Soil gas anomalies in the Dartmoor area

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Geochemical work was carried out at a sampling density of 1/km^2 in the South Zeal to Lustleigh area, along a 30 km length of the Sticklepath Fault. The survey revealed high soil gas helium, carbon dioxide and radon in areas close to the fault and at a number of other locations. Both the soil gas analysis and stream patterns suggest a fault zone rather than one single structure. The low density soil gas mapping and previous work has shown that soil gas helium has not been recorded higher than 604 ppb above normal atmospheric levels in the Dartmoor area. Carbon dioxide was only exceptionally above 6% and radon showed higher activity both in relationship to the granite and faulting.

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Introduction

Helium and carbon dioxide are normally present within the soil pores and concentrations are often above the normal atmospheric levels of 5220 ppb and 0.035% respectively. Radon is also, often present. Soil gas values may be particularly high when measured above faults and fractures which form permeable pathways for the gases. The measurement of these gases may be carried out using the methods described in Duddridge *et al.* (1991) and Duddridge and Grainger (1998).

There is no specific concentration of helium (He) and carbon dioxide (CO_2), or activity level in the case of radon (Rn), that sets a threshold for a soil gas anomaly. Klusman (1993) refers to work by other authors over the San Andreas Fault, USA where He of 430 ppm was recorded over a 50 m wide zone along the traverse. This was an exceptionally high value as normally only small differences (delta values) from the atmospheric value of 5 ppm or 5220 ppb are observed. Each geological situation is therefore different and consequently there is no set procedure for the interpretation of anomalies. A soil gas anomaly is normally recognised as an atypical concentration which is statistically distinct from the main population set containing background values.

Published soil gas data from Dartmoor

Published soil gas data was investigated to find values which characterise the Dartmoor area. Most of the published data was from traverses rather than spatial surveys and the number of data points and spacing varied considerably. Soil gas concentrations were obtained from tables of data where available and as values measured from graphs. Where necessary ^{222}Rn activity level has been converted to Bq/l from counts per minutes using a conversion factor of 0.2 Bq/l per cpm. However, this factor is only approximate and is only appropriate for activity measured with the EDA RDA-200 radon analyser using alpha particle scintillation in Lucas cells.

Using the data from Gregory and Durrance (1985), Gregory *et al*. (1986), Gregory (1985, 1987), Sibley and Grainger (1988), Sibley (1989) and Varley and Flowers (1992, 1993) together gave 589 data points for soil gas He, 404 for CO_2 and 405 for ^{222}Rn. The compiled results are plotted in Figures 1 to 3 as 'high-low' line graphs to show maximum, minimum and mean soil gas levels.

Two traverses over former mines run by Sibley (1989), from Gooseford to the north of Throwleigh and Frankmills in the Teign valley, gave the highest values of ΔHe at 604 ppb and 429 ppb respectively. The mean values of 202 ppb and 184 ppb were as high as many maximum values obtained at other locations (Figure 1). These two mining areas were clearly anomalous and

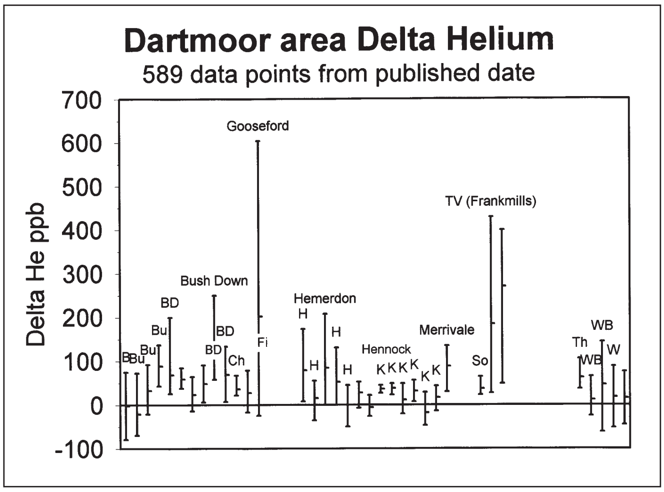

__Figure 1.__ Compilation of published ΔHe data from the Dartmoor area. B Belstone, Bu Buckfastleigh, BD Bush Down, Ch Chagford, Fi Fingle Bridge, H Hemerdon, K Kingswood, So South Zeal, TV Teign Valley, Th Throwleigh, WB Wheal Betsy and W Whitchurch.

it is likely that the Gooseford anomaly is associated with the Sticklepath Fault. However, overall the published data showed that few of the 589 published data points exceeded 200 ppb and the mean value of all of them was just 53 ppb ΔHe. Given that He is difficult to measure to a precision much greater than 25 ppb, the usefulness of this gas on its own as a mapping tool is limited.

