

Four new uranium-lead ages from Cornwall

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Summary. Four new isotopic U/Pb ages from Cornwall are reported. The Pb^{206}/U^{238} and Pb^{207}/U^{235} ages for each specimen are concordant. The Pb^{206}/U^{238} ages are: South Terras mine 225 ± 5 million years (Myr.), Redruth Area 124 ± 4 Myr., Wheal Owles mine 58 ± 3 Myr., and South Terras Area 62 ± 3 Myr. Cell sizes, calculated from X-ray powder photographs, decrease with decreasing ages of the specimens, indicating a progressive increase in the oxidation states of the uranium present. It is concluded tentatively that at least two periods of mineralization affected south-west England at about 290 Myr. and 225 Myr., and that a final event occurred at about 60 Myr. Whether this final event involved the remobilization of older uranium with loss of lead, or the introduction of additional uranium, or a combination of both effects cannot be established from this evidence. No unique explanation has been made for the 124 Myr. age.

THIS study was undertaken as an investigation of the chronology of mineralization in south-west England. One other isotopic U-Th-Pb age determination for south-west England had been reported prior to this work, by Darnley *et al.* (1960) on a uraninite from Geevor. The concordant age obtained (290 Myr.) was a useful point in the geological time-scale; initially it was hoped that this study might provide similar results.

The original aims have not been achieved with regard to the time-scale. Ages younger than Hercynian have been obtained in this work and in later studies by Darnley *et al.*, 1965. These results have revealed a more complex pattern of mineralization in south-west England than was previously understood. The geological implications of these new ages are discussed in this paper and in the forthcoming paper by Darnley *et al.*, 1965.

Specimens

No. 1 (A and B), South Terras mine,² St. Stephen-in-Brannel, Cornwall; 1 mile south-west of St. Stephen; 1 in. geol. 347; 6 in. Cornwall

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² Collected and supplied by A. W. G. Kingsbury.

50 SW. Two similar samples were selected from the same hand specimen. The specimen was 5 cm across and consisted of massive, fresh uraniferous vein material with a small amount of surface staining, probably of erythrite. The specimen came from a north-south cross-course vein in the south shaft of South Terras mine, which flanks the south edge of the St. Austell granite. The country rock is Lower Devonian 'killas' and greenstone dykes. The uranium-bearing lode intersects an earlier east-west lode of magnetic iron ore and a tin lode coursing east of north (Dines, 1956).

No. 2, Redruth Area.¹ The specimen consisted of 1 to 2 cm pieces of massive, fresh, uraniferous vein material with a little chalcopyrite, chalybite, and quartz and traces of löllingite. The observed mineral assemblage is typical of the cross-course lodes in the Redruth area, which borders the north edge of the Carnmenellis granite. Whereas this evidence supports its general area, it is insufficient to localize it further.

No. 3, Wheal Owles,² St. Just, Cornwall; 1 in. geol. 351, 358; 6 in. Cornwall 67 SW. This specimen was collected loose from inside the adit of the cliff section of Wheal Owles mine in Wheal Edward Zawn, this section also being known as Wheal Edward Cliff Lode. The specimen consisted of a 10 cm piece of massive, fresh pitchblende, mainly clean but with a little surface alteration and some iron staining. Some finely disseminated specks of galena and chalcopyrite occur within the pitchblende. No secondary uranium minerals were recognized. The lode sampled runs north-west to south-east through the narrow coastal strip of highly metamorphosed killas and greenstone bordering the Land's End granite. The killas-granite contact is traversed by the lode almost at right angles. The uranium ores were separated from the lode walls by earthy limonite, and the presence of some of this on one side of the specimen suggests that it may have come from the edge of the lode (Dines, 1956).

