Chapter 3 Lizard and Start Complexes (Group A sites)

Introduction

This chapter presents some of the classic sites from the Lizard Complex of south Cornwall, illustrating various aspects of its ophiolitic character in the light of relatively recent work. It is one of the few good examples of preserved Variscan ocean crust in the Rhenohercynian zone of northern Europe; together with the adjacent *mélange,* it illustrates the development and subsequent closure of the Devonian Gramscatho Basin. The metavolcanic greenschists of the Start Complex are also included here as they have chemical characteristics that are comparable with the ophiolite and basaltic clasts in the *mélange* and thus contribute additional evidence for the local preservation of Variscan ocean crust. The localities of all the sites are shown on (Figure 3.1).

List of sites

A1 Lizard Point [SW 695 116]–[SW 706 115]

A2 Kennack Sands [SW 734 165]

A3 Polbarrow–The Balk [SW 717 135]–[SW 715 128] A4 Kynance Cove [SW 684 133]

A5 Coverack Cove–Dolar Point [SW 784 187]–[SW 785 181]

A6 Porthoustock Point [SW 810 217]

A7 Porthallow Cove–Porthkerris Cove [SW 798 232]–[SW 806 226]

A8 Lankidden [SW 756 164]

A9 Mullion Island [SW 660 175]

A10 Elender Cove–Black Cove, Prawle Point [SX 769 353]–[SX 769 356]

Lithological and chemical variation

The following lithological units are now recognized within the Lizard Complex (Figure 3.2):

1. Partially serpentinized peridotite (Lizard Serpentinites);
2. Massive and weakly layered gabbros (Crousa and Trelan gabbros);
3. Variably metamorphosed basaltic dykes;
4. Heterogeneous acid/basic intrusive complex (Kennack Gneiss);
5. Traboe Cumulate Complex (Traboe Hornblende Schists);
6. Metabasalt amphibolites (Landewednack Hornblende Schists);
7. Pelitic, semipelitic and hornblendic metasediments (Old Lizard Head 'Series');
8. Intermediate orthogneiss (Man of War Gneiss).

The structure of the Lizard Complex has been a controversial issue for many years. The tremendous difference between the high-grade metamorphic rocks of the Lizard and the Devonian rocks to the north was recognized by the earliest workers (De la Beche, 1830). This gave rise to theories that it was either an upfaulted block of basement or part of a large thrust sheet, possibly associated with rocks of the Start Complex in south Devon (discussed in Flett, 1946). All workers had accepted that the peridotite was essentially a diapir-like intrusion until the work of Sanders (1955) who suggested that it was a thin sheet-like body. Green (1964a, 1964b, 1964c) carried out a very detailed study of the peridotite and concluded that it had formed as a diapiric intrusion of hot mantle, with a well-developed metamorphic aureole.

In the 1970s ophiolites became a topic of great interest and several workers interpreted the Lizard Complex in this light and, again, suggested that it was a thrust sheet. A borehole by IGS (now BGS) in the centre of the peridotite finally showed that it was only 360 m thick and proved its sheet-like form. Regional seismic studies have shown that the whole of the Lizard Complex is less than 1 km thick and that it is underlain by Devonian sediments. It is now well established that the Lizard Complex is relatively thin thrust sheet that overlies the south Cornish *melange* at the top of an allochthonous nappe pile.

Bromley (1979) suggested an internal structure for the complex consisting of three thrust sheets, that were from top to bottom:

1. Crousa Downs Unit – an essentially continuous ophiolite stratigraphy along the east coast of the Lizard from mantle peridotite through gabbros to a sheeted dyke complex; the sequence being tectonically truncated at this point.
2. Goonhilly Downs Unit – the main part of the complex; largely peridotite and overlain by the Traboe Hornblende Schists and other amphibolites and metasediments to the northeast.
3. Basal Unit – this occurs in a narrow strip around the south and south-east of the peridotite and includes the Landewednack Hornblende Schists, Old Lizard Head metasediments and the Kennack Gneisses intruded roughly along the contact between this and the overlying unit.

This interpretation has been broadly accepted by most recent workers. However, Leake and Styles (1984) and Leake *et al.* (1990) have questioned the separation of the Crousa Downs Unit from the Goonhilly Unit as they found some continuity of rock sequences across the supposed thrust contact in the Traboe–Trelan area. They have also suggested that the arm of the Goonhilly Downs Unit to the north of the Crousa Downs Unit is part of an imbricate sequence associated with the Lizard boundary. This interpretation is shown on the map (Figure 3.2).

The composition of the main lithological units is reviewed below.

Peridotite

Various schemes have been suggested for subdivision of the Lizard peridotites, the two best known being those of Flett and Hill (1912) and Green (1964a), although none of them is totally adequate to encompass the current level of knowledge. Flett and Hill's scheme had four main types:

1. Coarse lherzolitic type – this was the least-deformed type and was called 'Bastite serpentine' after the prominent orthopyroxene pseudomorphs. It occurred in the central and eastern parts of the body.
2. Tremolite serpentine – a highly deformed recrystallized type that was derived either by metamorphism of the bastite serpentine or an earlier intrusion. It occurred mostly in the western part.
3. Dunite serpentine – this had a significantly different bulk composition and was thought to have originated as dunite and occurred around the margins of the peridotite, particularly in the north around Traboe.
4. Chromite serpentine – was restricted to pods and veins and contained prominent chromite.

Green (1964a) carried out a major study of the peridotite and found similar groups and geographical distributions. From his detailed study of mineral assemblages and textures, he concluded that there was essentially a single intrusion that had undergone several stages of recrystallization and re-equilibration to produce the other types. The primary assemblage was closely analogous to the bastite serpentine' of Flett, and consisted of olivine, aluminous orthopyroxene, aluminous clinopyroxene and olive-green aluminous spinel. This had crystallized at 1250–1300°C and 15 kbar, a clear indication that it had originated in the mantle. Large areas had re-equilibrated to a recrystallized anhydrous assemblage, broadly analogous to the tremolite serpentine. This consisted of olivine, low-alumina pyroxenes, chromite and plagioclase and had equilibrated at around 1075°C and 7.5 kbar. The third type was the hydrous, recrystallized assemblage that occurred in narrow zones through the anhydrous types. It consisted of olivine, orthopyroxene, pargasite amphibole and chromite and had equilibrated at 900°C and 5 kbar. Green (1964a) suggested that the dunite serpentine (Flett and Hill, 1912), was a highly serpentinized version of this. The sequence of assemblages with decreasing temperature and pressure gave rise to the model of a diapir rising from the mantle, into the crust and undergoing re-equilibration. It has since been shown that the actual form of the peridotite is sheet-like not diapir-like, but there is no reason to doubt the petrological evidence and mineral assemblages on which the model was based. Styles and Kirby (1980) suggested that the peridotite was possibly the sliced-off top of a suboceanic mantle diapir.