The CO_2 data show that the Gooseford site and Aller mine in the Teign Valley gave maximums of 6.02 and 5.6% respectively against an overall mean of 1.69% from all the reviewed data. Compared to He, CO_2 was anomalous at a greater number of places as at Bush Down and Wheal Betsy. The greater range of values obtained at many of the survey sites shows that CO_2 is a valuable soil gas mapping tool, despite some of the CO_2 inevitably being of biogenic origin. This supports the findings in Duddridge (1994), where CO_2 proved to be the most useful gas in delineating fault related anomalies in the Bovey Basin.

With the exception of the Fingle Bridge anomaly, which is associated with a U vein and gave an activity of 2962 Bq/l ^{222}Rn (Gregory, 1987), the Bush Down survey (Sibley, 1989) and Throwleigh and Prewley surveys (Varley and Flowers, 1993) gave the highest maximum ^{222}Rn values of 585, 740 and 360 Bq/l. The high Rn activity from Bush Down and Throwleigh might be anticipated from their location within the Dartmoor Granite, but other sites such as Hennock and Chagford, also within the granite, were comparatively low. The high Rn activity from

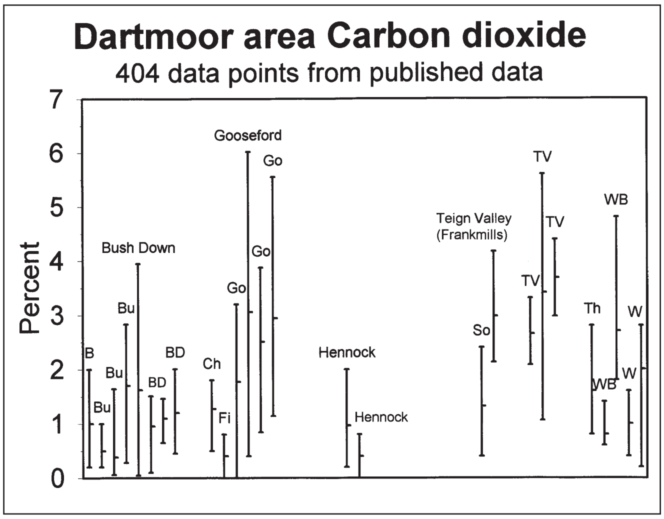

Figure 2. *Compilation of published CO_2 data from the Dartmoor area.*

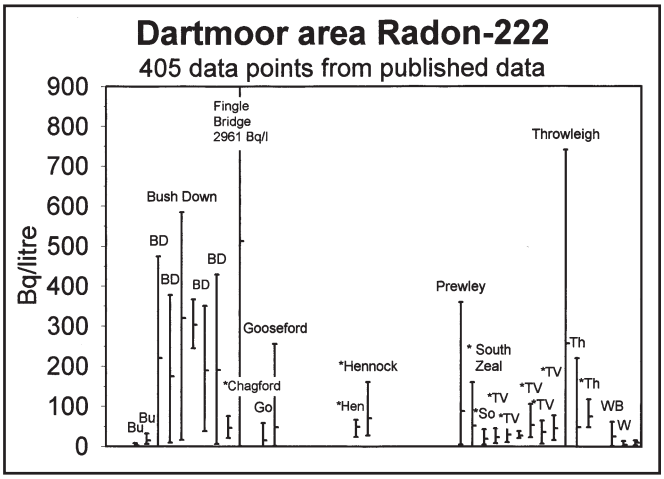

Figure 3. *Compilation of published ^{222}Rn data from the Dartmoor area.*

Prewley, and obtained by Varley and Flowers, was from a traverse across the Prewley Downs Fault and just beyond the granite margin. The range of ^{222}Rn values shows that like CO_2 it can be a valuable gas for mapping, although in some cases such as in the Teign Valley this was not the case (Figure 3).