No. 4, South Terras Area.¹ The locality and geological notes on this specimen are presumed to be the same as for No. 1. The bottle label read 'Pitchblende, Grampound Mine, South Terras', but this probably means that the specimen comes from South Terras mine, which lies in

¹ Supplied by F. W. Dunning from the Geological Survey and Museum collection. The localities of Nos. 2 and 4 are only known enough for general regional conclusions to be made from their ages. The word 'Area' has been added to the names of these specimens to emphasize that detailed local geological conclusions should be avoided, and should not be taken to indicate doubt about their general localities.

² Collected and supplied by A. W. G. Kingsbury.

the Grampound district. The specimen consisted of 1 to 2 cm pieces of massive uraniferous vein material with chalcopyrite, some quartz, and more surface alteration (unidentified) than is evident in No. 1.

Polished section studies

The pieces of the specimens used for making polished sections were selected similarly to those used for chemical and isotopic analysis. Autoradiographs of all specimens except Wheal Owles (No. 3) show considerable variation in α -track density, principally attributable to varying proportions of pitchblende and coffinite, which has a lower uranium content than pitchblende. A few point-centres of intense radioactivity are present in the South Terras mine (No. 1) and Redruth Area (No. 2) specimens. These point centres are due to minute concentrations of radium, and their presence reflects radiometric disequilibrium. However, they do not appear sufficiently numerous to suggest that disequilibrium is very marked.

Coffinite has been identified by X-ray powder photographs (taken by the Atomic Energy Division of the Geological Survey of Great Britain) in the South Terras mine (No. 1) and Redruth Area (No. 2) specimens. Visual inspection confirms its presence also in the South Terras Area (No. 4) and to a minor extent in the Wheal Owles (No. 3) material. Coffinite had previously been identified in the Geological Survey specimens from these localities. As usual, the coffinite tends to replace the smaller scattered pitchblende botryoids, forming a matrix enclosing both them and finely divided sulphides, etc. It also marginally or zonally replaces large areas of pitchblende. In some fragments, which can be seen in both the Redruth Area (No. 2) and South Terras Area (No. 4) specimens, pitchblende has been replaced completely, as shown by the relict pattern of inclusions, characteristic of the original pitchblende.

Hydrated uranyl minerals are present to a very minor extent in the South Terras mine (No. 1) and Redruth Area (No. 2) specimens. They are not obviously associated with microfractures, and they seem to form vugh fillings. They may or may not be of supergene origin. No other signs of weathering are apparent. All sulphides appear to be quite fresh.

Galena is most prominent in the Wheal Owles (No. 3) specimen, to a lesser extent in the South Terras mine (No. 1) and Redruth Area (No. 2) specimens, and to a minor extent in the South Terras Area (No. 4) specimen. Some finely disseminated galena within pitchblende

can be found in all specimens, but it varies very much, as does the amount of galena outside the botryoids. The Redruth Area (No. 2) specimen contains löllingite.

Experimental methods

Sample preparation. Specimens were broken down to pieces about 1 to 5 mm in size. The cleanest and freshest pieces were selected under a binocular microscope, and ground to a fine powder. The samples were not concentrated further with respect to pitchblende.

Chemical analysis. The uranium in the pitchblendes was analysed by chromatographic separation on a cellulose column, followed by ignition and weighing as U_3O_8 (Smith, 1955). For lead, a dithizone separation was used with subsequent precipitation and weighing as $PbSO_4$. Thorium was detected only in No. 3, but was not quantitatively analysed. There was good agreement between the triplicate analyses made in all cases. The absolute errors associated with the chemical data have been liberally estimated as: uranium analyses $\pm 1\%$, lead analyses $\pm 2\%$. The error associated with the mean figure was increased whenever replicate analyses did not agree as closely as usual.

Lead isotope analysis. Dithizone-separated lead was precipitated as lead sulphide for mass analysis. Highly pure, lead-free reagents were used throughout to avoid isotopic contamination. The mass spectrometer used was a Metropolitan-Vickers Type MS5 instrument with 12 in. radius, 90° analyser tube, using volatilization of solid lead sulphide from a heated tungsten triple filament as ion source. The lead sulphide was applied to the two outer filaments and the centre filament was heated electrically.