Green (1964a) produced a map that showed the distribution of the mineral assemblages. This is the most detailed map of peridotite variation available to date, but is possibly somewhat misleading. Large areas are shown as consisting of the primary assemblage, but the olive-green spinels essential to the assemblage are seen only in a handful of thin sections, and these come mostly from a relatively small area in the centre of the peridotite, around Gwenter. The aluminous pyroxenes are much more widespread, but the distribution shown on the map is actually based on the recognition of pseudomorphs after spinel.

The volume of rock that has equilibrated during these phases of recrystallization is very small; it is possible to see all three assemblages in one thin section. Only when deformation has been intense and has accelerated reaction have larger volumes re-equilibrated. These features are also partly obscured by later serpentinization. The degree of serpentinization varies considerably from place to place and from one rock type to another. The lherzolitic and amphibole-rich peridotites tend to be less serpentinized and the freshest rocks are around 30% serpentinized. The most serpentinized tend to be the dunitic types and many have no olivine remaining, but still preserve good ghost dunite fabrics. Serpentinization is often more intense close to shear zones and faults. These features make reliable mineral assemblage maps difficult to produce.

Green (1964a) proposed that all the ultrabasic rocks originally had a similar lherzolitic composition; this contrasted with the opinion of Flett and Hill (1912) who suggested there were several, particularly a dunitic type. The dunitic type can readily be distinguished from the others by the lack of orthopyroxene and amphibole and occurs in two distinct modes:

1. large bodies of regional extent that form part of the cumulate complex and will be discussed in a following section (dunite serpentine), and
2. as veins cutting through the primary type peridotite (chromite serpentine).

The latter is probably formed by the passage of melts or fluids through the upper mantle. More recent work, (Styles and Kirby, 1980; Leake and Styles, 1984) has shown that there is a wide range of bulk compositions that encompasses lherzolitic, harzburgitic and dunitic types, which is indicated by the range of Al_2O_3 and CaO contents (Figure 3.3). There does not seem to be a distinct division between lherzolitic and harzburgitic compositions, more a continuum; for example, both types can be found associated on the beach at Coverack. There are not yet sufficient chemical data to establish if there are regional variations in composition. (Figure 3.2) shows just two types, a 'primary' type that is coarse grained and less deformed and a recrystallized type that is finer grained, strongly foliated and intensely recrystallized. This refers to features visible in hand specimen and thin section, and hopefully will be improved when sufficient data are available for meaningful subdivision.

The rare-earth-element geochemistry of Lizard peridotites has been studied by Frey (1969) and Davies (1984). Frey showed that the primary type (spinel lherzolite) had very depleted light REE, typical of residual, mantle-derived, alpine peridotites (Figure 3.4). This is rather unusual as they have major-element chemistry similar to undepleted mantle where a relatively flat REE pattern would be expected. The anhydrous and hydrous recrystallized types were progressively less depleted with close to chondritic abundances and slight light-REE depletion. Davies (1984) also found a plagioclase lherzolite type that had five times chondrite abundances and slight light-REE enrichment. He suggested a model where the spinel lherzolite resulted from repeated extractions of very small fractions of melts which depleted the light REE, but showed little effect on the major-element chemistry. The plagioclase lherzolite and pargasite peridotite were interpreted as being produced by infiltration of melts and associated mantle metasomatism.

Deformation has had a marked affect on most of the peridotites, which often have a porphyroclastic texture. Rothstein (1977), however, has reported evidence of an original cumulate crystal framework preserved between the later planar fabric.

Serpentinization is regarded as a prolonged, retrograde alteration phenomenon. It probably started at relatively high temperatures, 400–500°C, with the formation of coarse lizardite associated with obduction in Devonian times and probably continues at the present time with the formation of fine chrysotile in veins, etc. due to the presence of groundwater.

Gabbro and dykes

The Crousa gabbro has had a rather turbulent history, with evidence of several closely spaced intrusive phases causing back-veining, autobrecciation and pegmatite formation. In many places there is evidence of deformation at various times, with flaser zones and shears with amphibolite and greenschist-facies mineral assemblages developed. Igneous lamination and layering are developed in a few places (Kirby, 1978), although, in general, apparent layering is due to secondary alteration.

The gabbros consist mainly of plagioclase and augite, with minor ilmenite and magnetite (Bromley, 1979). Olivine is also present, but is confined to the southern part of the outcrop. The top of the intrusive body is to the north, as there is evidence of progressive fractionation in that direction, as well as decreasing Mg/Mg + Fe in rocks and minerals and increasing incompatible elements such as titanium and phosphorus (Kirby, 1979a). There are also fractionated rocks such as hornblende diorites in the north. Leake *et al.* (1990) have described a second type of gabbro from the Trelan area which is a more fractionated type with iron-rich clinopyroxenes, a more sodic plagioclase and often considerable enrichment in Ti and Fe. Overall, the Crousa gabbros have low incompatible-element contents and light REE depletion which indicate derivation from a depleted mantle source and are consistent with an oceanic origin. In this respect they differ from the coarse-grained dolerites and gabbros in the rest of south Cornwall (Floyd, 1984).

