TELLUSSW: TOWARDS REMAPPING GRANITES, ELVANS AND LAMPROPHYRES

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The TellusSW survey of 2013-4 consisted of airborne magnetic, radiometric, LiDAR as well as stream sediment and soil geochemistry. These data allow remapping of granites and temporally related rhyolite-porphyry (elvan) and lamprophyre dykes. Radiometric data are particularly useful in providing an overview of units within individual granite plutons, notably by using eTh/eK ratios as Th is mainly immobile. When coupled with Nb, Ta and Zr stream sediment geochemistry these data allow interpretation of different granite units, supporting previous models of older, simpler, and younger, composite, plutons. Lamprophyre dykes can also be detected using a combination of eTh and LiDAR and elvans using LiDAR and eK.

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INTRODUCTION

Geological mapping in Devon and Cornwall and subsequent interpretation is often difficult due to lack of outcrop. Airborne geophysical and regional geochemical methods can aid mapping by sampling areas that are difficult of access or poorly exposed. Airborne radiometric and magnetic surveys were first flown in Devon and Cornwall in 1956 and 1957-9, respectively. Regional geochemical surveys were also conducted in the 1960s, notably 1969 (Webb *et al*., 1978). Many of these findings were incorporated into mapping of the 1970s onwards. However advances in geophysical data capture and positioning accuracy have led to a series of higher resolution public domain surveys in the UK: in the English Midlands, Isle of Wight and Northern Ireland, the latter combined with regional geochemistry and known as the Tellus project. The TellusSW survey was funded by NERC and covered Devon and Cornwall during 2013-4 on similar lines to that in Northern Ireland (TellusSW, 2015).

This contribution assesses the application of the TellusSW survey data to mapping the intrusive phases associated with the post-Variscan granite magmatism: the granites themselves, the associated quartz-porphyry (elvan) dykes as well as the temporally associated lamprophyre dykes. The emphasis is on the techniques used, particularly for the radiometric data.

TellusSW surveys

The TellusSW surveys consist of a number of geophysical and geochemical surveys (TellusSW, 2015). The data available to date (late 2015), and discussed to varying degrees in this contribution, are airborne magnetic and radiometric surveys, LiDAR as well as geochemistry.

The detailed parameters of the airborne radiometric and magnetic survey are discussed in Beamish and White (2014). These data were collected on 200-m flight lines with tie lines at 2000-m. Flying height was variable, typically 80 m over rural areas and 250 m over urban. Radiometric data are available online and were downloaded as total count (cps), eK % (^{40}K measured), eU ppm (^{214}Bi) and eTh (^{208}Tl) at 60-m intervals along lines from the TellusSW website (2015). As raw individual element channels contain 0 (zero) values which render ratioing between channels impossible, these zero values were replaced by 0.01 before gridding as 40-m cells using a square bi-cubic spline in ArcGIS 10.1, after masking off lines flown over the sea. Ratioing minimises the impact of variance due to correction of changes in flying height and rock exposure which are evident in individual channel and total count maps (Dentith and Mudge, 2014). These grids were combined into single images were used for interpretation, as were original radiometric data points.

LIDAR: LiDAR data were acquired by BAS in July-August 2013 with a 1-m ground resolution and height accuracy of <0.25 m. Data are available as DTM (Digital Terrain Models) and Digital Surface Models which represent the ground surface (with vegetation and objects above it removed) and the ground surface together with all objects above it, respectively (Ferraccioli *et al*., 2014). These data were downloaded and hill shaded images generated in ArcGIS 10.2. combined into single images were used for interpretation, as were original radiometric data points.

Geochemistry: Stream sediment and soil geochemistry were obtained using samples collected and analysed using standard GBase protocols of BGS (Johnson, 2005). Samples were analysed using X-ray fluorescence on pressed pellets. Soil data were used as point locations but stream sediment data were plotted as drainage catchments derived from point data kindly provided by the British Geological Survey (BGS). These catchment plots are much more indicative of the overburden sources of the sediments than plotting as points or contouring as used in the TellusSW website (Moon, 1999). Catchments were generated using Bluesky 5-m resolution DTMs (Bluesky, 2014) using the Hydrology functions of ArcGIS 10.2 and manually checked for consistency before linking to the TellusSW attribute geochemical data.

Digital geology

Geology for interpretation was based on DiGMapGB-50 of the BGS (Digimap, 2015). However this digital coverage was supplemented by georeferenced scans of older versions of published maps, as the current digital coverage omits some dykes and mineral veins shown on the earlier BGS maps, and known to occur from field checking by the author. In addition DiGMapGB-50 has inconsistencies at the boundaries of BGS 1:50,000 map sheets, notably of granitic units, which were compensated by using other published maps.

LAMPROPHYRE MAPPING

Lamprophyres are present as volcanic rocks near the base of the Permian red beds in the Exeter-Holsworthy area and as dykes intruding Devonian-Carboniferous rocks further west. Their exact relationship with granites and elvan dykes is in doubt as there are no exposed contacts, although recent dating shows both volcanic rocks and dykes are contemporaneous with granite intrusion (Dupuis *et al.*, 2015). In addition, the dykes appear to form a shadow zone around the granites (Floyd *et al.*, 1993). Leat *et al.* (1987) have suggested the lamprophyric magma is derived from depths of >16 km and could have provided K, U and Th input for the granites. The distribution of lamprophyres is thus of considerable interest as it could indicate major structural features that allow movement of fluids from depth as has been suggested in similar age rocks of the Erzgebirge (Seifert, 2008).

The conventional mapping of lamprophyres dykes is difficult as they are thin, typically a few metres thick, weather poorly and most known outcrops are on the coast or in estuaries (Smith, 1929). However, the strong enrichment of some lamprophyres in Th, U and K (Leat *et al.*, 1987) suggest that they should be detectable by airborne radiometrics, if their outcrop or subcrop is large enough. This was confirmed in the 1957-9 survey when anomalies were detected at Trelissick over dykes (Bowie *et al.*, 1958) and the Exeter volcanic rocks (Kimbell *et al.*, 2003).

TellusSW provides more comprehensive data for potentially discriminating lamprophyres than earlier surveys as eK, eU and eTh channels are available in addition to total count. Empirical evidence of this can be seen in a composite plot of the whole survey (Figure 1) in which U is plotted in blue, Th in green and K in red and total count indicated by lightness. The Permian Exeter volcanic rocks (Figure 1) show a variable response with distinct Th rich signal (light green in Figure 1) from known

