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OBSERVATIONS ON SOIL GAS VARIATIONS IN THE BOVEY BASIN

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INTRODUCTION

Gas concentrations within the pores of the unsaturated zone of soils may, in part, be determined by the geology below. Their measurement, therefore, has potential for revealing hidden information about the sub-surface geology. The detection of faults and other permeable pathways is based on the theory that ^4He, produced from alpha decay, will follow the routes of least resistance to the surface and induce a soil gas anomaly. Similarly, Rn and CO_2 concentrations, which can be associated with faults, may be enhanced as well.

The analytical technique involves the extraction of gases from 0.5 m depth using soil probes, into syringes for the subsequent analysis of ^4He on a Leybold UL400 mass spectrometer. Calibration is based on differences from the atmospheric air value of 5220 ppb (Holland and Emerson, 1987) and an accuracy of ±30 ppb is possible. Radon is measured by an EDA Electronics RD-200 using Lucas ZnS (Ag) scintillation cells and one count per minute has been calibrated to 0.2 Bq/1.

The success of soil gas analysis as a fault detection method is dependent on the identification of soil gas anomalies that may be reconciled to linear features. Additionally, the anomalous values must be different from those which may be attributed to biological, pedological and meteorological variations. These problems and the sampling methods are fully discussed in Duddridge *et al.* (1991). Research by the University of Exeter has in the past been confined to testing areas of known or suspected faulting and traverse lines with closely spaced 10 m sample points. Other workers (Lombardi and Polizzano, 1988) have employed regional surveys and this approach has been used in the current research reported here.

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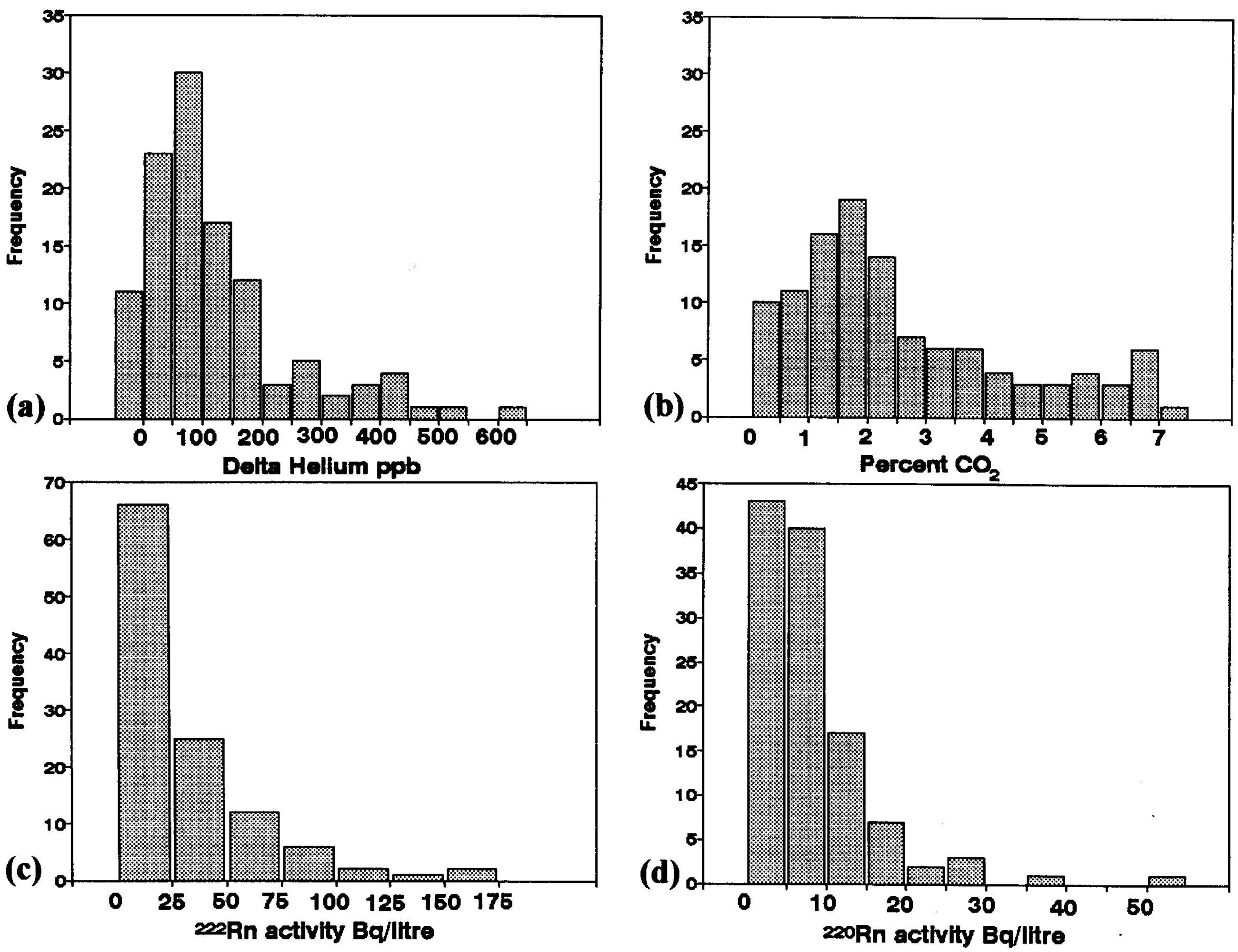