In the north, between Godrevy Cove and Porthoustock, the gabbro is cut by numerous basaltic dykes that can occupy between 50 and 80% of outcrop; these are thought to represent the root zone of a sheeted dyke complex (Bromley, 1979). Similar, but much less numerous, dykes also occur in the main gabbro and peridotite further south (lower down in the ophiolite pseudostratigraphy) and some are part of the same sequence. The dykes were intruded throughout the cooling and solidification of the gabbro, as contact relationships show gradations from early, disrupted dykes without chilled margins to cross-cutting vertical dykes. Mineralogically, the dykes are aphyric and sparsely olivine- and plagioclase-phyric tholeiites as well as their amphibole-bearing metamorphosed equivalents (Kirby, 1984). They show variable incompatible element ratios and depleted to mildly light REE-enriched patterns (Davies, 1984; Kirby, 1984; Floyd, 1984). Three chemical groups (Figure 3.5) were identified by Kirby (1984), each with its own fractionation sequence involving mainly plagioclase, together with lesser olivine and clinopyroxene. Overall, dyke Groups 1 and 2 (with La/Nb <1, Zr/Nb c. 30 and depleted light REE patterns) are chemically similar to oceanic basalts (Kirby, 1984), whereas Group 3 (considered to represent the earliest dyke phase) is more enriched than either group 1 or 2 and was probably derived from a 'recently' light REE-enriched or metasomatized source, similar to that of the recrystallized peridotites (Davies, 1984).

Kennack Gneiss

The Kennack Gneiss is a series of interbanded acid and basic gneissose rocks that occur along the south-east coast of the Lizard, roughly at the base of the Goonhilly Downs structural unit. They have been controversial since the time of Bonney (1877b) and interpretations of their origin fall into two main groups:

1. migmatization of Old Lizard Head metasediments and Hornblende Schist by a hot overriding sheet of peridotite (Sanders, 1955; Kirby, 1979b; Vearncombe, 1980; Malpas and Langdon, 1987);
2. composite intrusions of mafic and felsic magmas, probably along shear zones, followed by deformation (Flett and Hill, 1912; Green, 1964c; Bromley, 1979; Sandeman, 1988).

A consensus of opinion has yet to emerge, but the most recent and most detailed study by Sandeman (1988) favoured the composite intrusive model.

Hornblende Schists

The Hornblende Schists were divided by Flett and Hill (1912), into two types, the Landewednack type and the Traboe type. The Landewednack type is generally associated with sediments, has epidotic layers and masses, a well-developed, regular, flat-lying foliation and a rather homogeneous appearance. The Traboe type is usually associated with the 'serpentine' (peridotite), has a steep foliation, is often coarser grained and has a very variable mineralogical character. Flett and Hill (1912) thought that the Landewednack type was derived from basalt lavas and sills, and the Traboe type from gabbros that predated the intrusion of the peridotite.

The distribution of the two types of hornblende schist has been more or less accepted by all subsequent workers. The Landewednack type occurs largely around the southern tip of the Lizard and the Traboe type around Traboe, Mullion and Predannack. Green (1964b) suggested a radically different hypothesis for their origin. He proposed that all the hornblende schists had originated as basaltic lavas which had undergone amphibolite-facies regional metamorphism. Those close to the peridotite (Traboe type) had suffered an additional contact metamorphism during intrusion of the hot peridotite to form brown-hornblende granulites, whereas those immediately adjacent to the peridotite developed two-pyroxene granulites. He recognized several mineral assemblages formed at increasing temperatures and, on the basis of a few bulk rock analyses, suggested that the two types had similar compositions.

This interpretation has been rejected by most subsequent workers. On the basis of extensive field observations, Bromley (1979), suggested that the Traboe type were metamorphosed gabbros and basic dykes and not formed by the effects of metamorphism due to intrusion of the peridotite. Kirby (1979b), in addition to his field observations, produced numerous chemical analyses, which showed that although there was some overlap in composition, the Traboe type had a much wider range and could not be derived from the Landewednack type. He also thought that they were metagabbros. Styles and Kirby (1980) suggested that there were two types of Traboe Hornblende Schist; most of it metagabbro, but a small proportion (very close to the basal thrust of the peridotite along the south-east coast near Cadgwith and at the base of the peridotite in the Predannack borehole) was derived from 'contact' metamorphism of Landewednack type. Leake and Styles (1984) described three boreholes from the Traboe area and confirmed previous work that the Traboe type were metagabbros and apart from the few exceptions mentioned previously, could not be derived from the Landewednack type. They also showed that a series of metapyroxenites and dunites were intimately associated with the metagabbros, together forming the Traboe cumulate complex' (Figure 3.6). This complex overlies the main peridotite slab and is similar to cumulates found at the mantle–crust transition zone in many other ophiolites. This is a very important member of the Lizard ophiolite stratigraphy, as previously it was thought that the cumulate zone at the base of the crustal sequence was missing; the only possible rocks of this type being the small development of troctolite and associated rocks seen at Coverack. The only good surface outcrop of this cumulate complex is at Porthkerris.

The chemical composition of the Landewednack Hornblende Schists is very similar to ocean-floor basalt (Floyd *et aL,* 1976; Kirby, 1979b) and this is good evidence to suggest that they are part of an ophiolite complex. The Traboe Complex has more primitive chemical compositions but, as they are plutonic rocks that have formed by crystal fractionation, they cannot be directly compared with the Landewednack type which are dominantly metabasaltic lavas.

Mélange **metabasalts**

The south Cornish *mélange* (Barnes and Andrews, 1981) includes Mullion Island and the Meneage and Roseland areas (Figure 3.2); characteristically it contains many exotic clasts and huge blocks of basaltic parentage within a Middle–Upper Devonian argillite matrix. The larger blocks (Mullion Island, Nare Head) are composed of pillow lavas and pillow breccias, whereas smaller clasts include 'greenstones', aphyric and plagioclase-phyric basalts, dolerites and rare gabbros, together with their variably metamorphosed equivalents, including epidote–plagioclase–hornblende amphibolites (Barnes, 1984). Virtually all the basic rocks have undergone some degree of low-grade metamorphism, generally in the pumpellyite facies (Barnes and Andrews, 1981; Floyd, 1983). The Mullion Island pillow lavas show relict quench textures and primary calcic augite in a secondary groundmass (Floyd and Rowbotham, 1979).