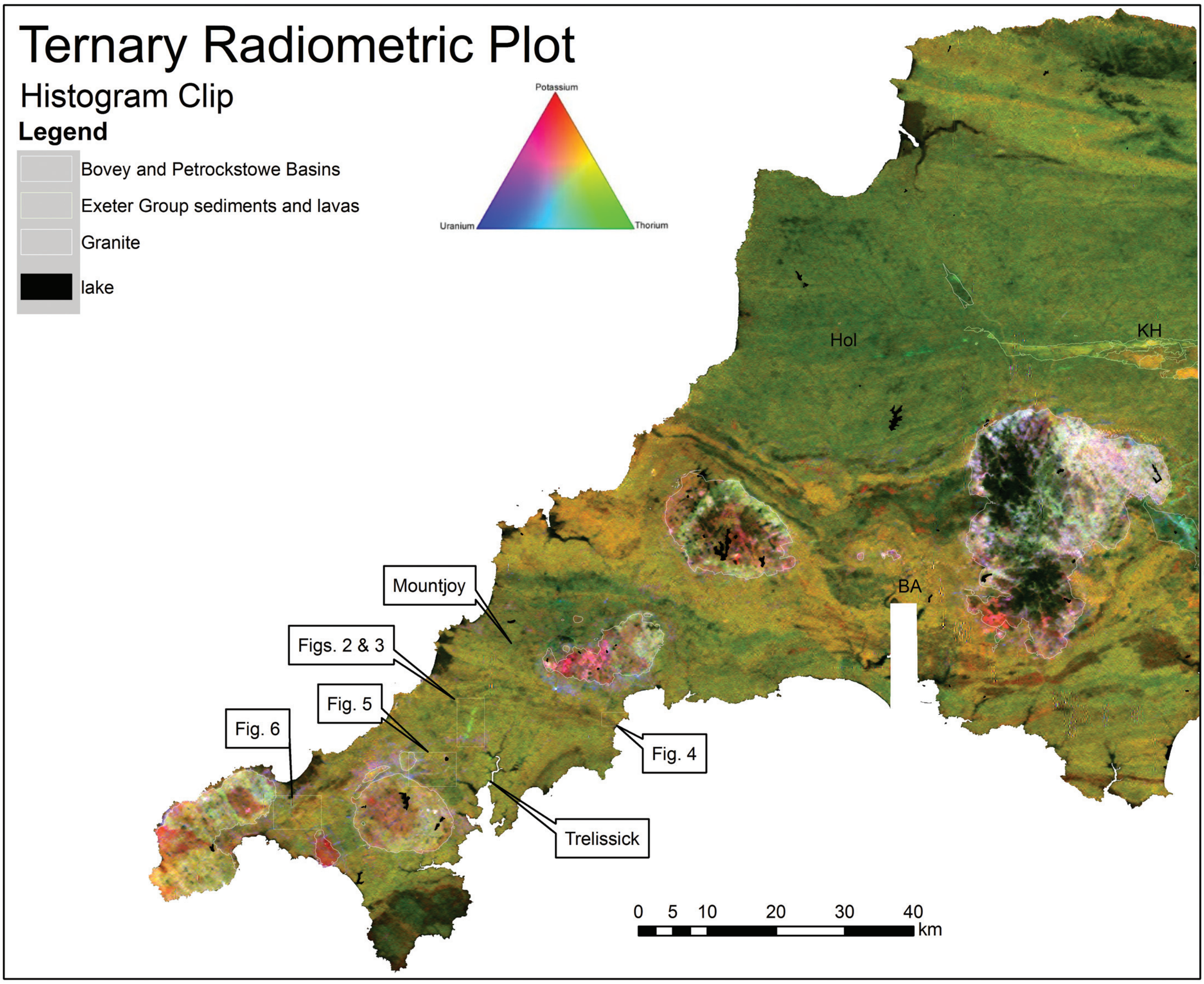

Figure 1. *Composite Ternary plot of Airborne TellusSW Radiometrics. Uranium-blue; thorium-green; potassium-red. Light areas high total counts, dark low total count. Black areas are lakes. Geological outlines of key units simplified from DiGMapGB-50 (Digimap, 2015). BA = Bere Alston, Ho = Holsworthy, KH = Knowle Hill.*

lamprophyres west of the Sticklepath Fault and a combined K and Th signature (light yellow-brown) from the lamprophyric lavas at Knowle within the Bow Breccia (Edmonds *et al* 1968; Edwards and Scrivener, 1999; Digimap, 2015). This difference reflects the alteration of feldspar and lack of K (~0.1%, Edmonds *et al.*, 1968) in the Holsworthy area relative to 5.1% K_2O (~4.2% K) in unaltered volcanic rocks at Knowle Hill. This light green signature can also be seen in Cornwall in Figure 1, particularly in the Fal estuary and notably north of Truro in the Shortlanesend area.

Shortlanesend Dyke

This dyke, which has a strike length of at least 4.6 km, has been studied in detail by Cooper (1976), who had followed up the 1957-9 airborne radiometric survey. His work included a total count ground radiometric survey which gave a contrast 80-100 μr/h relative to background in surrounding metasediments of 10μr/h (Figure 2). Cooper's mapping showed the intrusive to be sill like with a dip of ~40° SE and thickness of at least 3 m. Chemical analyses by Cooper indicate contents of 120-150 ppm Th and 27-31 ppm U; K was not determined.

The subcrop of the main part of the dyke between Boscolla Farm and east of Shortlanesend village is clearly detected in the hill shaded DTM derived from the LiDAR data as it has been pitted as a source of phosphate fertilizer (Figures 2, 3). There is a very strong spatial correlation between TellusSW total count radiometrics and Cooper's ground radiometric anomaly (Figure 2), with TellusSW highs of 2600 cps against background of about 1400 cps. However, the southern end of the dyke is difficult to define in the total count data as it merges into an ill-defined anomaly derived from anthropogenic signal of Truro housing, after a break around Boscolla Farm. This signal can be deciphered to some degree as the main part of the dyke has a Th/K ratio of typically more than 9 and up to 12. In the airborne Tellus data the dyke extension is detectable to the south (in the area of Truro Golf course), although outside the area sampled by Cooper to the A390. The small outcrop of minette described by Cooper at Gloweth, immediately south of the A390, is not distinguished. To the north, the dyke is detectable by total count as far as the area west of Lanner Barton Farm and in Th/K ratio to the east of St Allen church where fragments have been reported from soil survey (Jones and Tombs, 1975). The age relationship of the lamprophyre dykes with elvan dykes is not clear. Collins and Collins (1884) claimed that the elvan intersected the lamprophyre at Boscolla House (north of Boscolla Farm) but Hill and MacAlister (1906) and the author could find no evidence of this.

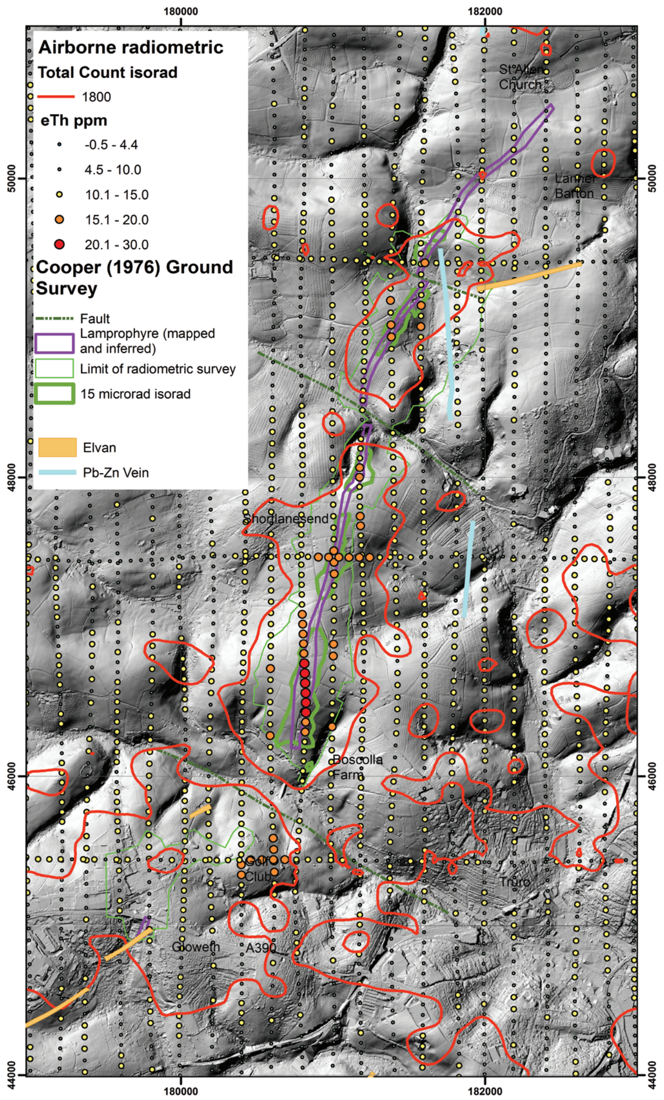

Figure 2. Airborne TellusSW radiometric eTh point data and 1800 cps total count isorad and ground radiometric plot, limit of ground survey, mapped and inferred fault and lamprophyre of Cooper (1976) overlaid on hill shaded DTM (Vertical Exaggeration x4), Shortlanesend area. Elvans from BGS published sheets. Note manure pits on subcrop of lamprophyre, north of Boscalla Farm.

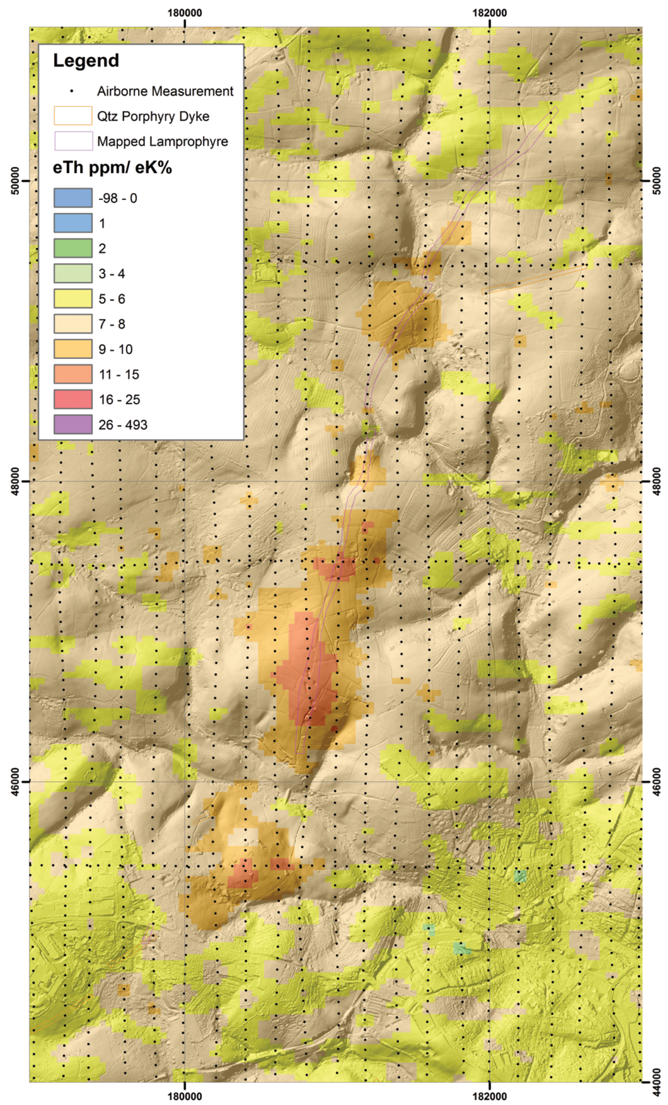

Figure 3. Overlay of gridded Th/K ratio from TellusSW radiometrics on DTM. Note correlation of high ratios with mapped dyke.