Each analysis consisted of 20–30 double scans across the lead mass spectrum in the order of mass numbers 208, 207, 206, 204; 204, 206, 207, 208. The techniques used were tested for reproducibility and for possible isotopic contamination by analysing Nos. 1A and 1B six times each on different dates and using separately prepared lead sulphide samples. All the results obtained agreed very closely for each specimen, and accordingly Nos. 2, 3, and 4 were analysed only once each. Regular checks of the absolute accuracy of the mass spectrometry were made by analysing inter-laboratory lead reference samples; these results will be reported in another paper.

X-ray analysis. All specimens were analysed by standard powder pattern measurements in duplicate. One measurement was also made

of the uraninite from Geevor, Cornwall, kindly supplied by A. G. Darnley, which was the subject of a previous age study (Darnley *et al.*, 1960).

Calculations

Isotope data. Corrections were applied for mass discrimination in the mass spectrometer. The mean percentage abundance for each isotope was calculated from the data of all the scans of the analysis. The limits quoted for each mean are double-sided 95 % confidence limits (twice the standard error). The mean figures and errors for Nos. 1A and 1B were calculated by weighting each of the six determinations according to its own error.

Common lead correction. Moorbath's figures (1962) for the isotope composition of seven galenas from south-west England were used for the correction for the common lead content in the minerals studied; these isotope data were obtained using the same techniques and instrument as in this study. The mean isotope abundances for the region were calculated by weighting each figure according to its own error. The errors for all isotope abundances given in table I are double-sided 95 % confidence limits.

Moorbath's mean regional isotope abundances were used for the common lead corrections in Nos. 2, 3, and 4, and his isotope abundances for a galena from the same lode in South Terras mine as No. 1 were used for the common lead corrections in Nos. 1A and 1B.

The negligible thorium content in Nos. 1A, 1B, 2, and 4 allowed Pb^{208} isotope abundances to be used in the correction for common lead in these specimens. For No. 3 the correction was made using the less accurate Pb^{204} isotope figures, owing to the presence of some radiogenic Pb^{208} .

Calculation of ages and their errors. The method outlined by Stieff *et al.* (1959) was followed in the calculation of isotope ratios of radiogenic lead to uranium. The final errors in the ratios $\text{Pb}^{206}/\text{U}^{238}$, $\text{Pb}^{207}/\text{U}^{235}$, and $\text{Pb}^{207}/\text{Pb}^{206}$ (hereafter abbreviated to 206/238, 207/235, and 207/206 respectively) were calculated using standard statistical formulae for the combination of errors, and taking into account errors in the chemical analysis for uranium, the chemical analysis for lead, the isotope analysis for the lead from the uranium minerals, and the isotope analysis for the lead from the galenas. For the 206/238 ratios, the dominant experimental errors were those of the chemical analyses; for the 207/235 ratios, the mass spectrometric errors made a contribution of 50-70 %

TABLE I. Summaries of analytical data and U/Pb age calculations†

No. 1A. *South Terras mine*. U = 59.9 ± 0.6 %, Pb = 7.3 ± 0.15 %.

Isotope analysis:

Isotope	Sample Pb abundances	Common Pb abundances*	Normalizing to Pb ²⁰⁸ = 38.58	Radiogenic Pb
Pb ²⁰⁴	1.013 ± 0.002	1.375 ± 0.002	1.016	(-0.003)
Pb ²⁰⁶	43.36 ± 0.02	25.08 ± 0.02	18.54 ± 0.02	24.82 ± 0.03
Pb ²⁰⁷	17.04 ± 0.01	21.34 ± 0.01	15.77 ± 0.02	1.27 ± 0.02
Pb ²⁰⁸	38.58 ± 0.02	52.20 ± 0.02	38.58	

Proportion of radiogenic Pb in total Pb = 26.1 %

Isotope ratios	Resulting ages with absolute errors
Pb ²⁰⁶ /U ²³⁸ = 0.0351 ± 0.0008	224 ± 6 Myr.
Pb ²⁰⁷ /U ²³⁵ = 0.247 ± 0.007	227 ± 11
Pb ²⁰⁷ /Pb ²⁰⁶ = 0.0512 ± 0.0008	259 ± 100

No. 1B: *South Terras mine*. U = 59.7 ± 0.6 %, Pb = 7.5 ± 0.2 %.