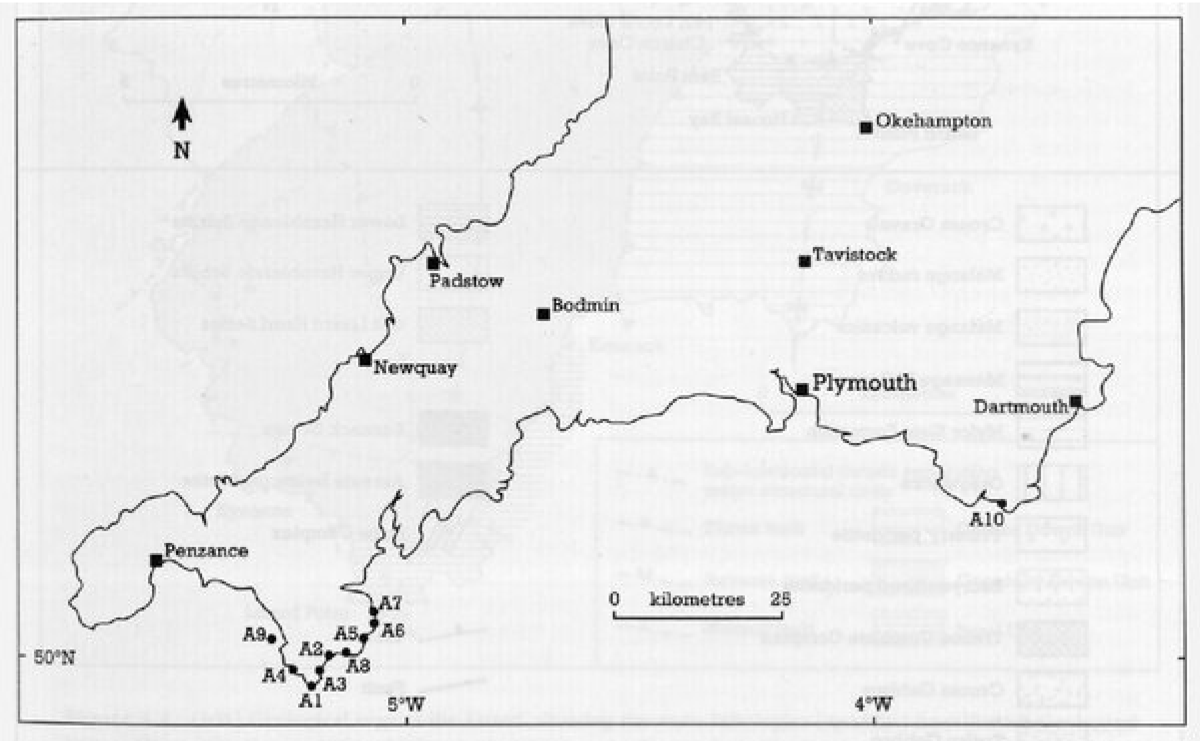
Floyd (1984) demonstrated that the south Cornish metabasalts (including those in the *mélange)* were mainly tholeiitic and exhibited distinct incompatible-element ratios (Ce/Y, Nb/Y, Y/Zr) when compared with the rest of the basic volcanics in south-west England. In general, all the metabasalts and amphibolites within the south Cornish *mélange* have a range of chemical compositions from normal type to variably enriched, transitional-type MORB (Floyd, 1982a, 1984; Barnes, 1984). They are dissimilar to the ophiolitic basic rocks of the normal-type MORB composition in displaying slightly enriched incompatible-element patterns (Figure 3.7). It is concluded that the volcanic debris within the *mélange* cannot be satisfactorily matched chemically with the ophiolitic dykes, in that the clasts do not represent the eroded volcanic carapace to the Lizard ophiolite. A stratigraphically *in situ* pillow lava sequence is found at the base of the Portscatho Formation (Tubbs Mill volcanics) in the allochthonous Gramscatho Group to the north of the *mélange* zone (Holder and Leveridge, 1986). These lavas have similar enriched chemical characteristics to the basic clasts and blocks within the *mélange,* and this suggests that the latter could have been derived from an ocean crust of similar composition, rather than Lizard-type ocean crust.

The Tubbs Mill pillow lavas and some of the *mélange* metabasalts in Roseland, however, show higher La/Nb (>1.5; (Figure 3.8)) and Th/Ta (>0.5) ratios than typical transitional-type MORB, together with chondrite-normalized negative Nb and Ta anomalies, which might reflect the influence of a subduction (back-arc?) environment. However, these minor chemical deviations could also have been generated by continental-crust contamination which, if the Gramscatho Basin was initially generated by the rifting of ensialic crust, might be expected for early segments of Devonian oceanic crust.

