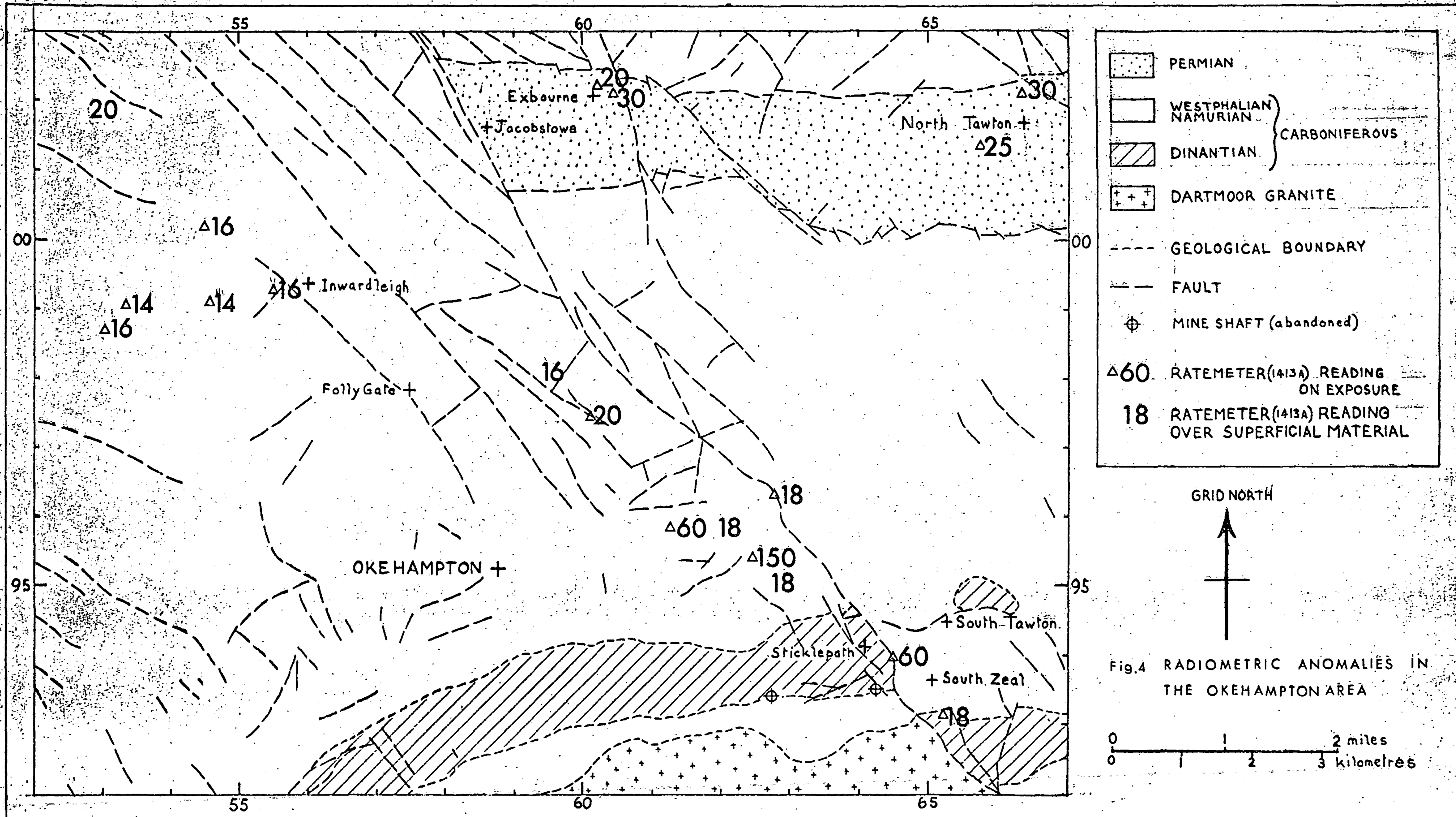


Fig.4 RADIOMETRIC ANOMALIES IN THE OKEHAMPTON AREA