Other dykes in Cornwall

The most obvious dykes detected in Th/K ratios and composite plots are the linear continuation of the Shortlanesend dyke at Mountjoy (Figure 1). This dyke also has a linear trend although only two short outcrops appear on the BGS maps of the early 1900s, and were sampled by Cooper (1976), although omitted from the 2011 edition of the BGS Newquay Sheet, 346. The Trelissick anomaly located in the 1957-9 survey is seen on the composite map (Figure 1) as is an anomaly 3 km to the north at Old Kea. Other known occurrences along the Fal such at Pendennis Point (Hall, 1982) are not detected. The Newquay dykes, which are known to be lower in Th (Cooper 1976), are not obvious. In East Cornwall known lamprophyres in the St Ive- Bere Alston area only appear as total count anomalies. The well-known Lemail dyke (Leat *et al.*, 1987), near Wadebridge, which is Th-rich but exposed in a railway cutting, is also not detected.

ELVANS

Rhyolite porphyry (quartz-feldspar) dykes, commonly known by the mining term 'elvans', have been the subject of study as they cross cut the coarse grained granites, although not fine grained granites, and often have the same strike as major lode mineralisation (Goode and Taylor, 1980). Elvans are infrequently mineralised (with a few notable exceptions such as Wherry, Penzance, and Parbola, Gwinear) but can act as barriers to the passage of mineralising fluids and physically concentrate mineralisation as at Wheal Jane and Wheal Coates, St Agnes. There appear to be at least two generations of elvans (Collins, 1912) and in the St Austell area these appear to relate to biotite and topaz granite phases (unpublished data).

Mapping has been largely based on outcrops and dykes encountered underground during mining. Elvan dykes were detected during the 1957-9 radiometric survey (Bowie *et al.*, 1958) notably south of the Carnmenellis Granite and some should be detectable from their K and total count response (Table 1).

	Basalt lava	Potassic lava	Minette dyke	Elvan	Elvan average
K%	1.74-8.5	4.3-8.1	5.6-6.5	2.6-7.5	4.8
U ppm	1.9-3.3	2.8-14.2	10-13.4	3-18	13.4
Th ppm	3.7-6	15-67	43-51	3-26	12

Table 1. *U, Th and K from volcanics, lamprophyre dykes and elvans. Sources mainly from Leat* et al. *(1987) and elvans, unpublished data of author compiled by B.Thompson.*

LIDAR data

The surface weathering of the elvan dykes is variable depending on alteration. The less altered dykes often stand proud and are obvious on hill shaded LiDAR data. An example shown in Figure 4 is the Pentewan elvan dyke which is a relatively late dyke related to the St Austell topaz granite based on Nb/Zr ratios (unpublished data). It has been mapped in different positions in the 1908 and 2000 versions of the BGS 1:50,000 Sheet 353 Mevagissey. The LiDAR data allow the quarried areas to be easily detected, immediately inland from its coastal outcrop [SX (2)02600E, 47550N] and linked by ground disturbance or curvature, so that a more accurate estimate of its subcrop can be made. Mapping has been largely based on outcrops and dykes encountered underground during mining. Elvan dykes were detected during the 1957-9 radiometric survey (Bowie *et al.*, 1958) notably south of the Carnmenellis Granite and some should be detectable from their K and total count response (Table 1).

Gwennap area

This includes the largest dyke (up to 200 m width) in South-West England and was used as a test of their detection, although exposure is poor (Hill and Macalister, 1906; Leveridge *et al.*, 1990). The main part of the dyke is detectable in both total count and K channels (Figure 5) although not detectable east of [SW (1)76500E]. A possible extension is visible from [SW (1)77000E] north-east to the Carnon River. The main part of the dyke appears from radiometrics to be more accurately mapped by the 1906 linework rather than the interpretation of 1990 of BGS 1:50,000 Sheet 352.

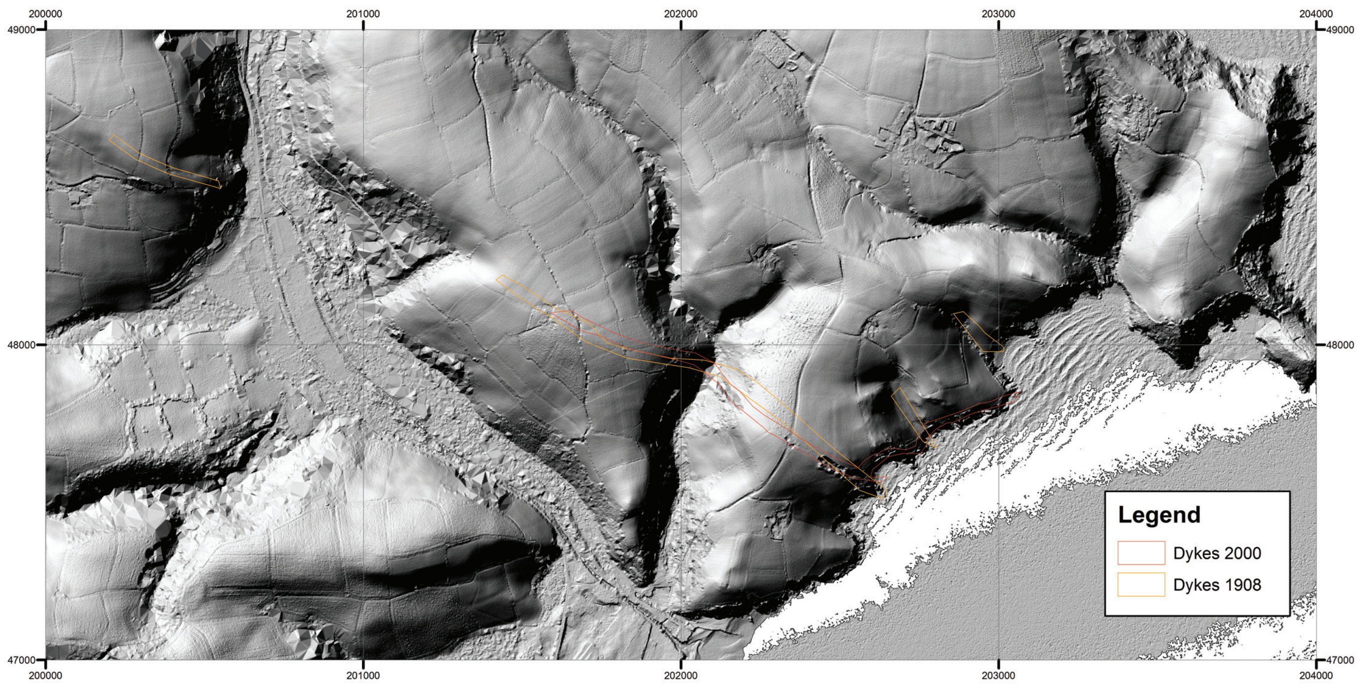

Figure 4. *Hill shaded DTM (Vertical Exaggeration x4) of the Pentewan area showing expression of elvans. The two outlines are BGS 1908 and 2000 outlines from the respective Mevagissey BGS 1:50,000 geological sheets. Main quarried area on the coast of the Pentewan Elvan is at [~SX (2)02500E, 47600N].*