Soil gas surveys over the Sticklepath Fault

A 30 km section of the Sticklepath Fault zone was divided into 3 soil gas mapping sub-zones of approximately 56 km² and mapped at a low density of 1 sample/km². The work was carried out during 1996/97. To minimise error from temporal variation, samples were taken so as to gradually increase the density within the 56 km² rather than progress systematically across the area. Nevertheless, a further complication arises as the He and CO_2 results of 570 ppb and 7.56% were obtained as peaks in the Throwleigh area, just prior to a 1.5 ML earthquake 20 km to the north. A mapped sample point recorded up to 11.0% CO_2 which is significantly higher than any of the values recorded at other locations (Figure 2). Some of the results from the South Zeal and Chagford areas were discussed in relation to seismicity by Duddridge and Grainger (1998). Adjoining to the south east was the Lustleigh area which adjoins previous soil gas mapping around the Bovey Basin (Duddridge, 1994).

Overall the distribution pattern of soil gas He and CO_2 from the South Zeal and Chagford mapping areas was found to be similar. Around Grid Reference SX 693 959, south of the village of Spreyton, ΔHe and CO_2 were high with values of 246 ppb and 5.26% respectively. Figure 4 and figure 3 of Duddridge and Grainger (1998) show this to be elongated in the NW direction, which being parallel to the trend of the Sticklepath Fault may indicate a similar sub-parallel fault. Whilst there is no direct outcrop evidence for a fault within the Upper Carboniferous, BGS Okehampton 1:63 360 Solid and Drift Sheet (BGS, 1969) shows displacements in the outcrop of the Permian Crediton Trough 7 km to the NW. The shape of the Dartmoor Granite margin 10 km to the SE would also be consistent with a fault cutting the Upper Carboniferous sediments around Spreyton.

The area to the SW of the Spreyton anomaly showed low to negative ΔHe values and also low CO_2 of 2% or less. This produces He and CO_2 contour patterns which appears to be more closely related to the outcrop of the Sticklepath Fault, where it passes through the northern margin of the Dartmoor Granite around Throwleigh. The distribution of ^{222}Rn and ^{220}Rn as shown in figures 5 and 6 is closely related to the outcrop of the granite in that significant levels of activity are largely absent from the surrounding country rock. Within the granite, the overall trend of both radon isotopes at the lowest level of activity shown in figures 5 and 6 may be interpreted as having a weak NW-SE trend. This 4 to 5 km wide zone of low radon activity may be linked to a number of NW-SE faults in parallel relationship to the Sticklepath Fault.

Within the granite, higher radon activity occurs, and in places, there are 'hot spots' as to the south west of Chagford. A SSW-NNE trend is also evident in the contour patterns and it may be speculated that this represents another fault trend. It is therefore possible that the soil gas mapping is showing evidence for a more complex pattern of faulting.