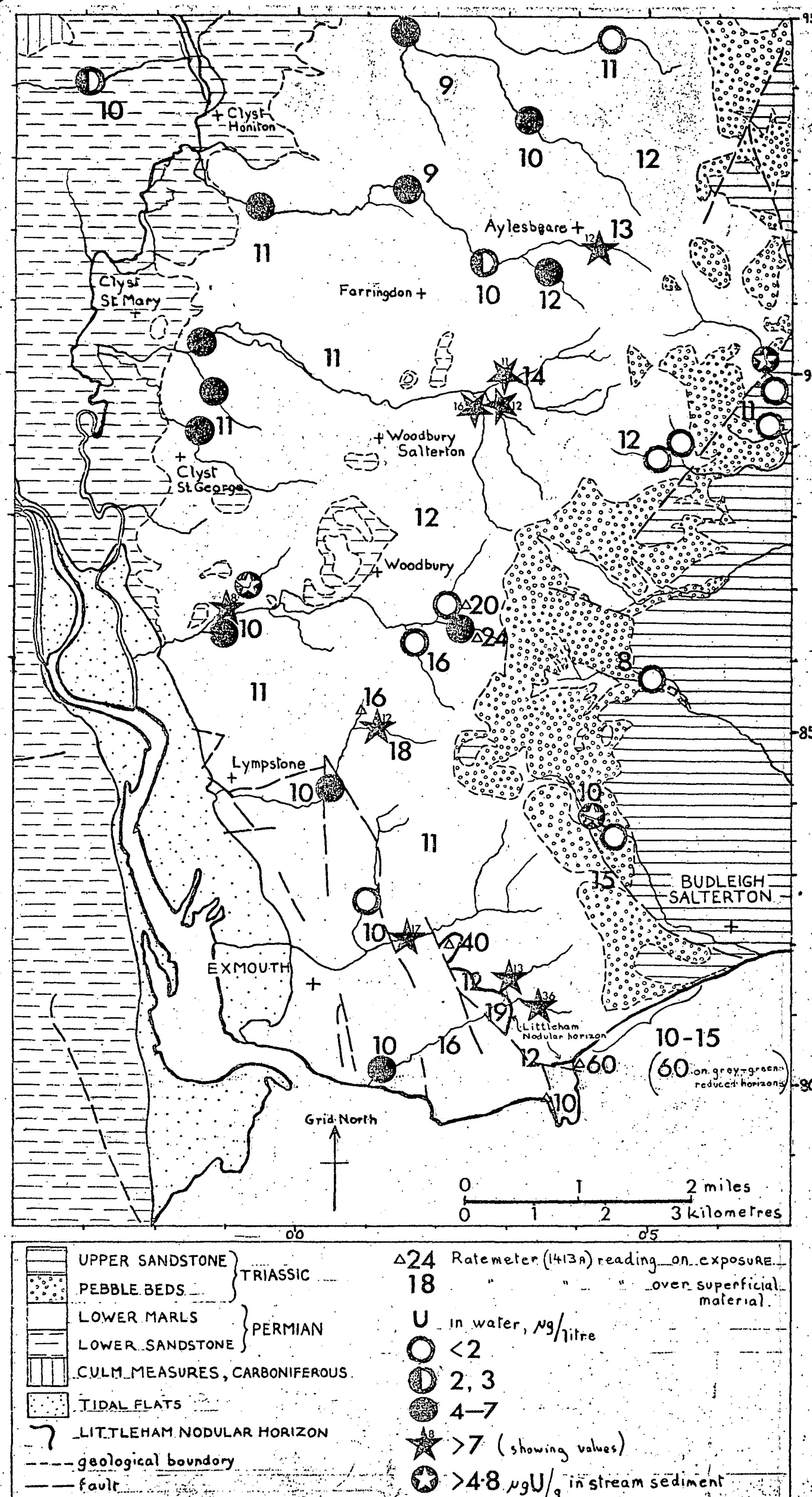


Fig.1 URANIUM ANOMALIES – EXMOUTH AREA