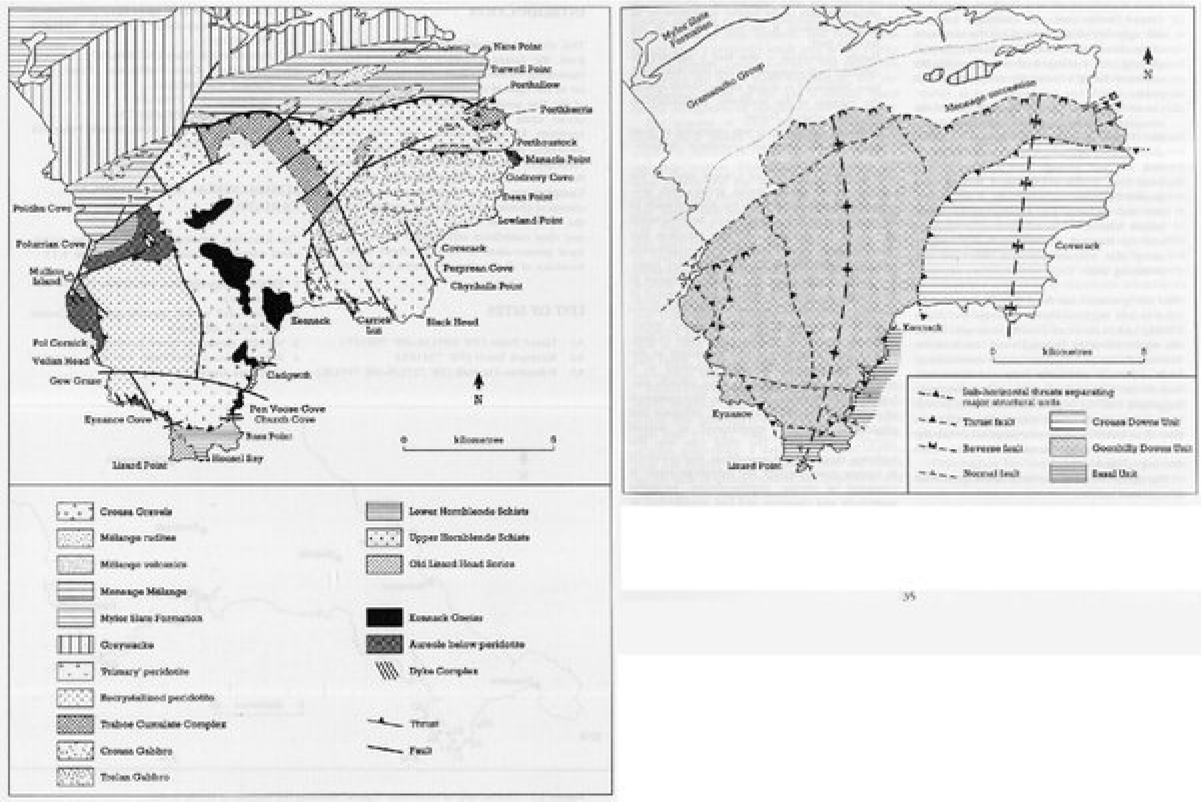
Start Complex greenschists

The greenschists occupy a unique position in southern Cornwall and have not been clearly identified with any other unit of basic composition. They are composed of fine-grained, variably foliated and laminated, quartz–albite–chlorite–epidote–amphibole schists, and they are generally considered to be a series of metavolcanic basic tuffs (Tilley, 1923) interbedded with pelitic and semipelitic metasediments. Little extensive chemical work has been done on the greenschists, although our unpublished data indicate that they were derived from a relatively uniform basaltic series with a tholeiitic character. The most interesting chemical feature is that these rocks are the closest to normal-type MORB in southwest England. In terms of the compositional variation exhibited by volcanic rocks in southwest England, therefore they have chemical characteristics that link them with the Lizard dykes and south Cornish *mélange* metabasalts. On this basis they could represent a volcanic segment of Variscan ocean crust docked against the Devonian parautochthon to the north.

