Observations on seismicity in South-West England and the north Dartmoor geochemical anomaly

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Duddridge, G.A. 2013. Observations on seismicity in South-West England and the north Dartmoor geochemical anomaly. *Geoscience in South-West England*, **13**, 232-241.

Seismic data obtained from the British Geological Survey suggest that earthquake activity across Britain, from Cornwall to the North Sea and northwards to Scotland, is linked. Whether over short distances or regionally over hundreds of kilometres, one seismic event appears to trigger a following earthquake. Only after a large event, such as the 3.8 magnitude Penzance earthquake of 10 November 1996, does this sequence appear to be broken. Seismicity is likely to relate to NW to SE compressive stresses across Great Britain. The continuous pattern of seismic events over time would be consistent with the gradual long-term plate tectonic movement of north-west Europe. Within Devon a geochemical anomaly is apparent over the NW to SE Sticklepath Fault system and close to the northern margin of the Dartmoor granite. A high soil gas helium anomaly and deep soil solution potassium showed a correspondence to the 1996 Penzance earthquake. In addition, high deep soil solution magnesium corresponded to the 3.6 ML Bristol Channel earthquake off Hartland on 31 May 2001. Other peaks in potassium and magnesium correspond with months when there was seismic activity. This suggests that there is a north Dartmoor geochemical anomaly providing a measure of the stress within the crust, as well as the stress responsible for earthquakes over large areas of South-West England.

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Keywords: Seismicity, geochemical anomalies, north Dartmoor, Bristol Channel, Cornwall, Jersey.

Introduction

Earthquake activity from around the world has occasionally been associated with enhanced radon emissions, and sometimes with changes in the concentration of ions in groundwater, as shown by the two following examples.

Using radon alpha tracks, Hirotaka *et al*. (1988) recorded radon anomalies before the Japanese 6.8 magnitude Nagano Prefecture earthquake on 14 September 1984. There was a gradual increase in radon counts three months before the quake and a remarkable increase two weeks before the shock. Yasuoka *et al*. (2005) recorded stable radon activity of 20 Bq l^{-1} in a 17-m deep well from the end of 1993. From October 1994 activity increased to 60 Bq l^{-1} in November 1994, and 1995 radon activity was anomalous 7 to 10 days before a 7.2 magnitude earthquake on 17 January. Radon activity returned to pre-October 1994 levels after the earthquake.

In South-West England, soil gas surveying using the methods described in Duddridge *et al*. (1991) was carried out from 1996 to 1997 by the University of Exeter. This was part of the EU-funded Seismic Hazard Zonation project (Ciotoli *et al*., 1998). The aim was to establish background soil gas values for helium, radon and carbon dioxide, and the relationship to meteorological variables, such as barometric pressure (Duddridge and Grainger, 1998). However, instead of background soil gas values, the work revealed soil gas anomalies at the time of the November 1996 Penzance and Okehampton earthquakes. Over a number of weeks before the seismic events, peak soil gas values rose significantly above background levels. After the earthquakes soil gas values returned to background levels.

The present paper reviews the 1996-97 soil gas anomalies, and presents additional information on earthquake patterns. The links between seismicity and geochemical anomalies in South-West England and elsewhere are also considered.

British Isles earthquake activity, the North Sea and Netherlands

Earthquake data from the start of instrumentation in 1980 up to 2012 was obtained from the British Geological Survey (BGS) Global Seismology Unit in Edinburgh. This consists of 9,174 events that include onshore earthquakes from the British Isles, the English Channel, Channel Islands, and the North Sea as far as Norway and Denmark.

Analysis by number of events is unreliable, as the density of seismometer recording stations can vary and they are not available for offshore areas. This paper therefore also uses relative energy values based on a modified empirical formula of $(10^{magnitude})^{1.5}$ first derived by Charles Richter and best explained by the U.S. Geological Survey (2014). This gives an energy increase of times 31.6 for every whole number step in magnitude and is a more straightforward way of comparing the magnitude data. Offshore areas may still be under represented by minor earthquakes, but not sufficiently to obscure overall results dominated by higher magnitude earthquakes.

The BGS earthquake data may be divided into two geographical areas of approximately equal size and relative energy. For the area covering the North Sea (Central North Sea,