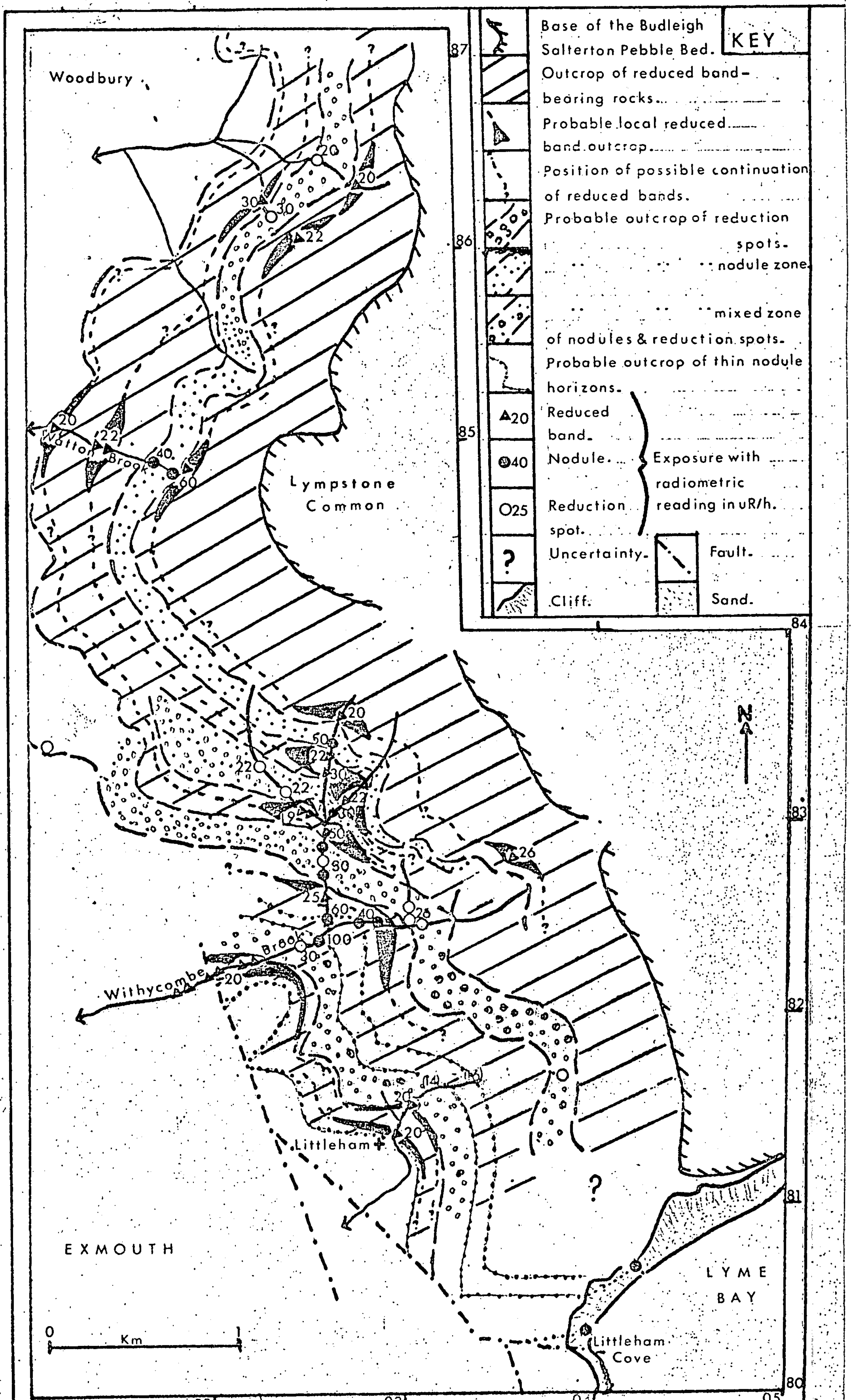


FIG 2 DISTRIBUTION OF REDUCTION FEATURES LITTLEHAM – WOODBURY