Isotope analysis:

Isotope	Sample Pb abundances	Common Pb abundances*	Normalizing to Pb ²⁰⁸ = 38.82	Radiogenic Pb
Pb ²⁰⁴	1.016 ± 0.002	1.375 ± 0.002	1.023	(-0.007)
Pb ²⁰⁶	43.04 ± 0.02	25.08 ± 0.02	18.65 ± 0.02	24.39 ± 0.03
Pb ²⁰⁷	17.11 ± 0.01	21.34 ± 0.01	15.87 ± 0.02	1.24 ± 0.02
Pb ²⁰⁸	38.82 ± 0.02	52.20 ± 0.02	38.82	—

Proportion of radiogenic Pb in total Pb = 25.6 %

Isotope ratios	Resulting ages with absolute errors
Pb ²⁰⁶ /U ²³⁸ = 0.0355 ± 0.0010	227 ± 7 Myr.
Pb ²⁰⁷ /U ²³⁵ = 0.249 ± 0.008	229 ± 12
Pb ²⁰⁷ /Pb ²⁰⁶ = 0.0508 ± 0.0008	247 ± 100

No. 2: *Redruth Area*. U = 55.5 ± 0.6 %, Pb = 3.06 ± 0.06 %.

Isotope analysis:

Isotope	Sample Pb abundances	Common Pb abundances†	Normalizing to Pb ²⁰⁸ = 35.72	Radiogenic Pb
Pb ²⁰⁴	0.938 ± 0.004	1.375 ± 0.002	0.940	(-0.002)
Pb ²⁰⁶	47.23 ± 0.08	25.04 ± 0.02	17.12 ± 0.04	30.11 ± 0.10
Pb ²⁰⁷	16.11 ± 0.04	21.33 ± 0.01	14.58 ± 0.04	1.53 ± 0.06
Pb ²⁰⁸	35.72 ± 0.09	52.25 ± 0.02	35.72	—

Proportion of radiogenic Pb in total Pb = 31.6 %

Isotope ratios	Resulting ages with absolute errors
Pb ²⁰⁶ /U ²³⁸ = 0.0192 ± 0.0004	124 ± 4 Myr.
Pb ²⁰⁷ /U ²³⁵ = 0.135 ± 0.004	130 ± 7
Pb ²⁰⁷ /Pb ²⁰⁶ = 0.0508 ± 0.0020	241 ± 160

No. 3: *Wheat Owles*. U = 53.6 ± 0.8 %, Pb = 3.04 ± 0.06 %.

Isotope analysis:

Isotope	Sample Pb abundances	Common Pb abundances†	Normalizing to Pb ²⁰⁴ = 1.167	Radiogenic Pb
Pb ²⁰⁴	1.167 ± 0.007	1.375 ± 0.002	1.167	—
Pb ²⁰⁶	34.93 ± 0.11	25.04 ± 0.02	21.25 ± 0.13	13.68 ± 0.17
Pb ²⁰⁷	18.89 ± 0.03	21.33 ± 0.01	18.10 ± 0.11	0.79 ± 0.11
Pb ²⁰⁸	45.01 ± 0.09	52.25 ± 0.02	44.34	(0.67)

Proportion of radiogenic Pb in total Pb = 14.5 % (omitting Pb²⁰⁸ figure)

Isotope ratios	Resulting ages with absolute errors
Pb ²⁰⁶ /U ²³⁸ = 0.00898 ± 0.00025	58 ± 3 Myr.
Pb ²⁰⁷ /U ²³⁵ = 0.071 ± 0.010	71 ± 12
Pb ²⁰⁷ /Pb ²⁰⁶ = 0.058 ± 0.008	542 ± 410

No. 4: *South Terras Area*. U = 45.6 ± 0.9 %, Pb = 2.61 ± 0.08 %.