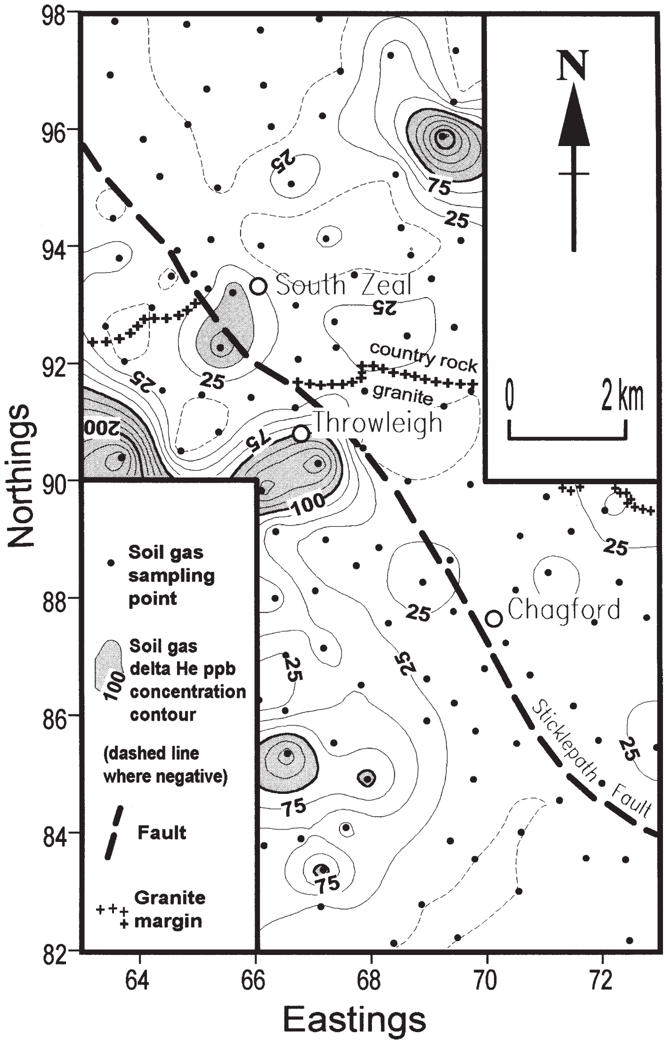

Figure 4. *Contoured soil gas ΔHe in ppb from the South Zeal and Chagford mapping areas.*

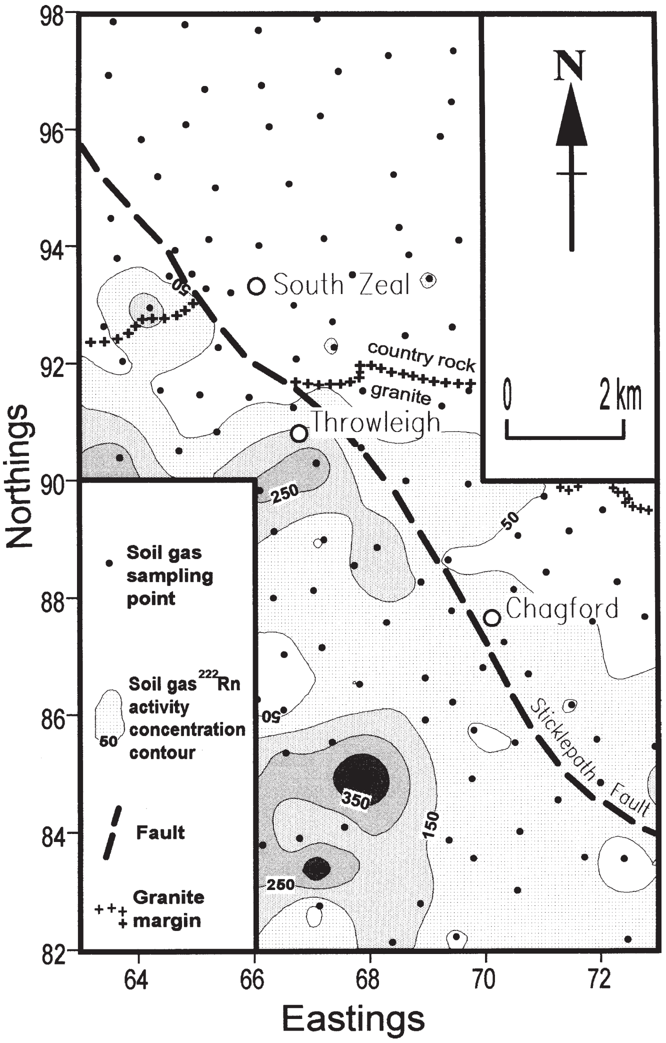

Figure 5. *Contoured soil gas ^{222}Rn in Bq/l from the South Zeal and Chagford mapping areas.*