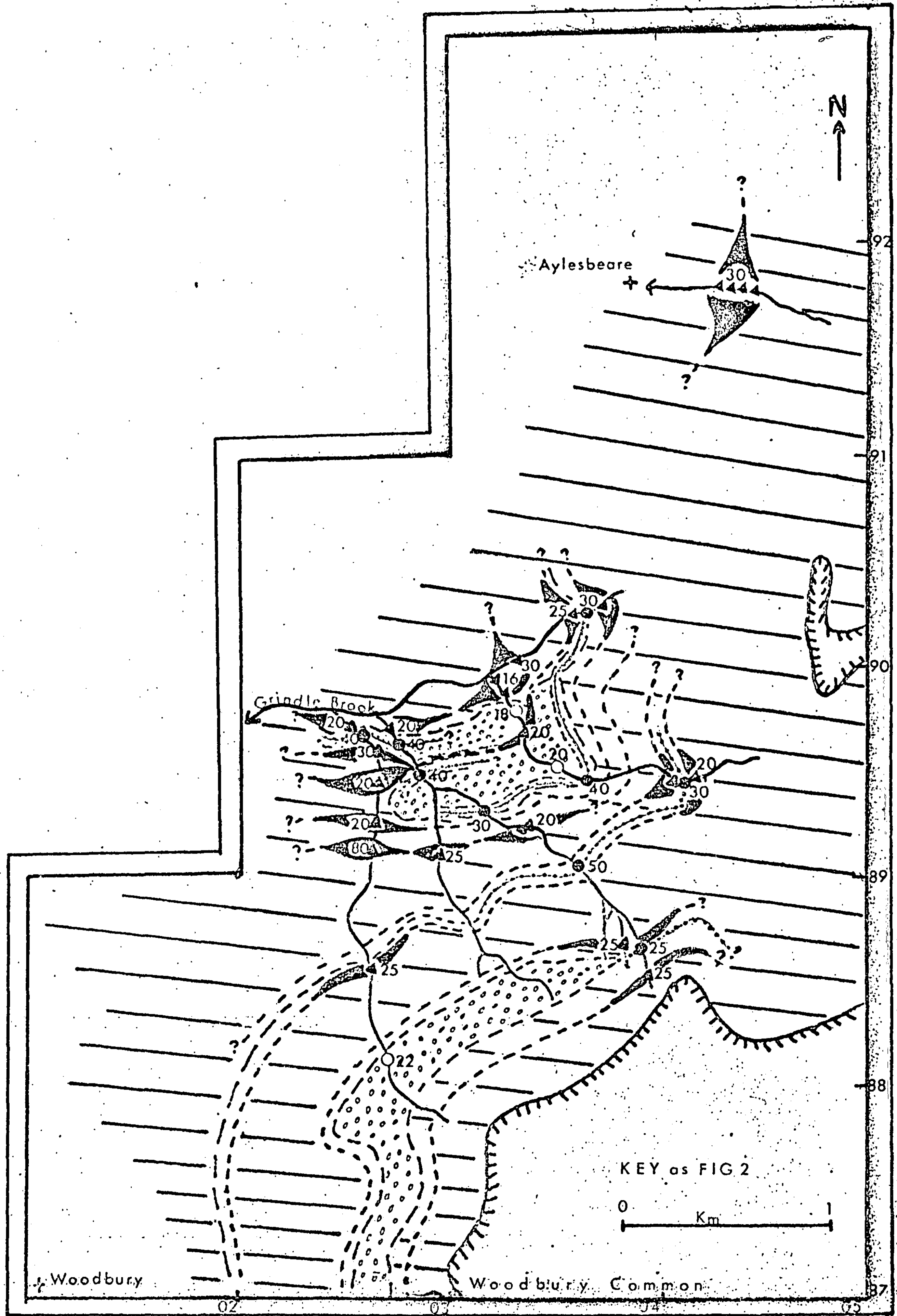


FIG 3 DISTRIBUTION OF REDUCTION FEATURES -
WOODBURY - AYLESBEARE