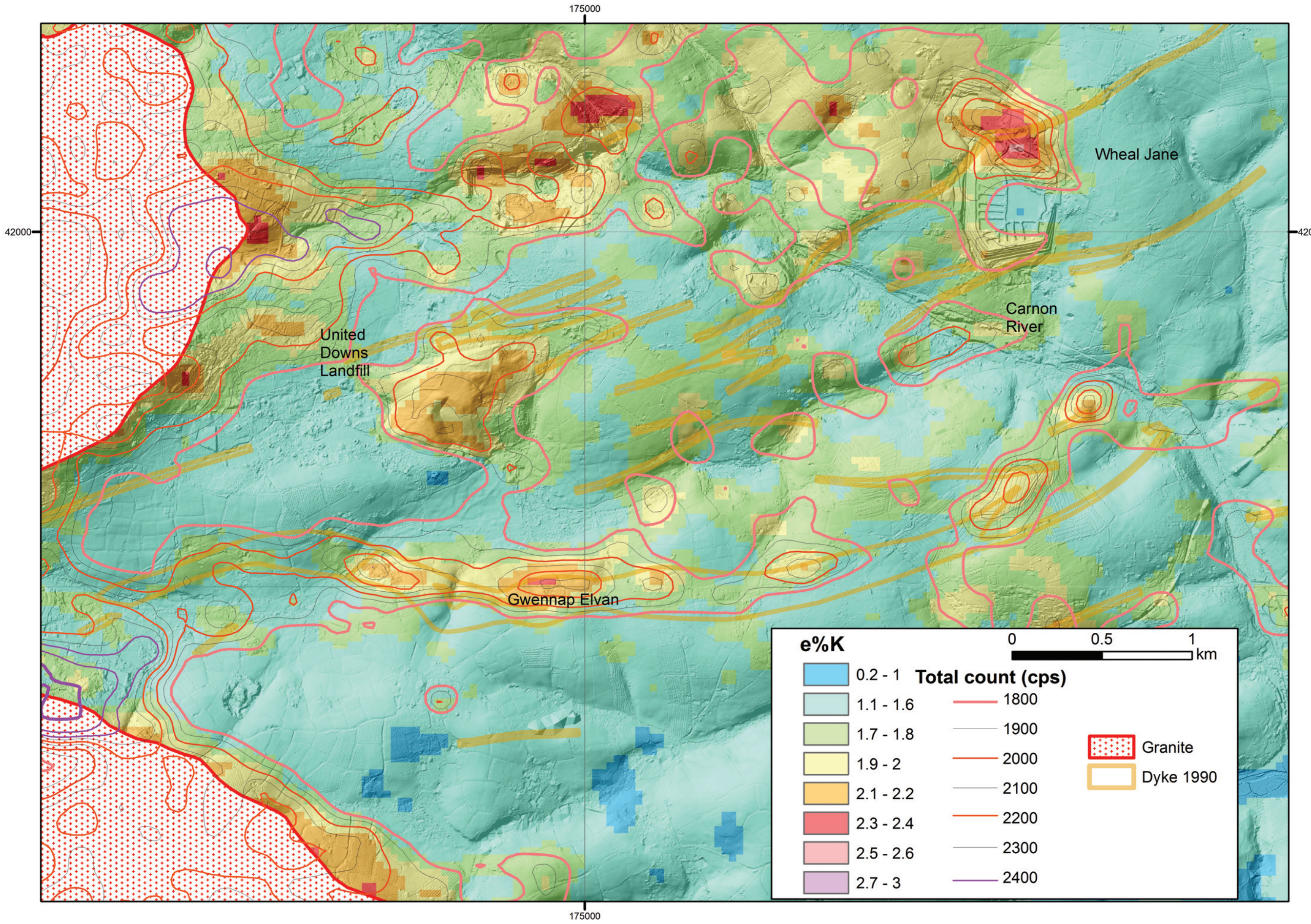

Figure 5. *Overlay of gridded eK% and total counts isorads on hill shaded DTM (Vertical Exaggeration x4), Gwennap area.*

St Erth area

The St Erth area provides a very good example of the detection of elvans in an area of low K background. Figure 6 shows a striking correlation of eK and total count with some of the mapped dykes. Field examination at Tregullan [~SX (1)55500E, 33600N] shows they have dark tourmaline-rich groundmass and geochemically appear to be derived from biotite granites.

GRANITES

There is an extensive literature on the granites, partly due to their economic importance. However, there has been little consensus on their overall classification. The most widely used classifications have been a textural one of Dangerfield and Hawkes (1981) based on phenocryst and groundmass type, and one of Exley and Stone (1982) which considers lithium mica and topaz-bearing granites as separate types, as well as having a distinct, paragenetically early, type of granitic inclusions. Neither of these classifications considers tourmaline granites separately (Bromley *et al.*, 1989). Many other studies have also been based on limited sampling of quarries and an assumption of homogeneity; there is a distinct lack of systematic geochemistry. This lack of geochemistry is particularly noticeable in the Bodmin Moor and Dartmoor Granites, which are partly peat covered.

Stone (2000) suggested that the older Carnmenellis, Bodmin Moor and Isles of Scilly (not flown in TellusSW) and younger Land's End, St Austell and Dartmoor plutons formed two distinct groups based partly on the age dates of Chen *et al.* (1993) and Chesley *et al.* (1993). Stone also regarded the Carnmenellis and Bodmin Moor plutons as having ring structures with the younger plutons being composite granites.

St Austell Granite

As a result of kaolin production, the main St Austell Granite is geologically the best documented of the granites and a good area for testing the use of mapping using TellusSW. The mapping of Manning *et al.* (1996) is the most widely used classification at present and has been used in this study to test whether airborne radiometrics could be used to classify the different granite types, although it was known that the area is extensively kaolinised (Figure 7). As the original surface geology has been modified by tipping of waste materials, these waste areas were removed from consideration before analysis.

Total count data show considerable variation probably mainly due to differences in exposure between the exposed rock in quarries and soil covered areas. However, the individual channel data do show some differences (Figure 8) with the fine tourmaline granites having high K% and the topaz granite low Th. More reliable discriminators are given by the channel ratios, which remove variance caused by height corrections and exposure effects, notably Th/K which discriminates the biotite granite from the others, particularly the topaz granite. In particular, a Th/K ratio of 4 appears to discriminate topaz granites and 4.75 to discriminate tourmaline granites from biotite granite. Other channel ratios do not appear to discriminate granite types and as discussed below, uranium is known to be mobile suggesting that U ratios reflect differential weathering and element mobility. Multivariate (discriminant) analysis was also undertaken in this study and was able to discriminate the biotite granite from the topaz and lithium mica granites but is unable to separate the tourmaline or fine tourmaline granites. As simple Th/K discriminators appeared effective they were then used to generate maps of Th/K for the other plutons as discussed below (Figures 9, 10).