Figure 1. Histogram of soil gas data

Radioactive Waste" (1990 - 1994) under contract F12W - CT91 -0064 to support studies to investigate the properties of clay for radioactive waste repositories. The Bovey Basin was selected for study as much published and unpublished geological work covering the area has been accomplished by various authors, including Selwood *et al* (1984). Additionally, it contains clay, has a varied marginal geology and is fault-related. This work has been conducted to increase the understanding of permeability of gases and the natural occurrences of radon in a fault regime.

SAMPLING

The methodology was to take soil gas samples for He, Rn and CO_2 at, so far as possible, random locations over 57 km^2 at a density of 2 per km^2. Known geology was therefore not a determinant in placing sample positions and the main factor was land access. In practice, suitable roadside and public footpath networks determined sample site positions although this was not always ideal. For non-public areas, permission was sought and was refused only once, though unfortunately this was for a major area of land.

The 114 sample sites showed a spread of values:

	ΔHe ppb	CO_2 %	^{222}Rn Bq/1	^{220}Rn Bq/1
Average	128	2.59	32	8
Maximum	606	7.32	170	54
Minimum	-26	0.04	1	0
St. Deviation	139	1.89	33	8
Number	113	113	114	114

Table 1. Statistics from the soil gas sampling points.

The distribution of values is skewed, particularly of He, ^{222}Rn and ^{220}Rn as illustrated by Figure 1. These also show that 57% of ΔHe samples lie between 0 and 100 ppb, 50% of CO_2 (Figure 1) between 0 and 2%, 58% of ^{222}Rn between 0 and 25 Bq/1 and 73% of ^{220}Rn between 0 and 10 Bq/1. These values can therefore be considered to be background for the area as part of the process of identifying fault-related anomalies.

Sampling was confined to days within the period from July 1992 to April 1993. From November 1992 to March 1993 periodic measurements were made from a fixed sample site probe at Twinyeo [SX 844 762]. The range of variations observed are set out in the following table:

	ΔHe ppb	CO_2 %	^{222}Rn Bq/1	^{220}Rn Bq/1
Average	62	2.35	41	14
Maximum	129	3.85	56	22
Minimum	22	1.32	22	4
St. Deviation	39	0.79	10	5
Number	11	11	11	11

Table 2. Statistics from the permanent monitoring point.