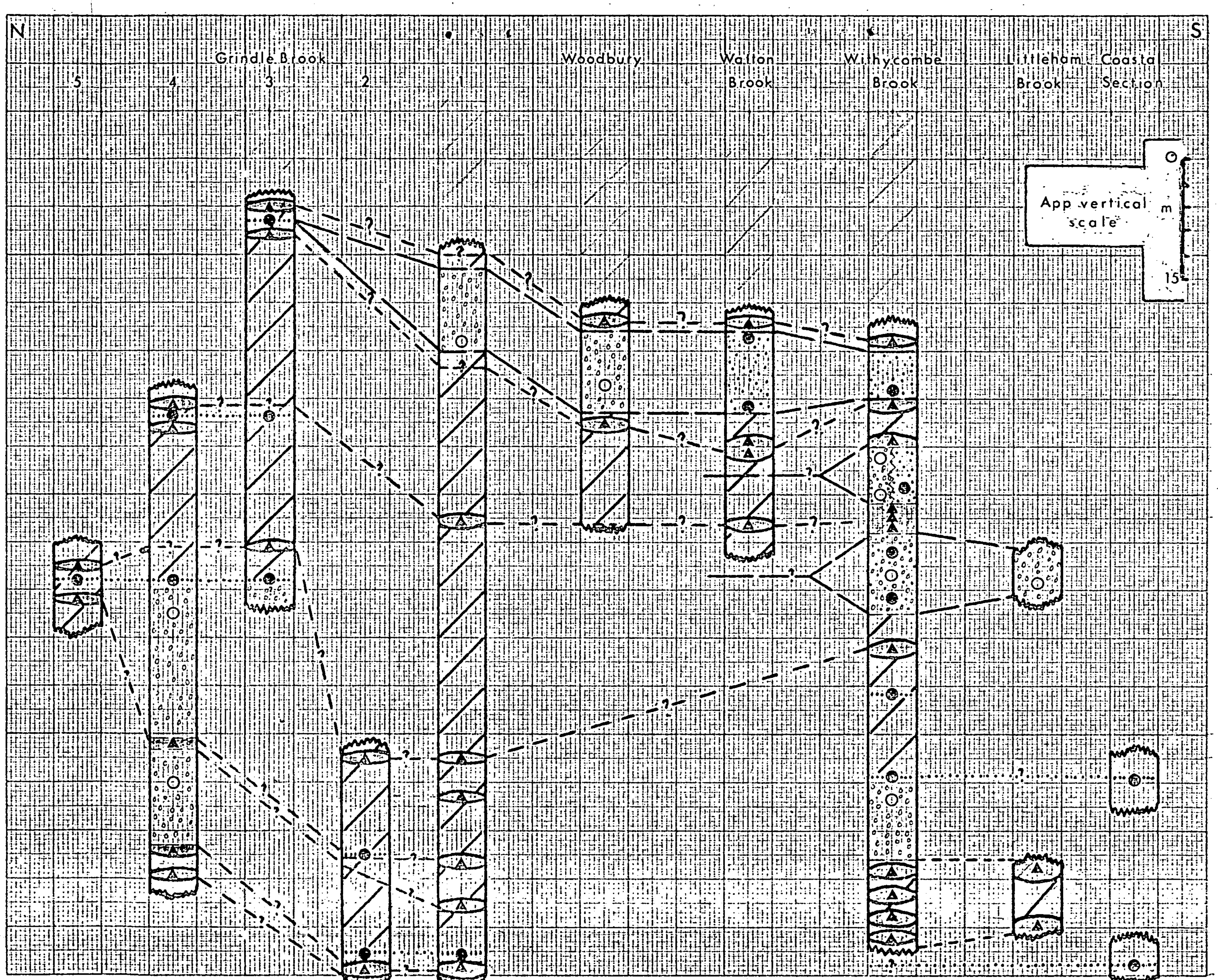


FIG 4 DIAGRAMATIC SECTIONS & CORRELATION KEY as Fig 2