Isotope analysis:

Isotope	Sample Pb abundances	Common Pb abundances†	Normalizing to Pb ²⁰⁸ = 44.45	Radiogenic Pb
Pb ²⁰⁴	1.174 ± 0.006	1.375 ± 0.002	1.170	(0.004)
Pb ²⁰⁶	35.58 ± 0.06	25.04 ± 0.02	21.30 ± 0.04	14.28 ± 0.08
Pb ²⁰⁷	18.80 ± 0.05	21.33 ± 0.01	18.15 ± 0.03	0.65 ± 0.06
Pb ²⁰⁸	44.45 ± 0.06	52.25 ± 0.02	44.45	—

Proportion of radiogenic Pb in total Pb = 14.9 %

Isotope ratios	Resulting ages with absolute errors
Pb ²⁰⁶ /U ²³⁸ = 0.0095 ± 0.0003	62 ± 3 Myr.
Pb ²⁰⁷ /U ²³⁵ = 0.059 ± 0.006	59 ± 8
Pb ²⁰⁷ /Pb ²⁰⁶ = 0.0443	Negative

* Data of Moorbath (1962) for galena from South Terras with errors associated with mean regional abundances for 7 S.W. England galenas.

† Data of Moorbath for mean regional abundances for 7 S.W. England galenas.

‡ The constants used in the age calculations were (Stieff *et al.*, 1959):

$$U^{238}: T_{\frac{1}{2}} = (4.51 \pm 0.01) \times 10^9 \text{ yr. } \lambda_{238} = 1.53_{69} \times 10^{-10} \text{ yr.}^{-1}$$

$$U^{235}: T_{\frac{1}{2}} = (7.13 \pm 0.16) \times 10^8 \text{ yr. } \lambda_{235} = 9.72_{16} \times 10^{-10} \text{ yr.}^{-1}$$

$$U^{238}/U^{235} \text{ now: } k = 137.7 \pm 0.3_2$$

of the final error; and for the 207/206 ratios the errors were entirely due to the mass spectrometry.

The age corresponding to a given isotope ratio was read directly from the tables of Stieff *et al.* (1959). The experimental error in the age was determined by finding the ages corresponding to the upper and lower limits of the isotope ratio as defined by its error. The absolute error in the age was obtained by adding the experimental error to the 'calculation error' (due to errors in the constants used in computing the ages) given in the tables.

The experimental data and the results of the important stages in the age calculations are given in table I. The resulting ages are summarized, together with the cell sizes calculated from the X-ray measurements, in table II. The age results of Darnley *et al.* (1960) for the Geevor uraninite are reproduced with the present author's cell-size measurement for this specimen in table II.

TABLE II. Summary of U/Pb age results, cell-size measurements, and stratigraphical correlations

No.	Locality	Age in millions of years				Cell size*	Grouped 206/238 ages in Myr.	Stratigraphical correlation†
		206/238	207/235	207/206	208/232			
—	Geevor (Darnley <i>et al.</i> , 1960)	290 ± 7	291 ± 15	302 ± 85	308 ± 85	5.48 Å	290 ± 7	Permian-Carboniferous
{ 1A	South Terras	224 ± 6	227 ± 11	259 ± 100	—	5.44	225 ± 5	Triassic-Permian
{ 1B	South Terras	227 ± 7	229 ± 12	247 ± 100	—	5.44		
2	Redruth Area	124 ± 4	130 ± 7	241 ± 160	—	5.42	124 ± 4	Lower Cretaceous
3	Wheal Owles	58 ± 3	71 ± 12	542 ± 410	—	5.42	60 ± 4	Lower Tertiary
4	South Terras Area	62 ± 3	59 ± 8	Negative	—	5.41		

* All $\pm < 0.01 \text{ \AA}$.

† Time-scale of Kulp, 1961.