It can be seen that at no time did the monitoring site values increase above those seen on the main survey, whose maxima were: 606 ppb ΔHe, 170 Bq/1 of ^{222}Rn and 7.32% CO_2. In comparison to the main survey data the standard deviation for each gas was significantly lower than the mean concentration. This continues to support the theory of spatial as well as temporal variation (Hinkle, 1990). A weather station recorded meteorological conditions throughout the period, but as yet it has not proved possible to establish the exact relationship to soil gas variations. Other work by the writer does, however, suggest that temperature variation alone, in well aerated soils, is insufficient to explain the higher 4 to7% CO_2 values recorded. Wind speed and pressure are factors that may reduce CO_2 concentrations, but will not of course increase them while waterlogging is considered to reduce recorded radon activity. To minimise the effects of meteorological variations sample collection was first completed at a density of 1 point per km^2, before a second phase of sampling doubled this density. On each individual day care was taken not to concentrate sampling in too small an area, while additionally no sampling was done within 24 hours of significant rainfall and waterlogged sites were rejected.

RESULTS AND DISCUSSION

When sampling reached an average density of 1 sample per km^2, the data was analysed and it was noticed that anomalies were delimited by contour concentration maps. The subsequent completion of sampling to a density of 2 per km^2 did not significantly alter the overall patterns

Sample	ppm	ppm	Soil Group	Soil type	Geology	Sample notes
R86	5.01	2.93	Gleyed Brown Earth	HALSTOW clayey, over Culm or shaley head	Close to fault between granite and Wolley Grit over Culm?	Shale and some granite fragments
R85	16.01	7.37	Brown Warp soil	TEIGN coarse loamy, riverine alluvium from granite and shale	Crackington Formation	Brown silty soil with feldspar fragment
R72			Gleyed Brown Warp soil	BOVEY Silty, riverine alluvium from granite and shale	Alluvium over undifferentiated Bovey Formation	Brown clay soil with shale fragments
R1	9.29	1.33	Peaty or humic gley soil	KNIGHTON Clayey; over clayey Bovey Beds	Undifferentiated Bovey Formation	Silty, iron stained and with few fragments
R112	8.82	4.62	Surface-water gley soil	TEIGNGRACE Clayey; over clayey Bovey Beds	Southacre Clay and Lignite of Bovey Formation	Clayey with some shale and granite fragments
R64	7.55	2.51	Surface-water gley soil	TEIGNGRACE Clayey; over clayey Bovey Beds	Undifferentiated Bovey Formation	Iron stained
TW1	8.27	3.08	Gleyed Brown Earth	STOVER Fine loamy, Head from Bovey Beds and slate	Southacre Clay and Lignite of Bove Formation	Silty with shale and granite fragments
R20	8.31	4.19	Surface-water gley soil	TEIGNGRACE Clayey; over clayey Bovey Beds	Undifferentiated Bovey Formation	Clay with few fragments
R107			Gleyed Brown Warp soil	BOVEY Silty; riverine alluvium from granite and shale	Alluvium over undifferentiated Bovey Formation	Brown silty soil, no fragments
R98	5.79	1.3	Ochreous Brown soil	MILBER Coarse loamy and gravelly; over sand and gravelly Bovey Beds and Cretaceous Sands	Undifferentiated Bovey Beds	Brown silty soil with no fragments
R99	3.6	0.54	Brown Earth	HIGHWEEK Fine loamy over Devonian Slate or slaty Head	Gurrington Slate and Spillite	Volcanic fragments

