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# A RE-INTERPRETATION OF THE INTERNAL STRUCTURE OF THE LIZARD COMPLEX OPHIOLITE, SOUTH CORNWALL.

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Previous models for the tectonic-stratigraphy of the Lizard complex ophiolite have proposed three thrust-bounded units. However, our studies indicate that post-obduction extensional faulting may have exerted a hitherto unrecognised effect on the present distribution of lithologies. Field and previously published geophysical evidence suggest that the uppermost tectonic unit (the Crousa Downs Unit) represents the downfaulted upper levels of the Goonhilly Downs Unit. Deformed lithologies previously thought to be part of the Goonhilly Downs Unit are reassigned to the underlying Basal Unit. A revised model for the tectonic-stratigraphy is presented. The Basal Nappe is underlain by the Basal Thrust and comprises the Traboe schists, the Landewednack schists and the Old Lizard Head Series. The Goonhilly Downs Nappe, underlain by the Goonhilly Downs Thrust, structurally overlies the Basal Nappe and comprises serpentinised peridotite, Trelan and Crousa Gabbro and the Porthoustock Sheeted Dyke Complex. This work highlights the importance of late- to post-Variscan extensional deformation in south Cornwall.

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## INTRODUCTION

Recent work has demonstrated that geological structures exposed within the Variscan basement of south Cornwall provide evidence, not only of Variscan convergence, but also of the subsequent latest Palaeozoic and Mesozoic tectonic evolution of the region (Shail and Wilkinson, 1994; Alexander and Shail, 1995). Late- to post-Variscan extensional tectonics appear to have strongly influenced granite emplacement, mineralisation, and the development of adjacent offshore Permo-Triassic sedimentary basins (Shail and Wilkinson, 1994; Harvey *et al.,* 1994). In common with the rest of south Cornwall, extensional structures can also be identified throughout the Lizard complex. This paper demonstrates the influence of post-obduction extensional faulting upon the tectonic-stratigraphy of the Lizard ophiolite.

## LITHOLOGIES

Although many of the lithologies within the Lizard complex are intensely deformed, most show clear ophiolitic affinities (Floyd *et al.,* 1976; Kirby, 1979), and are summarised below.

*Peridotite:* This largely comprises variably serpentinised harzburgites and lherzolites (Flett, 1946; Green, 1964). Dunite pods containing schlieren of chrome spinel are abundant. An early, primary, cumulate texture within the peridotite is cross-cut by a later tectonic foliation (Rothstein, 1977).

*Crousa Gabbro:* A wide band of gabbro crops out between Coverack and Carrick Luz. Two types, the Trelan and Crousa gabbros, have been defined (Smith and Leake, 1984).

*Porthoustock Sheeted Dyke Complex:* This crops out north of the Crousa Gabbro. Dolerite dykes intrude the gabbros and may make up as much as 80% of the outcrop (e.g. south of Porthoustock).

*Landewednack Schists:* These are hornblende-plagioclase amphibolites which have a pronounced foliation and lineation defined by the preferred orientation of amphibole prisms (Flett, 1946). The Landewednack Schists have immobile trace element signatures similar to ocean floor basalts (Floyd *et al.,* 1976) and have therefore been interpreted as the metamorphosed equivalent of the sheeted dyke complex and pillow lava sequence (e.g. Bromley, 1979).

*Traboe Schists:* The Traboe Schists are coarse grained, heavily deformed amphibolites which contain pyroxene and show relict gabbroic texture and hence they have been interpreted as the metamorphosed equivalent of the gabbro unit of the ophiolite (Kirby, 1979; Bromley, 1979).

*Traboe Cumulate Complex:* A series of ultramafic to mafic cumulates comprising lherzolites, dunite, pyroxenite, gabbro and anorthosite have been described from the Traboe Cross area (Leake and Styles, 1984). Similar rocks crop out south of Mullion and in the Porthkerris area. Geochemically the gabbroic layers are similar to the Crousa Gabbro of the Coverack area (Leake and Styles, 1984).

*Old Lizard Head Series: The* Old Lizard Head Series comprises metasediments and metabasites which crop out in the far south of the Lizard Peninsula. The rocks are predominantly well foliated mica-schists (Jones, 1994).