Manning *et al.* (1996) showed that it is possible to

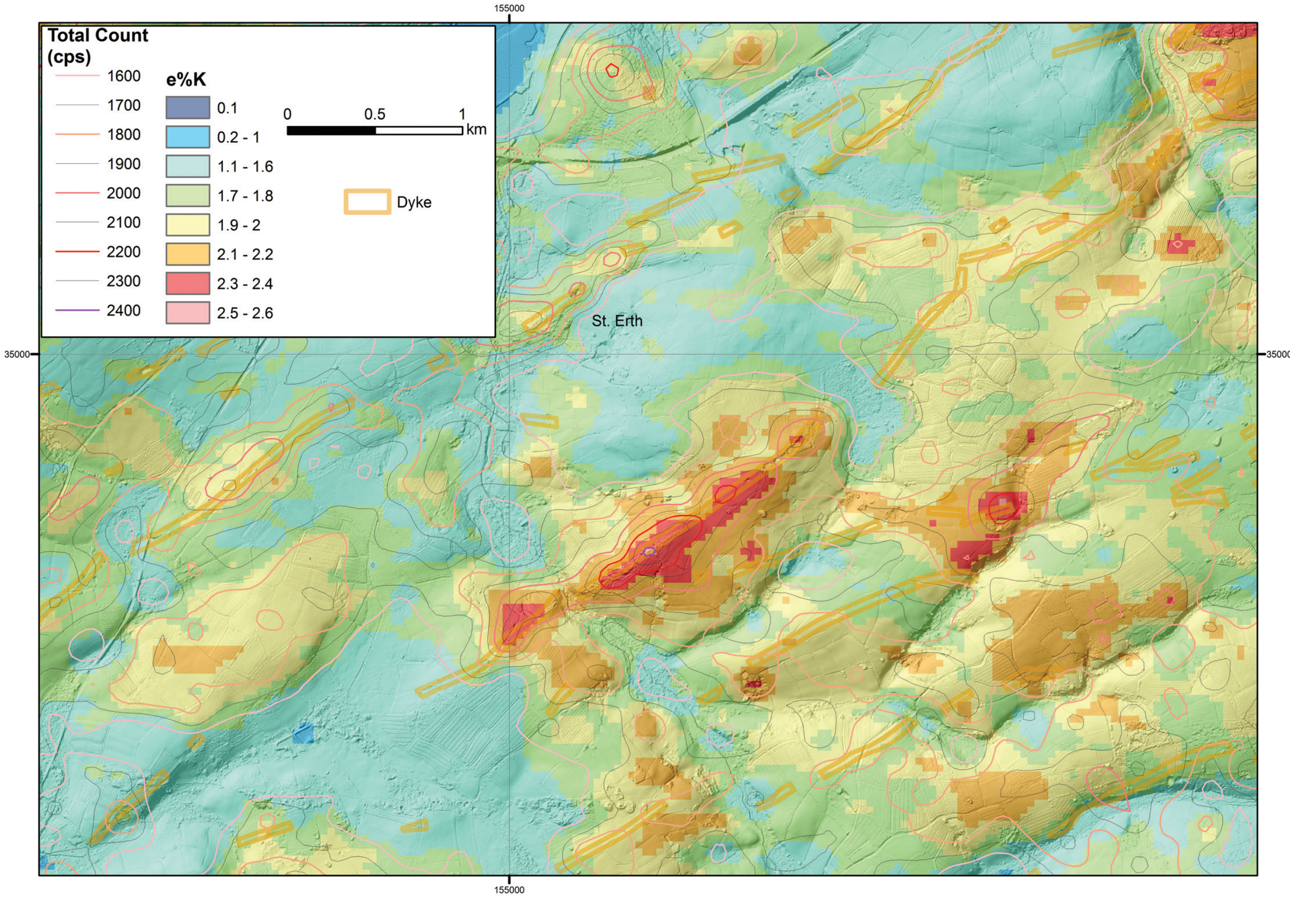

Figure 6. *Overlay of gridded eK% and total counts isorads on hill shaded DTM (Vertical Exaggeration x4), St Erth area.*

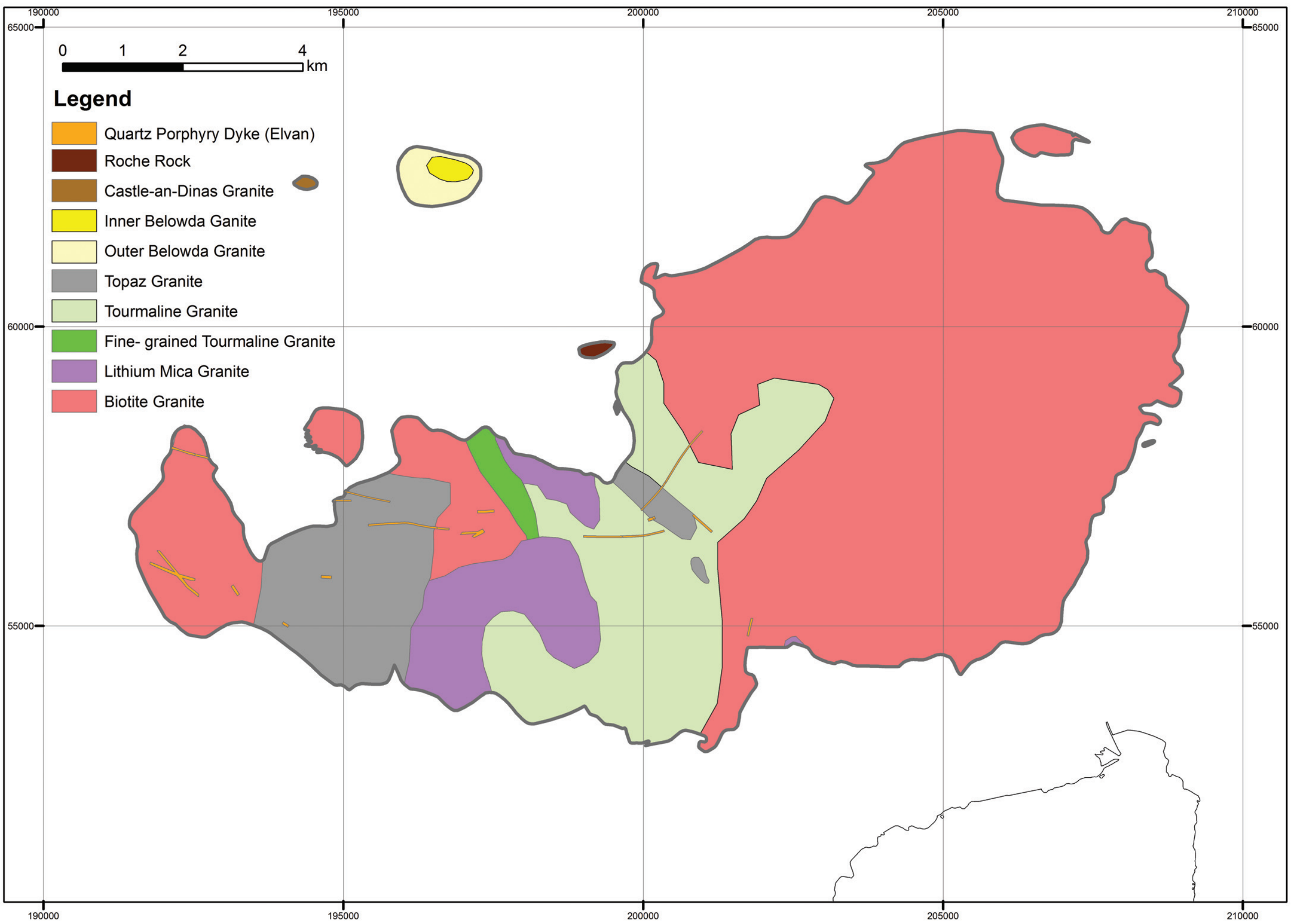

Figure 7. *Subdivision of St. Austell Granite used for testing radiometric data. Adapted from Manning* et al. *(1996).*