Discussion of results

In this low age range, and with the large common lead corrections required, the 207/206 ages are of no significance and should be disregarded. The 206/238 and 207/235 ages are concordant within the errors for every specimen; concordance is least close for No. 3. This indicates the unlikelihood of radon loss in the specimens. The 206/238 ages are taken as the most reliable results for further consideration, because they have smaller errors than the 207/235 ages.

The agreement between the ages for the South Terras specimens No. 1A and No. 1B is very good. These are essentially duplicate measurements on the same specimen, and so a mean 206/238 age of 225 ± 5 Myr. can be quoted with confidence for No. 1. Likewise the 206/238 ages for No. 3 and No. 4 agree closely, with a mean of 60 ± 4 Myr., and may be considered jointly. The 206/238 ages obtained so far for south-west England are summarized, together with their stratigraphical correlations in table II.

The major problem is the explanation of the significant differences between these 206/238 ages. Two explanations can be dismissed imme-

diately: The magnitude of the common lead corrections cannot explain the differences between the groups of calculated ages, since the effects of all the errors involved in these corrections have been taken into account. Secondly, the 206/238 ages are remarkably insensitive to possible variations in the isotope composition of lead used for the common lead corrections; common lead isotope figures vary only within narrow limits over the last 300 Myr.; furthermore, such variations are not probable because of the close agreement between the isotope compositions of the galenas used for the common lead corrections (Moorbath, 1962).

None of the four groups of 206/238 ages approaches any other even closely (see table II). There remain four major interpretations of these widely disparate results:

The ages may represent actual periods of primary mineralization. The close connexion between the granite intrusions and the mineralization in south-west England has been widely recognized from geological evidence (e.g. Dunham, 1952; Dines, 1956). Potassium-argon and rubidium-strontium age measurements for the main granites in south-west England fall in the range 290-250 Myr. (Long, 1961). Only the concordant age of the Geevor uraninite (290 ± 7 Myr.) comes within this range, and there can be little doubt that this represents a primary mineralization.

It is noticeable that the 206/238 and 207/235 ages for No. 1 are very closely concordant. It could be that there was a primary uranium mineralization at 225 ± 5 Myr. Further age data in support of this hypothesis is furnished by other similar U/Pb ages from Britain, e.g. two uraninites from Tyndrum, Perthshire (206/238 ages = 230 ± 8 Myr. and 231 ± 4 Myr.; Darnley *et al.*, 1960, and personal communication). Geological studies do not appear to contradict this hypothesis. Neither does the present geological evidence preclude the possibility of the younger ages of 124 Myr. (No. 2) and 60 Myr. (Nos. 3 and 4) representing primary mineralizations (although Dunham, 1952, considers mineralization younger than Hercynian to be unlikely in this region).

Loss of lead could have caused apparently low ages, and this might have occurred recently, or at some intermediate date. The freshness of the minerals observed in the polished sections shows that recent lead-loss could not have occurred by simple weathering in situ. The absence of any clear signs of internal supergene alteration also indicates that simple lead-loss is not very probable. However, the effect is considered quantitatively below.

For simplicity of the calculations, it is assumed that the original mineralization of all specimens occurred at 290 Myr. and that all lost lead in recent times; this mechanism would cause the greatest changes in the apparent ages. The effect can be estimated readily by a simple algebraic application of the graphical procedure of Wetherill (1956). The experimental 206/238 ratio of each sample is divided by the 206/238 ratio for an age of 290 Myr. to give the fraction of radiogenic lead remaining. The 207/235 ratio for 290 Myr. is then multiplied by this

TABLE III. Lead-loss calculations

No.	Percentage recent lead-loss for original mineralization at 290 Myr.	Experimental ages in Myr.		Calculated 207/235 age in Myr.
		206 238	207 235	
1A	23 %	224	227	230
1B	22 %	227	229	233
2	58 %	124	130	133
3	81 %	57	71	63
4	79 %	62	59	67

fraction and the age calculated from the resulting figure. These calculated 207/235 ages are compared with the experimental 206/238 and 207/235 ages in table III. In all cases except No. 3 the recent lead-loss hypothesis results in a slightly greater degree of discordance between the 206/238 and 207/235 ages than is observed experimentally. Also, for Nos. 3 and 4, the experimental 207/235 ages and thus the lead-loss calculations have little meaning because of their very small radiogenic Pb^{207} contents. It should also be noted that such high degrees of lead-loss in recent times are not compatible with the polished section studies.