*Kennack Gneiss:* The Kennack Gneiss occurs as large irregular masses or small dykes whose compositions range from basaltic to granitic. They are considered to represent bimodal melts intruded during internal thrust stacking (Sandeman, 1988; Sandeman *et al.,* 1995).

## PREVIOUS MODELS

Several models have been proposed to account for the nature and distribution of one or more of the lithologies outlined above since the greater part of the Lizard complex was recognised as an ophiolite (Bromley, 1973, 1975, 1979; Kirby, 1979). All have generally invoked internal thrusting prior to final northwards obduction over the low grade regionally metamorphosed sediments of the Gramscatho Basin. Bromley (1979) suggested that the ophiolite comprised the Basal Unit, the Goonhilly Downs Unit, and the Crousa Downs Unit (Figure la). He envisaged that the Basal Unit was intensely deformed by the over-riding Goonhilly Downs Unit which, in turn, was deformed by the over-riding Crousa Downs Unit. The Landewednack Schists were subdivided into the Upper Landewednack Schists (within the Goonhilly Downs Unit) and the Lower Landewednack Schists (within the Basal Unit), whilst the Kennack Gneiss was considered to be emplaced along the base of the Goonhilly Downs Unit (Bromley, 1979). Styles and Kirby (1980) also chose to recognise the Crousa Downs Unit as a separate thrust sheet (their Eastern Unit) but did not subdivide the other lithologies (their Western Unit). However, they implied that the Western Unit comprised several thrust slices. Vearncombe (1980) defined an ophiolite unit of peridotite, gabbros and sheeted dykes, which was thrust over the parautochthonous Basal Unit, exposed in the Lizard Point area. He did not specifically define a unit which comprised the hornblende schists and metasediments in the north of the area.

Leake and Styles (1984) renamed the Traboe schists in the Traboe Cross area as the Traboe Cumulate Complex and recognised geochemical and petrological similarities between it and the lower levels of the Crousa Gabbro. Borehole data (Leake and Styles, 1984) have shown that that the cumulate sequence dips towards the north-east and is immediately underlain by peridotite. They proposed that the Traboe Cumulate Complex represents a similar stratigraphic level to the lowermost levels of the Crousa Gabbro and hence the significance of an individual Crousa Downs Unit was questioned (Leake *et al.,* 1992). Additionally the Crousa Gabbros were subdivided into the Trelan and Crousa gabbros on the basis of soil geochemistry (Smith and Leake, 1984). However, the differences cited (vanadium content and mineralogy) may be due to lateral, or vertical, variations within a multiple magma chamber (e.g. Robinson and Malpas, 1990).

Much of the deformation within the gabbros, originally interpreted as thrust related (e.g. Styles and Kirby, 1980), has since been reinterpreted as having formed within ductile oceanic realm extensional shear zones (Gibbons and Thompson, 1991; Roberts *et al.,* 1993). It was suggested by Gibbons and Thompson (1991) that the Crousa Downs Unit may have been downfaulted to the south during this period of oceanic realm deformation. Jones (1994) has proposed that the Basal Unit is composed of a number of individual thrust nappes which developed in response to internal ductile imbrication prior to final obduction.

## A RE-INTERPRETATION OF THE LIZARD TECTONIC-STRATIGRAPHY

### *Crousa Downs Unit: a downfaulted block?*

We have undertaken detailed field-based investigations to determine the nature of the contact between the Crousa Downs Unit and the underlying Goonhilly Downs Unit. This contact is supposed to be represented by a series of thrust faults exposed in the coastal sections between Kennack Sands and Carrick Luz, and Porthoustock and Porthallow (Bromley, 1979; Styles and Kirby, 1980). However, our own observations suggest that thrust contacts are absent and that extensional and oblique slip faults predominate. East-north-east and north-north-west striking high angle brittle faults are commonly observed both between Porthoustock and Porthallow, and Kennack Sands and Black Head (Figure 3). Slickenlines on the east-north-east striking faults generally pitch steeply, implying dip-slip extension, whilst those on the north-north-west striking faults may exhibit either low or high angles of pitch. This association may imply that during north-north-west — south-south-east extension the north-north-west striking faults acted as transfers. North-north-west striking strike-slip faults are particularly well developed between Kennack Sands and Black Head. A more detailed investigation of these faults is presented by Alexander and Shail (1996). These data and the continuity of peridotite between Kennack Sands and Black Head leads us to question the interpretation of the Crousa Downs Unit as a separate thrust nappe.