Table 3. *Notes on soil samples and related published information.*

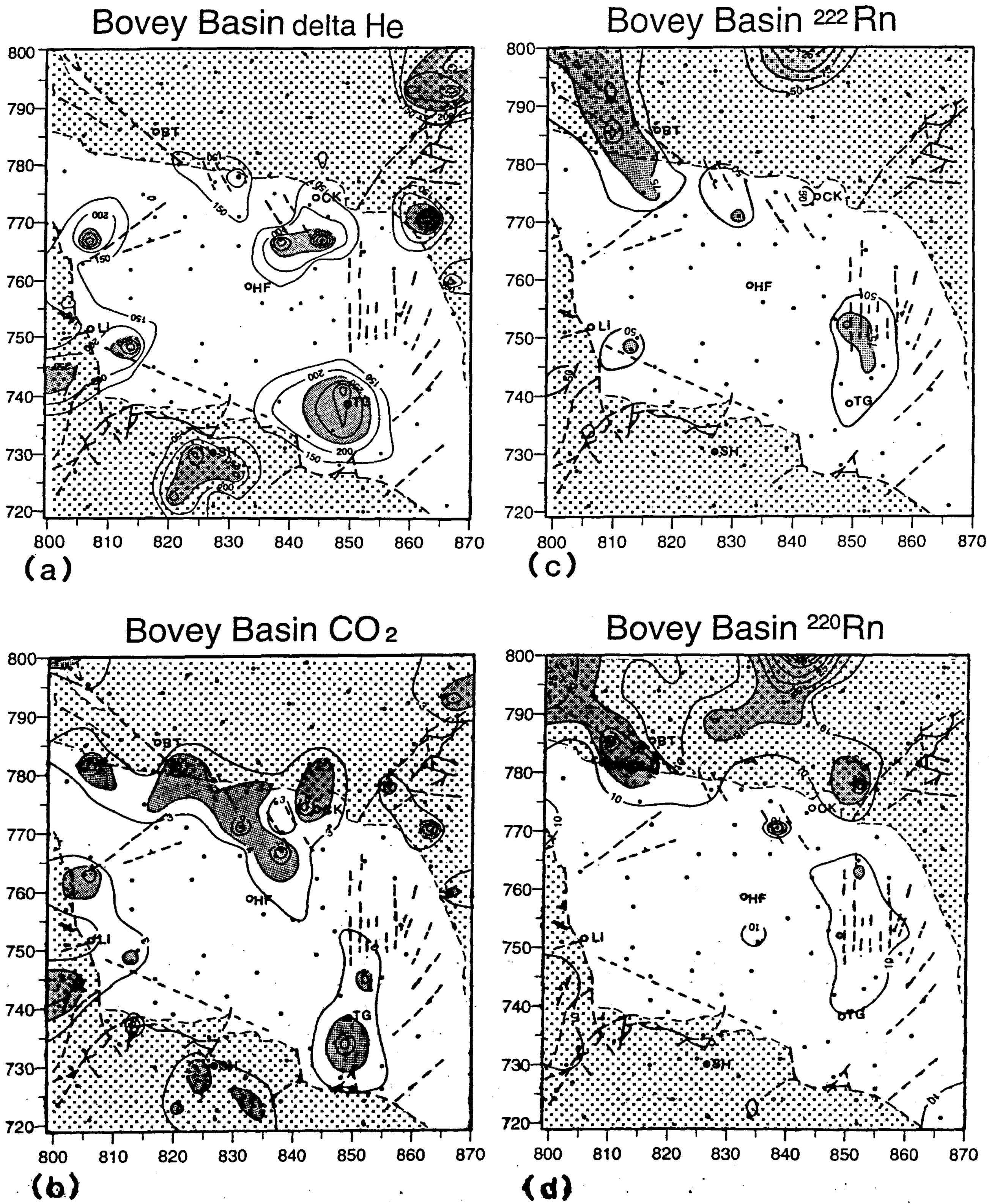

Figure 2. Contoured soil gas data.

Central non-patterned area shows the outcrop the Bovey Basin deposits, thin dashed lines geological boundaries and thicker lines, faults. Areas of high soil gas concentration are dark shaded, ΔHe values are ppb, Rn Bq/ litre and CO_2 percent.