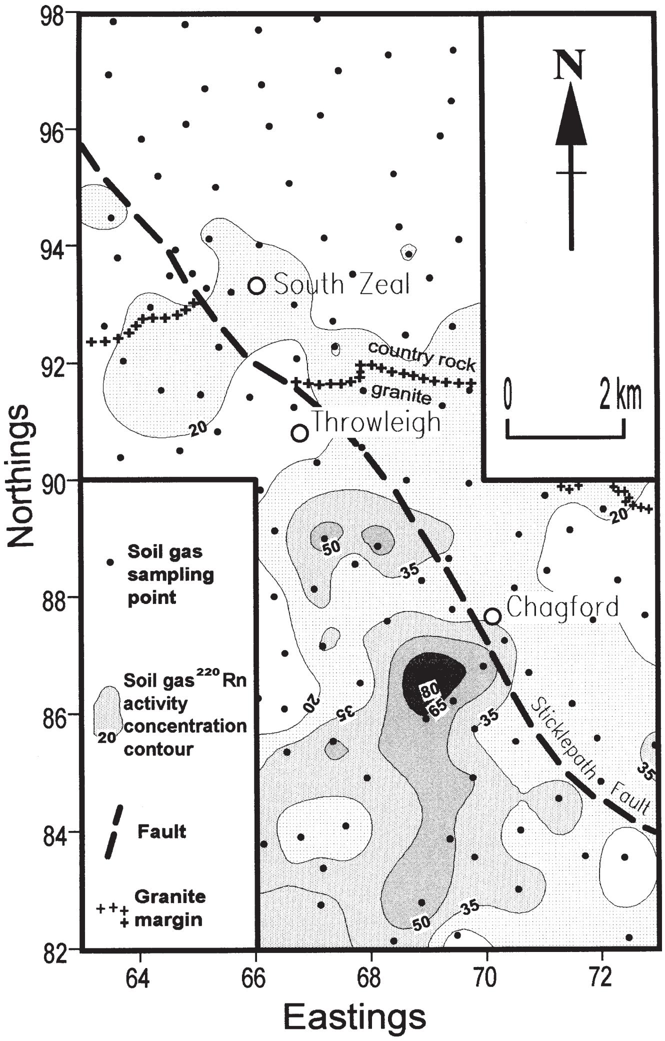

Figure 6. *Contoured soil gas ^{220}Rn in Bq/l from the South Zeal and Chagford mapping areas.*

Comparison with other work

Gregory (1987) ran soil gas traverses across the Sticklepath Fault. His Traverse 1 (5 sample points over 3800 m) crossed the Sticklepath Fault to the north of the Dartmoor Granite near South Zeal and Traverse 2 (4 sample points over 2600 m) was about 2 km further south, near East Week where the fault forms the boundary between granite and country rock. Some enhancement of He and CO_2 was found over the fault outcrop, but his Traverse 3 (7 sample points over 7300 m) just to the north of Chagford showed little variation. Traverse 2 recorded a high of 105 ppb ΔHe and 2.8% CO_2, but these values are far lower than those discovered to the south of Throwleigh as described here. This helps support the contention by Duddridge and Grainger (1998) that He as mapped in Figure 4, and CO_2 were temporarily enhanced prior to the 1.5 ML earthquake (26th November 1996). Little or no correlation of this event was observed with Rn.

About 2 km WSW of Chagford, Gregory (1987) in his Traverse 3 showed a peak with a total alpha count (^{222}Rn+^{220}Rn) of 380 cpm (about 76 Bq/l) from a mean of 236 cpm (about 47 Bq/l). This is consistent with the ^{220}Rn and ^{222}Rn activity from the soil gas mapping which showed higher values 1 to 2 km west of the known Sticklepath fault outcrop shown on BGS Okehampton 1:63 360 Solid and Drift Sheet (BGS, 1969). The consistency in contrast to He and CO_2 may reflect the fact that no correlation was seen between Rn and the 1996 seismicity (Duddridge and Grainger, 1998). Both Gregory's and the current survey showed no notable correlation of Rn data with the Sticklepath fault outcrop.

In contrast Varley and Flowers (1993) ran 3 traverses across the Sticklepath Fault zone, in the area between South Zeal and Chagford, and interpreted the presence of faulting. This is likely to be due to the closer spaced sampling. His northernmost Traverse II was located mid-way between South Zeal and Throwleigh and trended ENE. Like Traverse 2 by Gregory (1987) it passed from granite to country rock within the metamorphic aureole, where the actual boundary is formed by the Sticklepath Fault. With 18 sample points and a length no more than 670 m, it was sufficiently detailed to detect the fault with a 160 Bq/litre anomaly over the position of the main fault and an average ^{222}Rn activity of 52 Bq/l. Over a branch fault within the granite aureole, an activity of 74 Bq/l was reached. In contrast the soil gas mapping described here did not detect the fault, but instead placed the area below the 50 Bq/litre threshold (Figure 5). However, the differences between the two surveys are not great and 9 out of 18 sample points from Varley and Flowers (1993) traverse lay between 0 and 50 Bq/litre.