If any significance is to be attached to these calculations for Nos. 1A, 1B, and 2, the negative conclusion can be made that either one or both of the initial assumptions of primary mineralization at 290 Myr. and recent loss of lead are incorrect or over-simplified.

Any more detailed calculations based on assumptions of different periods of primary mineralization and loss of lead in intermediate times are likely to be even less conclusive than the above. Nevertheless some form of lead-loss cannot be excluded definitely.

A process might have occurred some time after primary mineralization that entailed the solution of the vein-material, the partial or complete separation of radiogenic lead from the uranium and subsequent re-crystallization of the uranium mineral.

Such a process, variously described as remobilization, regeneration, rejuvenation, or redistribution, has been recognized independently

from geological and geochronological evidence in some European mineral deposits in the Hercynian orogenic belt, notably the deposits of Saxony (Baumann, 1958; Vinogradov *et al.*, 1959), Portugal (Davidson, 1960), and France (Roubault and Durand, 1961). A process of remobilization would encompass some of the ideas expressed in the above sections, and is the explanation favoured on the data available so far.

Evidence for remobilization would be furnished by the discovery of an abnormal radiogenic component in any galena coexisting with a uranium mineral studied. An unsuccessful search was made for such positive evidence. Moorbath (1962) analysed isotopically a galena from the same South Terras lode as specimen No. 1 of this study; there is no abnormality in its isotope composition. However, incomplete mixing of radiogenic and common lead isotopes might be expected during the local remobilization of a lode, and so the remobilization hypothesis cannot be refuted on the evidence of a single galena measurement.

A problem is posed by No. 4. Since it is not known definitely whether No. 4 comes from the same South Terras lode as No. 1, it is not possible to say whether remobilization did occur at least once in this lode.

Further evidence, which tends to support the remobilization hypothesis, is provided by the X-ray measurements of the cell sizes of the pitchblende in the specimens. A significant decrease in the cell size of the pitchblendes accompanies the decrease in their 206/238 and 207/235 ages (table II). This decrease in cell size is presumably due to a progressive increase in the oxidation state of the uranium in the pitchblendes (Brooker and Nuffield, 1952; Sidorenko, 1958). One explanation of this marked regularity is that, at some time following the original mineralization, the pitchblendes were subjected to alteration by oxidizing solutions, the degree of oxidation being greater for the apparently younger specimens. This could have accompanied partial loss of radiogenic lead during remobilization. No other combined isotopic U/Pb age and X-ray measurements appear to be available for testing the above explanation. Such combined studies may prove fruitful in further work on similar mineralization problems.

Addition of some new uranium may have occurred together with the partial remobilization of older uranium. The present age data are inadequate to test this possibility. If two such effects occurred together, the term 'remobilization' would be misleading for this region.

Further age results and mineralogical and geological evidence concerning the uranium mineralization in south-west England are to be

presented shortly by Darnley *et al.* (1965). Clearly more measurements of accurately located uranium and lead minerals from this region are necessary before more positive conclusions can be made. However, the tentative conclusions drawn from this work are: That primary mineralization occurred in south-west England at about 290 Myr. and 225 Myr. That at about 60 Myr. there was either localized remobilization (during which the older uranium minerals suffered partial loss of radiogenic lead together with oxidation of the uranium in corresponding proportions) or further primary mineralization, or a combination of these two processes. And that the significance of the single 124 Myr. age is uncertain; it could represent a real geological event (either remobilization or primary mineralization) or it could represent a mean between several unidentifiable events of other ages.

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