BT - Bovey Tracey
CK - Chudleigh
HF - Heathfield
Li - Liverton
SH - Seale Hayne
TG -Teigngrace

of ΔHe, Rn and CO_2. At the full density ΔHe, CO_2, ^{222}Rn and ^{220}Rn values are contoured and the maps superimposed on the known geology of the area (Figures 2a to 2d). The faults are from the British Geological Survey sheet 339, while additional faults are shown within the basin as they appear in Holloway and Chadwick (1986) and Bristow (1993). The short 55.6 second half-life ^{220}Rn isotope and that of ^{222}Rn has been separated from the original total radon readings using the formula of Morse (1976).

Though some high and anomalous soil gas concentrations appear as random spots, many form contiguous features requiring explanation. Their relationship to faulting is equivocal, although specific faults suggest that a relationship may exist as at Seale Hayne [SX 828 735]. Here, a south-south-west trending fault, which offsets thrust elements on the southern margin of the Bovey Basin, may well extend south-south-westwards, so explaining the ΔHe and CO_2 anomalies at [SX 824 730] and [SX 821 722]. On the other hand the Western Margin Fault, near Liverton [SX 806 752], does not directly correlate with any peaks, although the area is generally enhanced with He and CO_2. The Sticklepath Fault Zone has no associated He anomaly, at least as defined in the area to the north-west of Bovey Tracey, beyond the margin of the Bovey Basin. Interestingly, this area is high in Rn, including the 220 component, but this might be expected as it is close to and partly on the granite margin. Within the basin from near Bovey Tracey [SX 822 781] to New Bridge near Chudleigh Knighton [SX 850 765] there is an elongated zone of soil gas anomalies represented in places by one or a combination of elevated He, Rn and CO_2. The published map shows north-northwest - south-south-east and north-west - south-east faults in this area which may provide gas permeable pathways, or possibly the anomalies are associated with an extension of the Bovey Tracey Fault.

Considering the overall distribution of anomalies it is noticeable that they dominate the margins of the basin. It may be that gases carried in groundwaters come out of solution as they discharge into the lower less permeable rocks of the basin. This has not been studied further. However, a trial investigation of soils as sources of parent isotopes for Rn has been. Approximately 100 g of soil was collected by auger at 0.5 m depth at 11 sites arranged north-west to south-east across the area. These were air dried, the entire sample Tema ground and pelleted for X-Ray Fluorescence Spectrometry analysis for U and Th content. The results together with notes on the soils and geology derived from published maps are given in Table 3.

Nine samples gave U and Th results above the 1 ppm detection limit, the remaining two were noticeble, however, for having a high Pb content. These were in areas of alluvium east of Bovey Tracey [SX 827 777] and between Teigngrace and Preston [SX 853 743], the former close to a minor valley running south from an area of north - south Ba/Pb/Zn mineralisation in the middle Teign Valley.

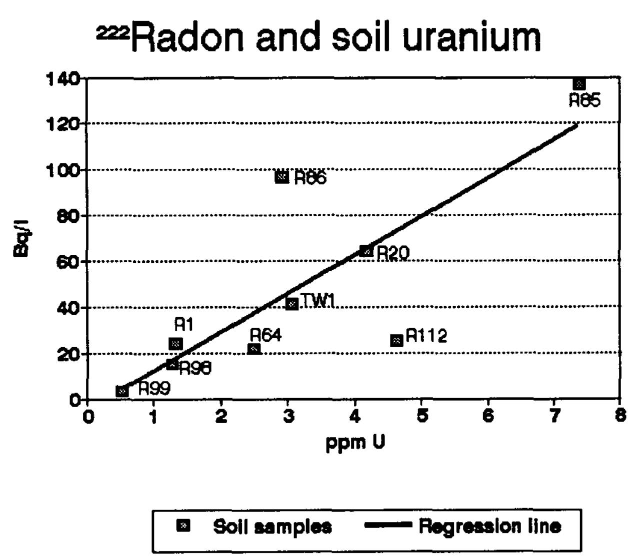

Figure 3. Soil U content compared to soil gas ^{222}Rn.