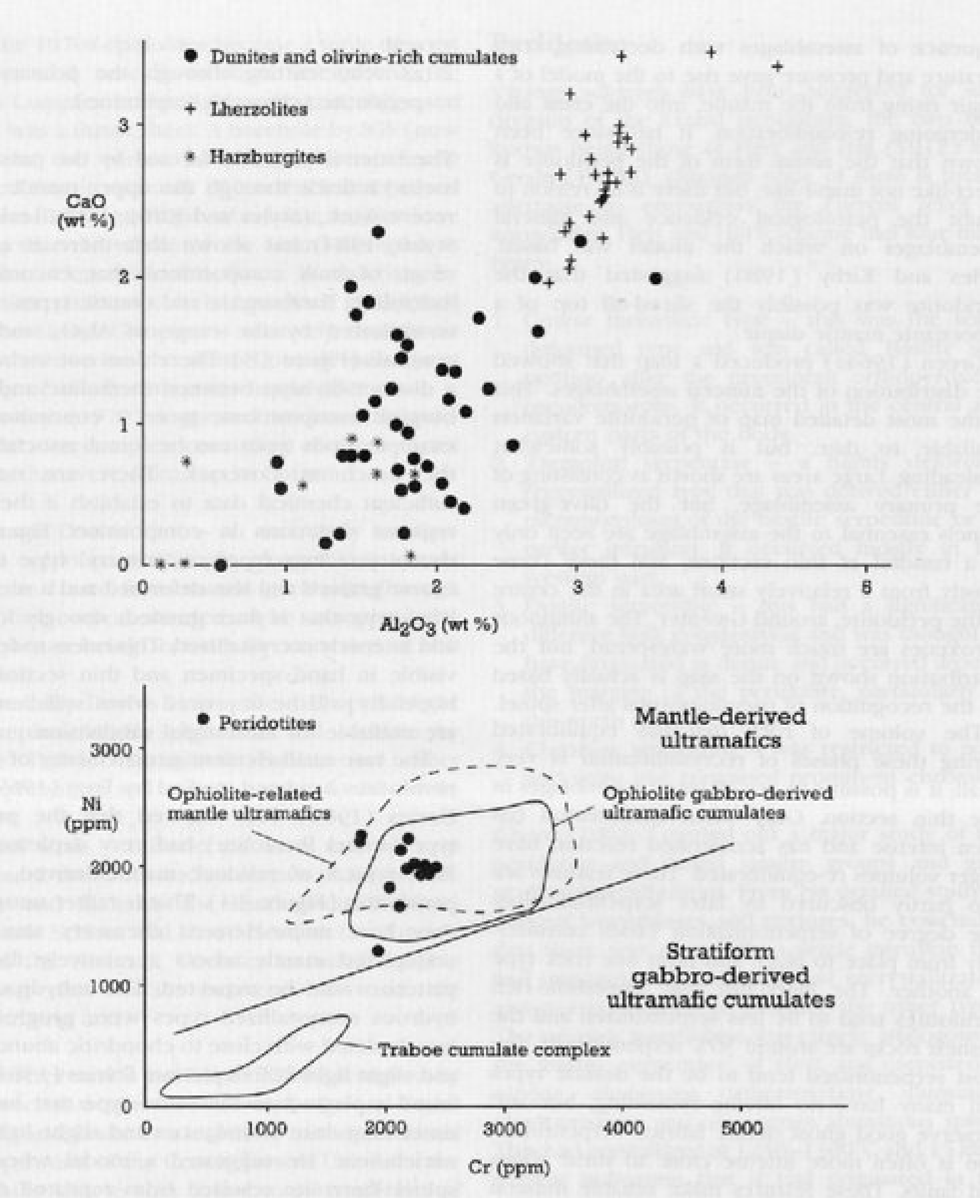
References



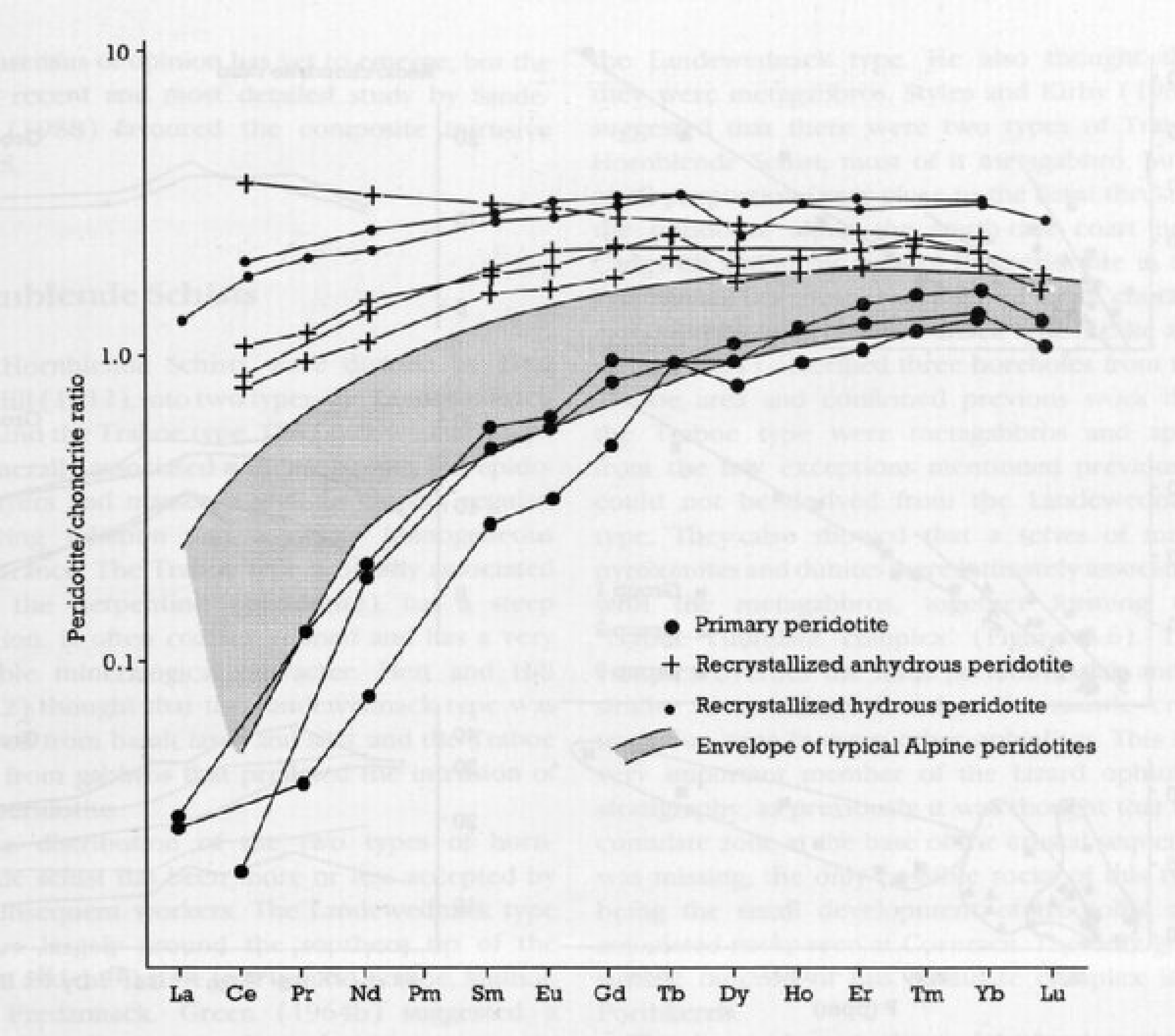
(Figure 3.1) Outline map of south-west England, showing the location of Group A sites.



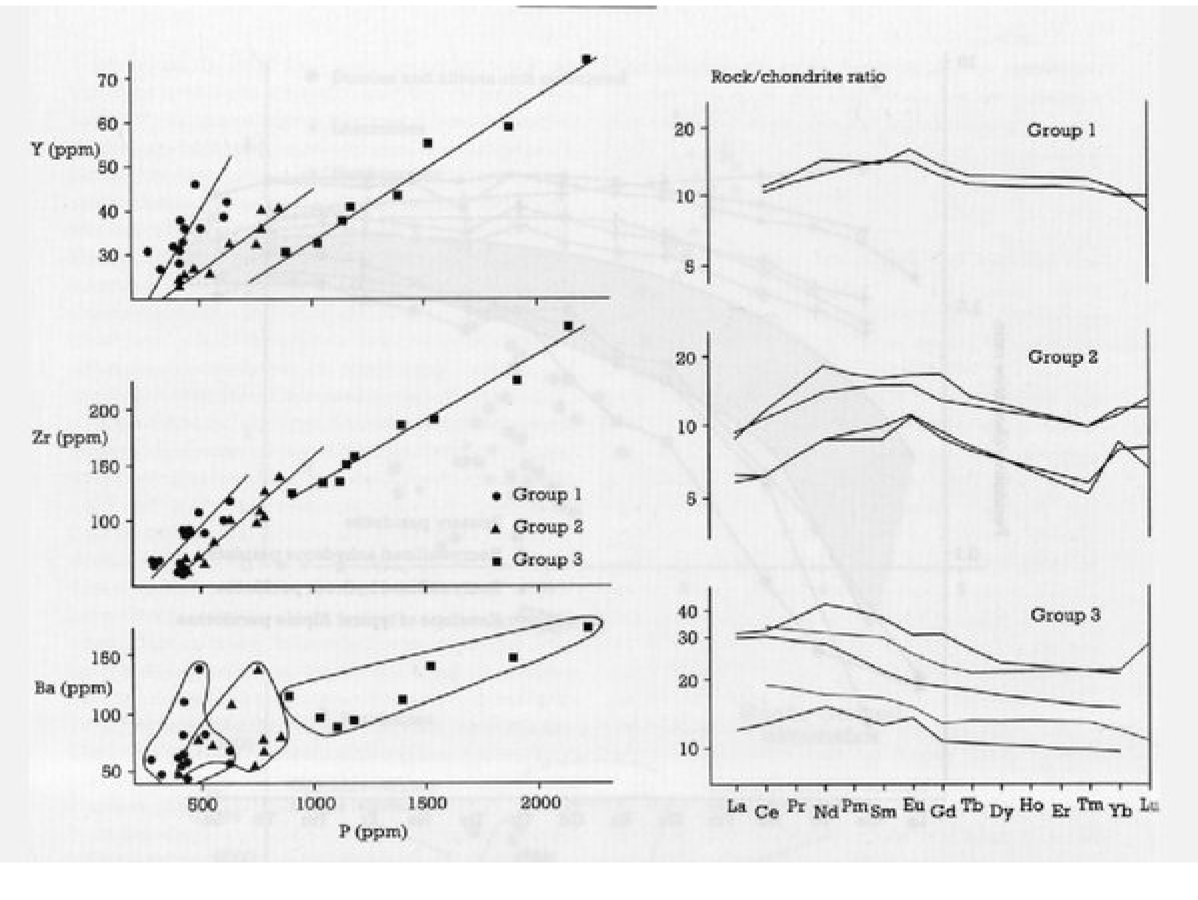
(Figure 3.2) (left) Geological map of the Lizard, showing the main lithologies (modified from British Geological Survey Sheet 359; Green, 1964a; Leake et al., 1990); and (above) their division into three tectonic units (after Bromley, 1979).