Varley and Flowers (1993) had a 1200 m long Traverse I at Clannaborough, between South Zeal and Throwleigh, running SW - NE and gave a distinctive ^{222}Rn peak of about 220 Bq/l over the main fault against a mean of about 50 Bq/l for 20 sample points. The soil gas mapping indicated activity between 50 and 150 Bq/l. The E-W Traverse III by Varley and Flowers (1993) was about 200 m long and was situated within the granite between Chagford and Throwleigh at a point where the soil gas mapping indicated activity of around 150 Bq/l. However, this traverse by Varley and Flowers (1993) gave a mean of 257 Bq/l from 18 sample points and a clear ^{222}Rn peak around 740 Bq/l. This peak was close to the reported position of the Sticklepath Fault.

Patterns of faulting

Straight sections of river valleys may in places result from preferential erosion along fault lines, so a straight valley coincident with soil gas anomalies increases the probability of there actually being a fault. Therefore a study of the stream system was made over a 696 km^2 area of Dartmoor by using the 1:25,000 Ordnance Survey map (Figure 7 inset).

Figure 7 shows that it is possible to reconcile a number of straight valleys to the NW-SE Sticklepath Fault trend which runs parallel to the River Bovey and its left bank tributary the Wray Brook from Moretonhampstead to Lustleigh. This zone is extended to the NW by tributary valleys of the River Teign around Throwleigh and Chagford. Short SW-NE valleys suggest that minor faults might link the major faults as part of a fault zone system.

The wide fault zone suggested by the distribution of both radon isotopes and already referred to, is supported by the evidence of the stream survey. Whilst ^{222}Rn activity is largely controlled by the outcrop of the Dartmoor Granite this drainage analysis helps to explain secondary variations. The more detailed variations are likely to be controlled by other factors such as drift cover and soil sampling conditions. For example between South Zeal and Chagford the area to the west of the Sticklepath Fault is covered by alluvial deposits and soil gas values were low for all measured gases.

A NW-SE structure following the Forder Brook, between Throwleigh and Chagford, may explain the distribution of ^{222}Rn which forms the anomaly partly parallel but SW of the mapped Sticklepath Fault. The ^{220}Rn activity also shows high values. As already indicated Gregory (1987) also found that Rn peaked in this area.

Also revealed is a prominent SSW-NNE trend along the valleys of the South Teign River, the Walla Brook and Becka Brook. The stream pattern analysis suggest that ^{222}Rn could relate to the South Teign River and ^{220}Rn to the Walla Brook (Figures 5, 6 and 7). A fault relating to the SSW-NNE Walla Brook trend would also explain the high Rn activity observed by Sibley (1989) at Bush Down (Figure 3). Rn activities are at their highest where the two SSW-NNE and NW-SE trends intersect to the SW of Chagford.

In areas beyond the granite outcrop, such as the Bovey Basin (Duddridge, 1994) and the Spreyton anomaly, CO_2 and to a lesser extent He, have been most valuable in giving anomalies associated with known or suspected faults. Within the Bovey Basin, eastward from Bovey Tracey an elongated zone of soil gas anomalies was represented in places by one or a combination of elevated He, Rn and CO_2. Taking the CO_2 results from all the mapping squares, together with the inferred structural trends (Figure 7 and 8), it can be seen that the distribution of the soil gas may relate in detail to a number of different faults. It is therefore possible to conclude that CO_2, followed by both Rn isotopes, are the most useful soil gas mapping tools in the Dartmoor area. Helium may indicate faulting, but anomalies are not sufficiently widespread to allow features to be delineated.

Conclusions

Soil gas measurements along a 30 km length of the Sticklepath Fault zone in the South Zeal to Lustleigh area has revealed high values in areas close to the fault, but also at a number of other locations. No soil gas ΔHe values higher than about 600 ppb were found and CO_2 was only exceptionally above 6% in the current and reviewed surveys.