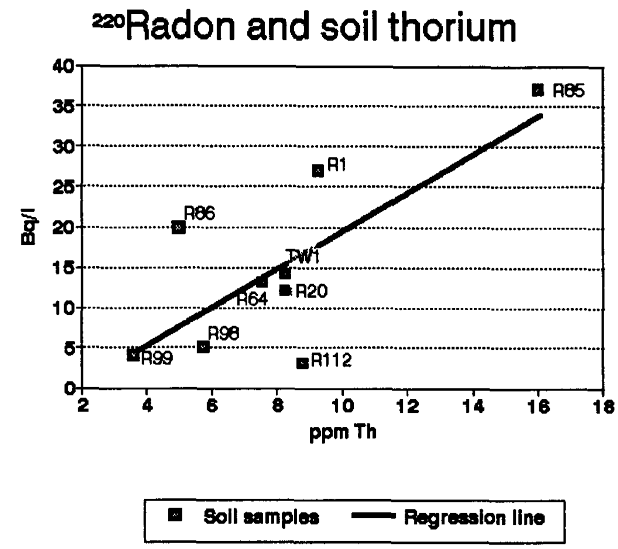

Figure 4. Soil Th content compared to soil gas ^{220}Rn.

The U and Th ppm contents of the samples are plotted against the measured soil gas Rn separated into its 222 and 220 components (Figures 3 and 4). A regression line has been fitted in each case, but with the reservation that there are a limited number of data points. The graphs show the relationship between U and Th soil content and ^{222}Rn and ^{220}Rn as soil gas. Samples deviating from this line are perhaps indicators that radon gas has moved into or out of the surface source area, a fault or other permeable zone may provide the necessary pathway. Further work would be necessary to determine whether the U and Th is derived from the parent rock below, has been physically transported, or in the case of U alone moved by groundwater to its current soil environment.

However, the multi-gas approach helps to distinguish those areas where faulting may be a factor. The sample R86 from between Lustleigh and Bovey Tracey [SX 800 800] on the Bovey Fault has enhanced ^{220}Rn above the regression line, and for this to be transported in from an alternative source area requires a particularly permeable pathway. Even though ΔHe is only 120 ppb, the Rn information coupled with an anomalous 6.39% CO_2 is good evidence for a fault-related explanation.

The sample R112 from just north of Heathfield [SX 837 766] is depleted in both ^{222}Rn and the 220 isotope. A fault, which might be related to a sub-surface extension of the Bovey Tracey or a fault parallel to it, could again be responsible for anomalous radon and this is supported by high ΔHe at 402 ppb and 7.32% CO_2. In the Teigngrace area anomalies are seen and site R20 [SX 848 742] is enhanced in Rn though not above the regression line relating to soil U and Th, but it is accompanied by anomalous ΔHe at 436 ppb and above average CO_2 at 3.25%. The contouring shows a slight north - south elongation to the anomaly pattern, but it remains speculation as to whether this represents a relationship to the known north - south faults to the north as recorded in the literature (Selwood *et al.,* 1984).

CONCLUSIONS

A regional approach to soil gas analysis as an aid to geological interpretation of an area, can reveal information even at a 1 to 2 sample per km^2 density. Data collected for He, Rn and CO_2 produces patterns on contoured maps that are more than just random sets of data associated with, for example, meteorological factors and analytical error. In places, anomalous values of He and CO_2 strongly suggest an association with faulting, particularly where associated with anomalous Rn, but not an exceptionally high soil U or Th content. Correlation of CO_2 with ΔHe is significant with a Pearson value of 0.583 for 112 data points. It is hoped that work on this relationship of Rn to soils and CO_2 to meteorological variables will enable 'background' soil gas values to be eliminated, so enhancing soil gas signatures over faulted ground.

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