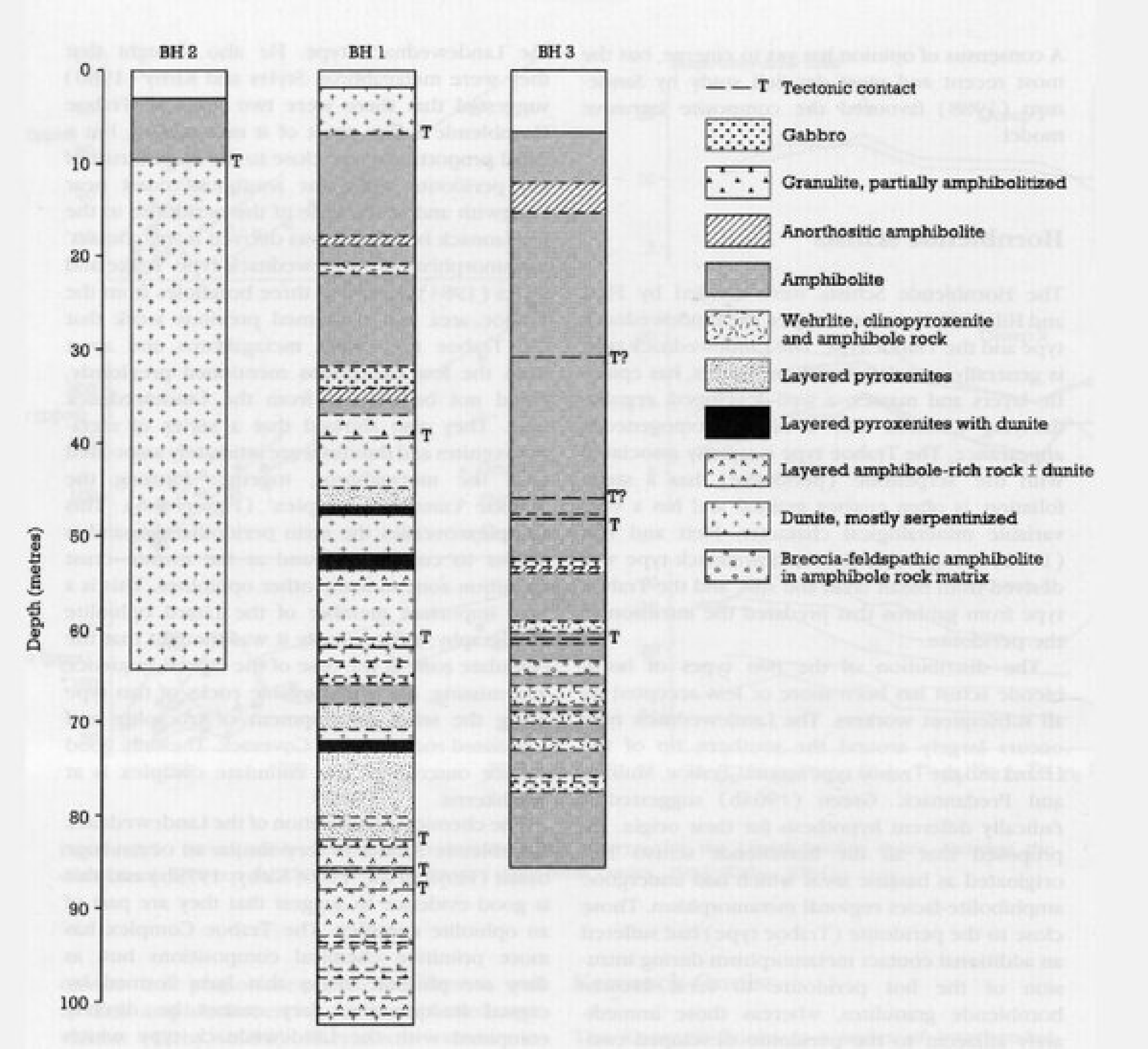
(Figure 3.3) Distribution of Al_20_4—CaO and Ni—Cr in Lizard peridotites, dunites and ultramafic cumulates (data from Parker, 1970; Kirby, 1979a; Leake and Styles, 1984) relative to typical ophiolite- and stratiform-related ultramafics (data from Rivalenti et al. (1981) and the literature).