Variations in soil gas concentrations may be used to help detect fault patterns even at a low resolution of 1 sample/km^2. The anomalous soil gas values to the west of Chagford do not correspond to the mapped outcrop of the Sticklepath Fault, but may instead indicate an unmapped branch fault parallel to it.

In practice, it may be necessary to employ other methods or a higher density survey to produce conclusive results. In a detailed soil gas survey it would be useful to take into account sampling conditions, such as soil moisture content that may influence small scale variation. The structural trends suggested by the drainage analysis help to further explain the pattern of soil gas anomalies as seen for example along the South Teign River. Soil gas analysis could be employed to help elucidate fault traces both within and beyond the Dartmoor Granite. Carbon dioxide followed by radon are the most useful gases for this type of work.

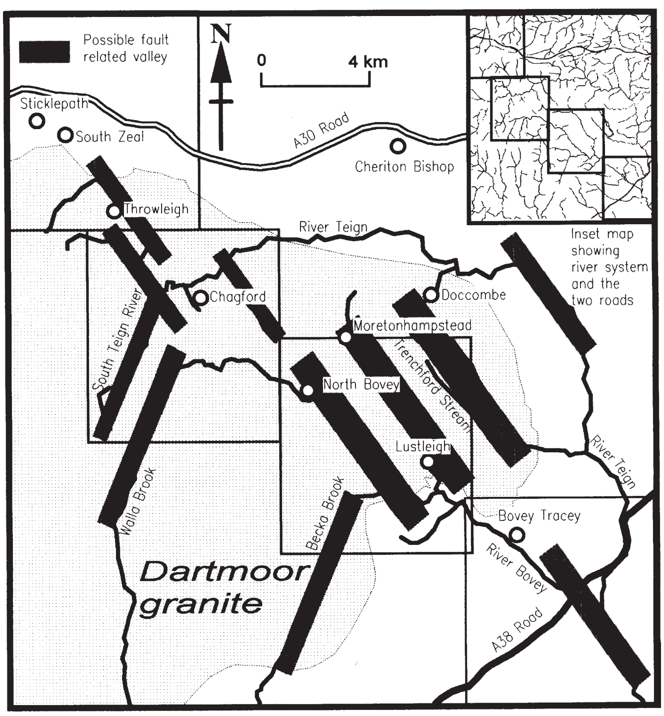

Figure 7. Dartmoor stream and river valleys that could be related to faults.

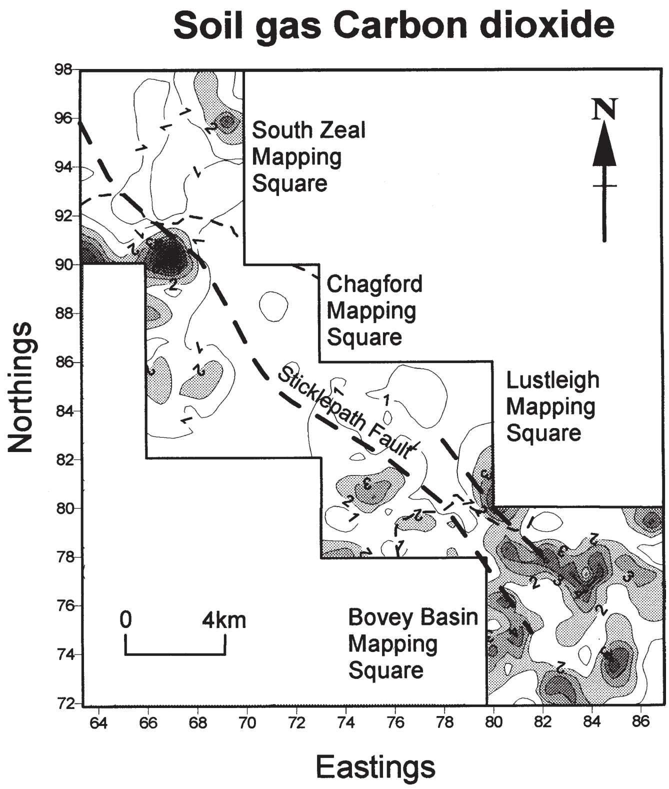

Figure 8. Overall CO_2 distribution from the 4 soil gas mapping squares.

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