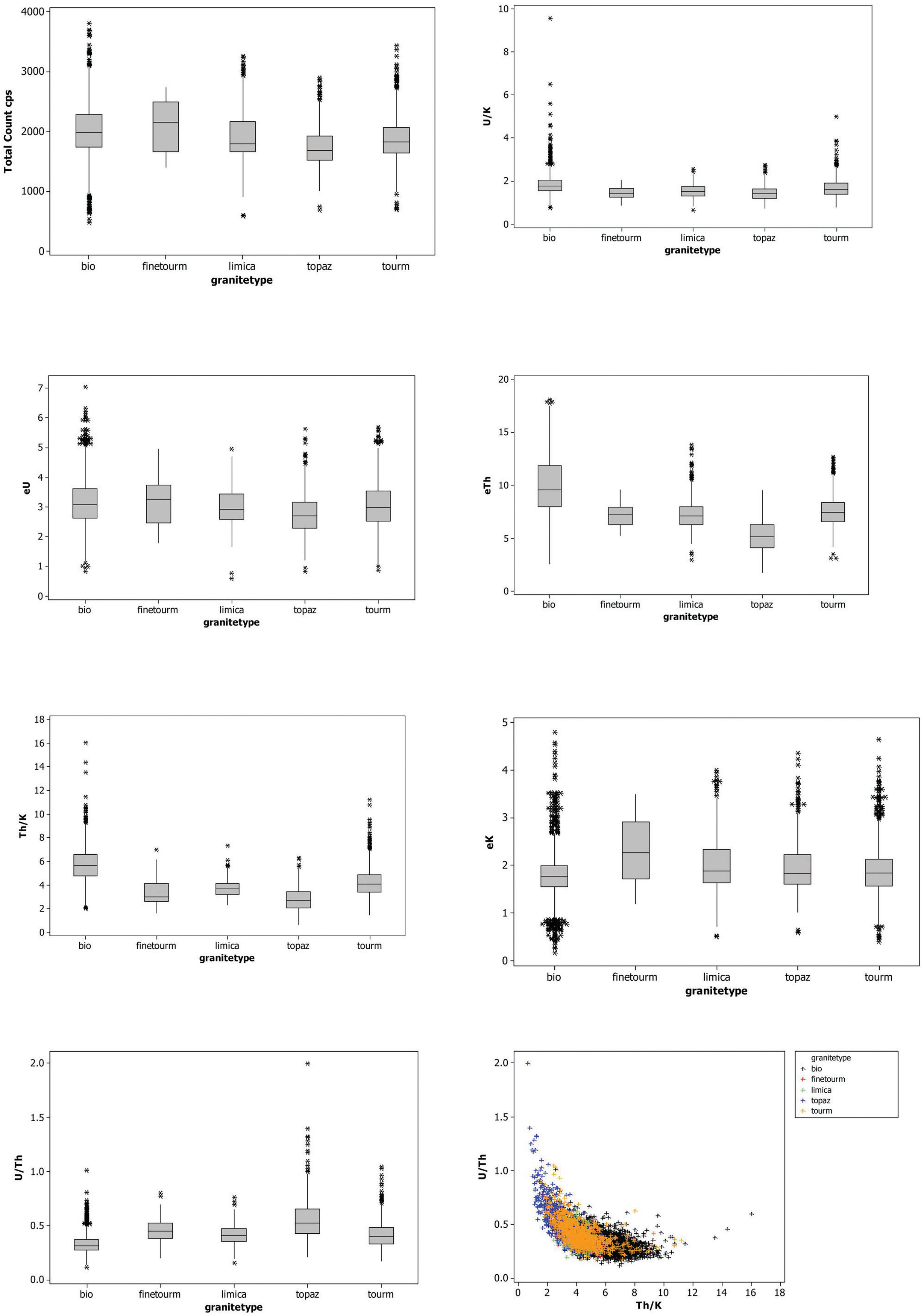

Figure 8. *Boxplots of radiometrics subdivided by units of Figure 7, bio = biotite granite, finetourm = fine-grained tourmaline granite, limica = lithium mica granite, topaz = topaz granit,; tourm = other tourmaline granites. Scatterplot shows the overlap of groups.*

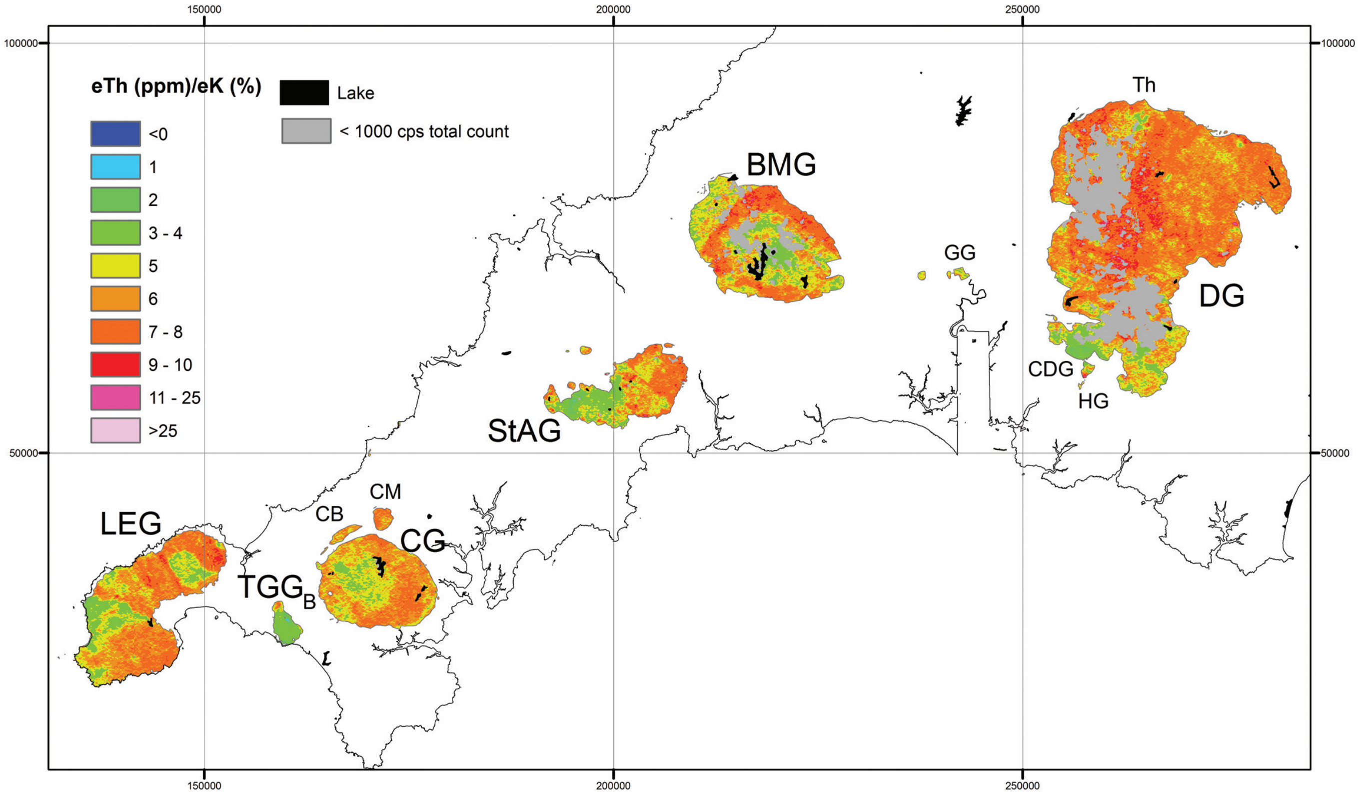

Figure 9. *Gridded eTh ppm /eK% for granites. Peat covered areas are indicated by total count <1000 cps. Larger granites: BMG = Bodmin Moor Granite, CG = Carnmenellis Granite, DG = Dartmoor granite, LEG= Land's End Granite, StAG = St Austell Granite, TGG = Tregonning-Goldolphin Granite; Smaller granites: B = Boswyn, CDG = Crownhill Down Granite, CB = Carn Brea, CM = Carn Marth, GG= Gunnislake Granite, HG= Hemerdon Granite, Th = Throwleigh.*

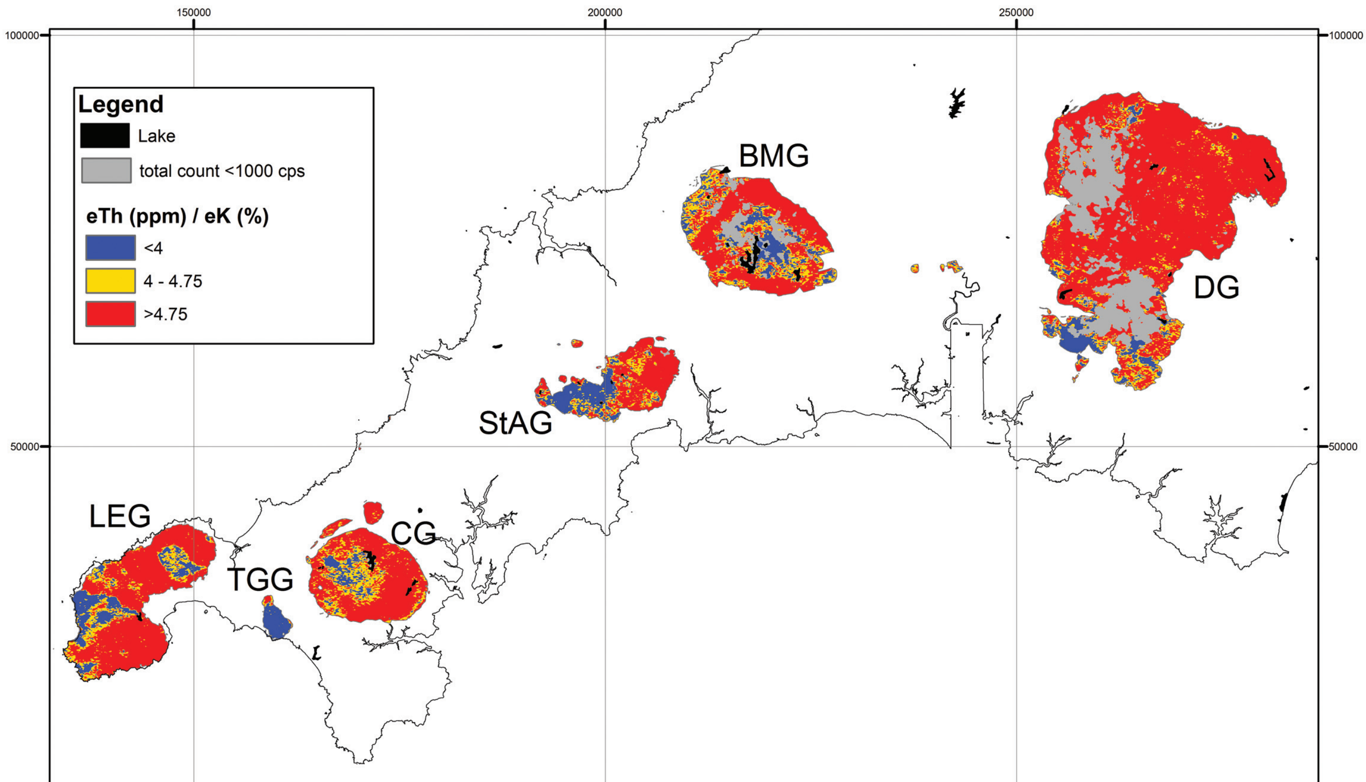

Figure 10. *Data of Figure 9 (Th/K) subdivided into three units in order to attempt to map topaz granites based on Figure 8. Blue <4, red >4.75, yellow 4-4.75. Larger granites: BMG = Bodmin Moor Granite, CG = Carnmenellis Granite, DG = Dartmoor granite, LEG = Land's End Granite, StAG = St Austell Granite, TGG = Tregonning-Goldolphin Granite.*