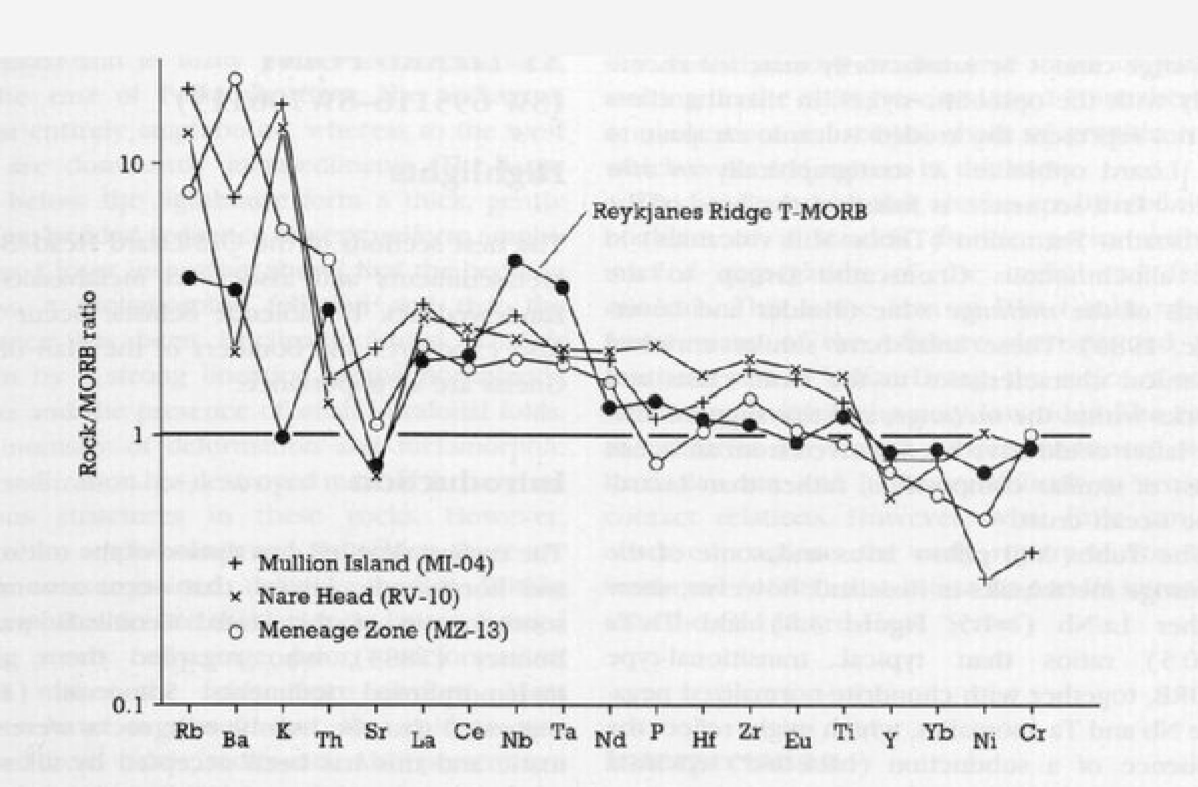
(Figure 3.4) Chondrite-normalized REE data for the different assemblages of the Lizard peridotite (from Frey, 1969; Davies, 1984) and typical Alpine peridotites (data from Frey, 1984).



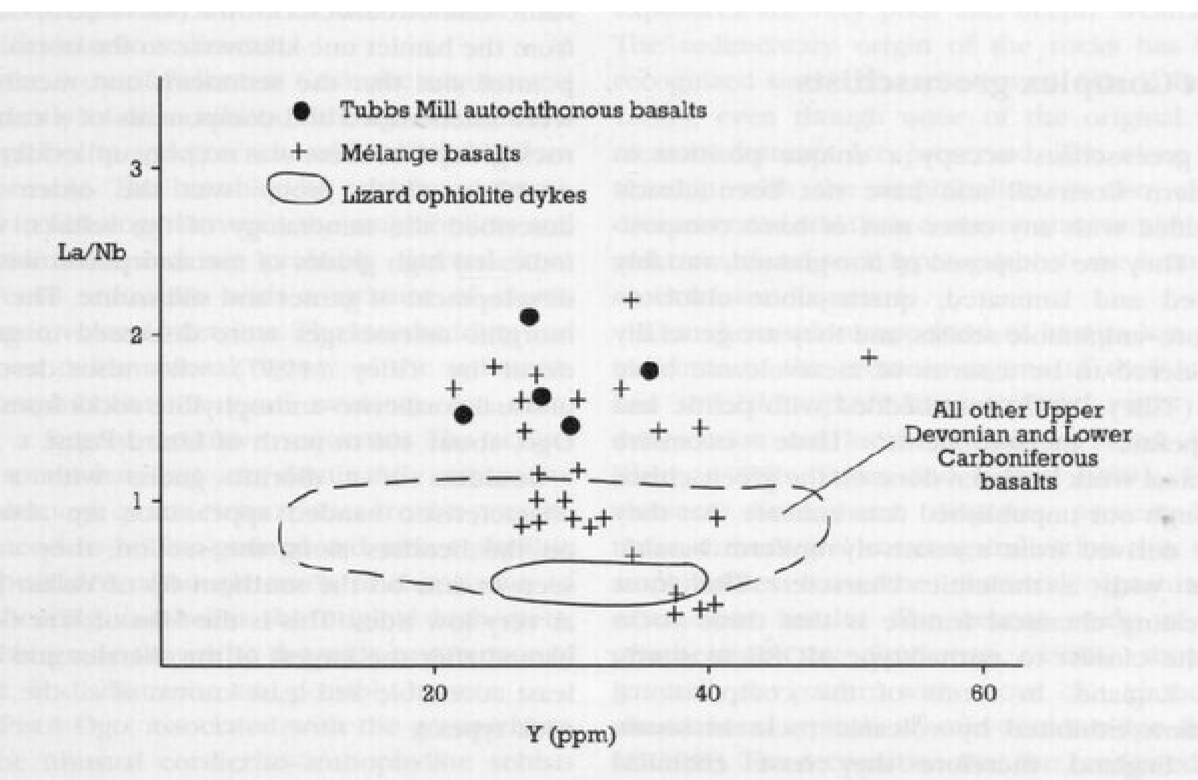
(Figure 3.5) Incompatible-element and normalized REE patterns for the Lizard basaltic dykes, showing the distinctions between the three chemical groups (data from Davies, 1984; Kirby, 1984).



(Figure 3.6) Lithological borehole logs for the Traboe ultramafic—mafic cumulate complex at Traboe, Lizard area (data from Leake and Styles, 1984).



(Figure 3.7) MORB-normalized multi-element patterns for selected mélange metabasalts compared with an example of transitional-type MORB from the Reykjanes Ridge.



(Figure 3.8) Diagram showing the variation in the La/Nb ratio for the Tubbs Mill pillow lavas and some of the mélange metabasaltic clasts relative to the Lizard dykes and Upper Devonian—Lower Carboniferous basic volcanics from south-west England.