discriminate the different granite types on the basis of elemental ratios in rock geochemistry, particularly Nb/Zr, and tanatalum was also found to be a good indicator of topaz granites (Manning and Hill 1990). These elements were available in XRF determined TellusSW stream sediment data and were used in an attempt to aid delineation of topaz, lithium and tourmaline granites. Plots of Nb and Ta as well as Nb/Zr (Figure 11a) were overlain on airborne radiometrics to aid interpretation. One issue in stream sediments is that Nb and Zr are likely to behave differently in streams as mineralogical hosts have different densities so individual Nb and Ta plots may be more useful (Figure 11b, c). All these maps show that strong anomalies are developed over the topaz and lithium-tourmaline granites, in contrast to low concentrations over the eastern biotite granite. Highest concentrations appear to detect the topaz granite.

Land's End Granite

The composite nature of the Land's End Granite is clearly seen in Figure 12 based on LiDAR and Th/K ratio radiometrics. In particular, the fine grained Castle-an-Dinas (West) Granite is clearly delineated, as is a smaller area west of St Ives. However, the agreement of the radiometrics with other mapped outcrops of fine grained granites is less clear. Radiometrics detect a large area with low Th/K ratios in the area inland from St Just that is much larger than the area of fine grained granite mapped by Goode and Taylor (1988), and correlates with the poorly megacrystic variety of Dangerfield and Hawkes (1981). The Th/K ratios also map out an area of fine grained granite in the south-west of the pluton but do not correlate with two other areas of fine grained granite mapped by Goode and Taylor (1988).

The Tellus stream sediment data for Nb and Ta show enrichment (up to 61 ppm Ta) over both the Castle-an-Dinas (West) fine grained granite and the area with low Th/K east of St Just. This strongly suggests that these fine grained granites are lithium or topaz granites as described by Müller *et al*. (2006) on the coast.

Dartmoor Granite

This presents a challenge for radiometrics as much of the western part is peat covered and signals are blanketed or attenuated. This peat covered area can be removed by blanking off areas with less than 1000 cps in airborne radiometric total count, which is in agreement with the independent findings of Beamish (2015) on peat covered areas.

The Th/K plot shows good correlation with the classification of Dangerfield and Hawkes (1981). The eastern part of the granite has high Th/K and correlates with coarse megacrystic granite whereas the western part is lower in Th/K and is either fine grained or poorly megacrystic according to Dangerfield and Hawkes (1981) classification. Fine grained granites are concentrated in the southern part of the granite, and Th/K ratios are low over the south-west part, which has been mapped by Knox and Jackson (1990) as a lithium-topaz granite, and where the granites have been kaolinised along a NW-SE controlled fault. In detail, the Lee Moor kaolin area can be detected with very low Th/K in contrast to higher values over the southern part of the Crownhill Down Granite and the whole of the Hemerdon Granites. In the north of Dartmoor, low values appear to detect poorly megacrystic granite in the Throwleigh Common area, which has been largely unrecognised. Stream sediment Ta data also reflect this pattern with higher Ta over the poorly megacrystic granite mainly in the west of the Dartmoor Granite and small areas in the east in the Haytor area. Highest Ta concentrations occur in the Lee Moor area in areas draining the lithium granites extracted for kaolin.

Tregonning-Godolphin Granite

The variable nature of this granite is clearly visible on the airborne radiometrics although the Th/K ratios are low over most of the granite and approach values seen over the topaz granite at St Austell. Only the very northern part of the granite has high Th/K and correlates with the coarse grained granite of Dangerfield and Hawkes (1981) and is much smaller than indicated by Stone (1992). The limited Ta and Nb stream sediment data confirm the lithium-topaz nature of the southern part of the granite.

Bodmin Moor Granite

This granite is partly covered by peat and according to limited studies of Ghosh (1927) and Exley (1996) has only one intrusive phase of coarse and fine grained granite. This is very different to the Th/K map which shows a ring of high Th/K correlating with coarse grained granite and low Th/K in the centre of the ring and to the north. These low Th/K areas correlate with areas of known kaolinisation in the St Neot, Temple and Camelford areas. Stream sediment data show little evidence of Nb or Ta enrichment except in the far south-east draining the Caradon area.

Carnmenellis Granite

This granite is one of the geologically best mapped and most of the differing granite types are clearly seen in the Th/K ratio map (Figure 9). The central medium-grained granite is distinguished from the coarse grained granites although the south-west of the mapped coarse-grained granite shows similar Th/K ratios to the central medium-grained zone. The fine-grained Boswyn granite is much lower in Th/K than the granite at the periphery although there is no Nb or Ta anomaly in the stream sediment data. Both Carn Brea and Carn Marth Granites have similar signatures to the coarse grained biotite granites in the radiometric data although they have higher Nb/Zr ratios (Figure 11a). There is little evidence in the Tellus data of the F-rich disturbance of Charoy (1986) detected in a late aplite, which might indicate the occurrence of topaz granite. More detailed stream sediment sampling by the author (unpublished) has detected very spatially limited Ta anomalies (unsampled in the TellusSW geochemistry) associated with known minor Nb, Ta pegmatites (Moulding and Hooper, 2005) in the south-east of the granite.

Other smaller granites

These have very limited spatial expression in the radiometric data. An exception is the Gunnislake Granite which has a moderately low Th/K signature, especially on its northern side, and high Ta in soils suggesting that it may be a topaz granite. This correlates with the observations of Li enrichment (Ward, 1971) and of kaolinisation in its northern subcrop (Reid *et al*., 1911).

Discussion and further work

The classification of granite types by radiometric elemental channel ratios is evident in all plutons. Although these variations could be related to different intrusive phases they could also be due to alteration (kaolinisation and tourmalinisation) as well as weathering.

Tammemagi and Smith (1975) on the basis of 64 samples observed that the Castle-an-Dinas (West) fine-grained granite was much lower in Th and U than other granites but concluded that they were atypical and may have been rafts of unassimilated country rock rather than a separate intrusive phase. In addition, they thought that weathering and kaolinisation may have remobilised U and Th but not K. In discussion with Exley (1977) they admitted that the fine-grained granites might be intrusive. Very detailed investigations by BGS of uranium occurrences produced conflicting interpretations of

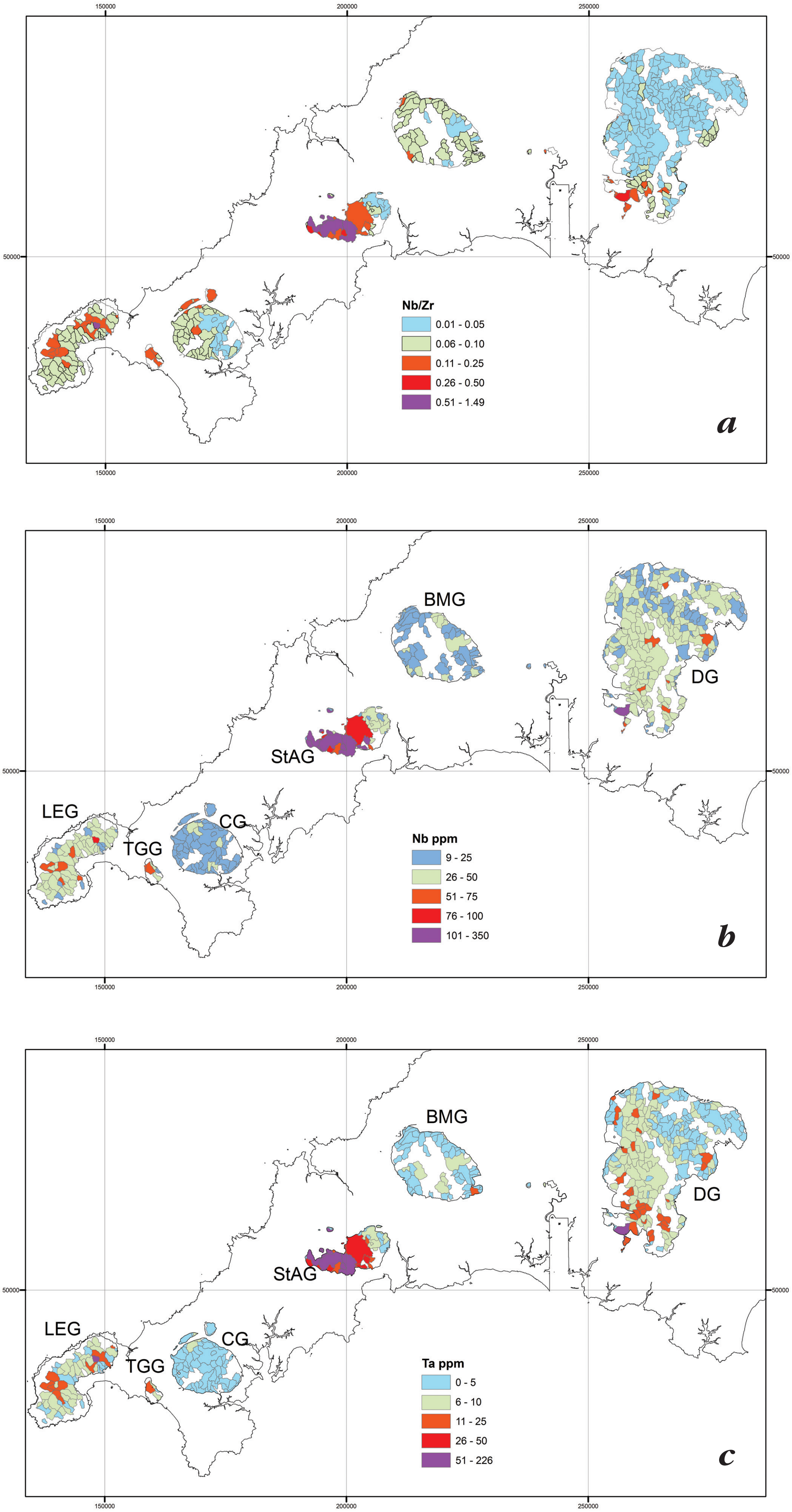

Figure 11. *TellusSW stream sediment plotted as catchment basins. Only catchments on granite are shown. (**a**) Nb/Zr. (**b**) Nb ppm. (**c**) Ta ppm. Larger granites: BMG = Bodmin Moor Granite, CG = Carnmenellis Granite, DG = Dartmoor granite, LEG = Land's End Granite, StAG = St Austell Granite, TGG = Tregonning-Goldolphin Granite.*

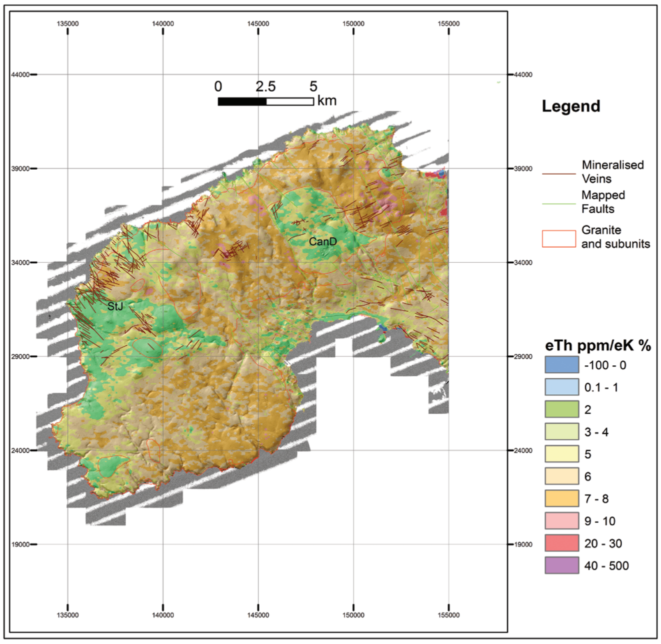

Figure 12. *Overlay of Th/K ratio grid on DTM and BGS linework for the Penwith peninsula. CanD = Castle an Dinas (West), StJ = St Just.*

U and Th mobility. Ball and Basham (1979) showed that uraninite is the dominant phase in granite, and susceptible to weathering, whereas Simpson *et al*. (1979) believed uranium is mainly contained in resistate phases. Jeffries (1984), in a detailed study of Carnmenellis Granite, agreed with Ball and Basham and showed most uranium is in uraninite and Th in monazite. Allman-Ward (1985), in a detailed study of the St Austell Granite, concurred and showed that most Th could be accounted for by monazite abundance. Thus it appears that Th is immobile, at least at low alteration temperatures, whereas uranium is mobile. Quantifying the mobility of Th during kaolinisation is less easy. However, Allman-Ward (1985) suggested on the basis of limited data that Th was immobile. His arguments support the use of Th/K ratios in mapping bedrock geology and the downplaying of any use of U/Th or U/K which would be affected by weathering.

The overview radiometric ratio plots (Figures 9, 10), as well as the uncorrected composite plot (Figure 1), therefore allow differentiation of different phases within plutons. In particular, fine-grained phases can be differentiated from coarse-grained parts. The topaz granites are very low in Th/K in the St Austell granite, and topaz granites of St Austell are clearly distinguishable on the airborne plot, as is Tregonning. However, in the St Austell Granite a similar, if higher, Th/K signature is present over tourmaline and lithium-mica granites. Elsewhere very low Th/K values (<2) occur over kaolinised areas in the Land's End (St Just), Bodmin Moor (St Neot) and Dartmoor Granites (Lee Moor). Previously, topaz granites have been reported from Lee Moor (Knox and Jackson, 1990) and St Just area (Manning and Hill, 1990) but not from Bodmin Moor.

The stream sediment data have much less spatial resolution but Nb/Zr, Nb and Ta maps provide an additional test of the occurrence of topaz granites which are indicated by highest concentrations (Figure 11). The St Austell topaz granite is detectable, although this may partly be a result of mining, as is the Lee Moor area of Dartmoor. Intermediate concentrations reflect lithium-mica and tourmaline granites. Unfortunately Li was not determined in the Tellus stream sediment and soil data but some idea of distribution can be obtained from the Wolfson Atlas (Webb *et al*., 1978). In general lithium correlates strongly with Ta distribution of the Tellus data.

Overall the Tellus data confirm the distinction proposed by Stone (2000) between the composite younger granites, which have Nb-Ta (Li) rich phases, and structurally simpler, older, granites of Carnmenellis and Bodmin Moor. However, Bodmin Moor appears much more complex than previously mapped. The composite nature of the Land's End and Dartmoor Granites, as well as Tregonning-Godolphin, is confirmed. In particular, the fine-grained granite distribution is much better defined in the Tellus data than on current mapping. The exact nature of the relation between the fine-grained and coarse-grained granites will require further work. Systematic rock sampling and analysis of fine-grained phases to determine Ta, Nb, Li would be very useful. Highest concentrations of Nb, Ta and lowest Th/K are associated with topaz granites but there is little evidence to test Manning and Hill's (1990) hypothesis that topaz granite has a separate source to other granites. The immobility of Th in the weathering environment explains the detection of thin high Th lamprophyres. However, it appears from comparison of the data of Cooper that Th <50 ppm in a 3-m wide dyke would be difficult to detect. The overall distribution of dykes in the Truro area was unexpected with the high Th units forming linear features which appear to cross cut stratigraphic units and structure. It appears that most lamprophyres have been detected by conventional outcrop mapping and no new occurrences are obvious although some weaker anomalies require ground checking as does the linear extension of the Mountjoy area.

Elvan detection depends on a combination of LiDAR and eK signals and is relatively easy in low background areas such as St Erth or where dykes are thick as at Gwennap. Dyke detection elsewhere depends on interpretation of DTMs and a number of dyke extensions have been noted. Confirmation will require detailed brash mapping and augering.

Conclusions

The TellusSW surveys provide extensive data to improve granite-related unit mapping, notably of granites themselves. The individual radiometric channels provide much improved location of the contact of granite internal units, particularly when artefacts such as variance due to correction of flying heights and exposure are removed. The immobility of Th means that Th/K ratio is best at mapping granite lithologies using radiometrics and can be used to infer unit origins when coupled with sediment chemistry, particularly Nb, Nb/Zr and Ta.

These surveys suggest that some plutons, such as Bodmin Moor Granite, are more complex than shown on current mapping. Land's End and Dartmoor Granites also appear candidates for detailed remapping and systematic geochemistry. The TellusSW surveys also provide considerable information on lamprophyre and elvan occurrence although the relatively thin nature of the dykes makes detection difficult.

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