The Crousa Gabbros are juxtaposed, to the north-west, against peridotite of the Goonhilly Downs Unit (Figure 2). As noted by Gibbons and Thompson (1991), this strongly implies downward movement of the Crousa Downs Unit relative to the Goonhilly Downs Unit; this was attributed to ductile extension within the oceanic realm by these authors. However, the strike of the northern contact of the Crousa Downs Unit is inconsistent with the east-north-east — west-south-west extension implied by the orientation of the sheeted dyke complex (Barnes and Andrews, 1986).

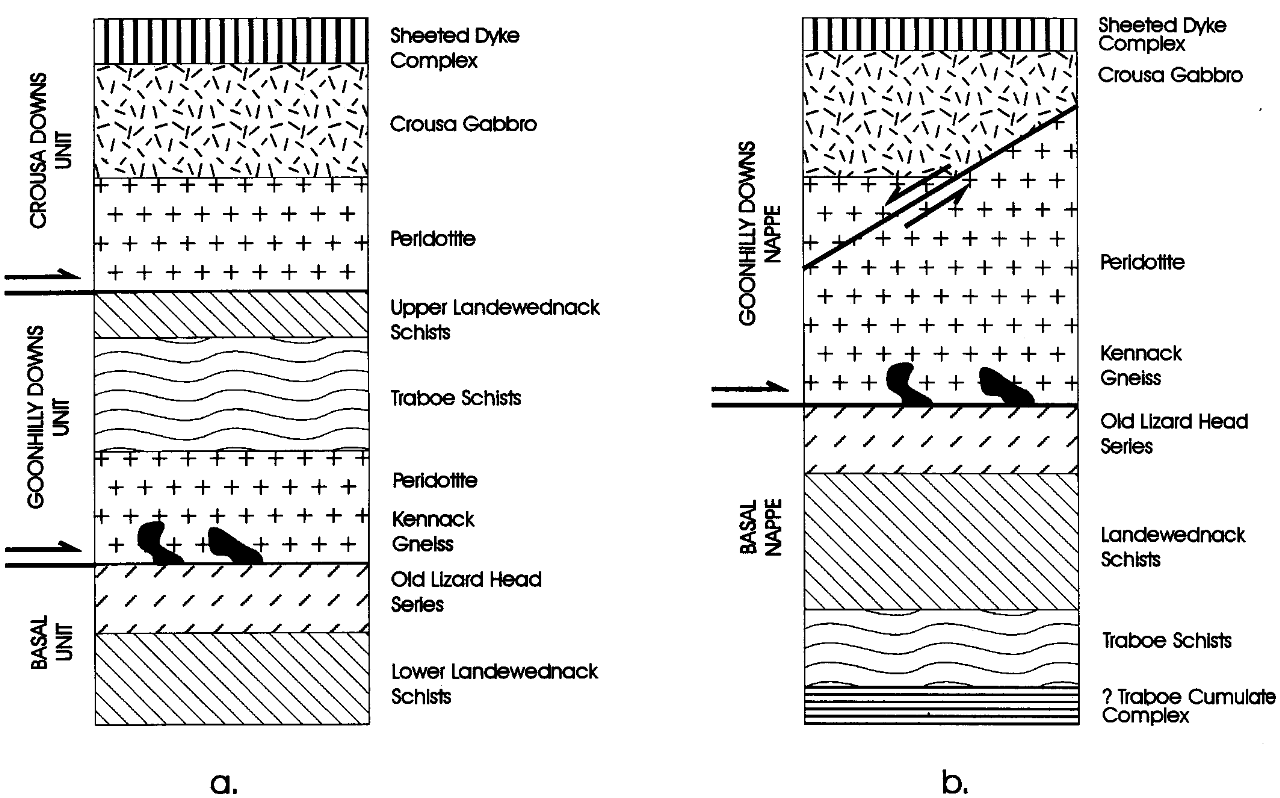


*Fig. 1. Possible interpretations of the tectonic-stratigraphy of the Lizard Complex. (a) previous workers, (b) this study.*

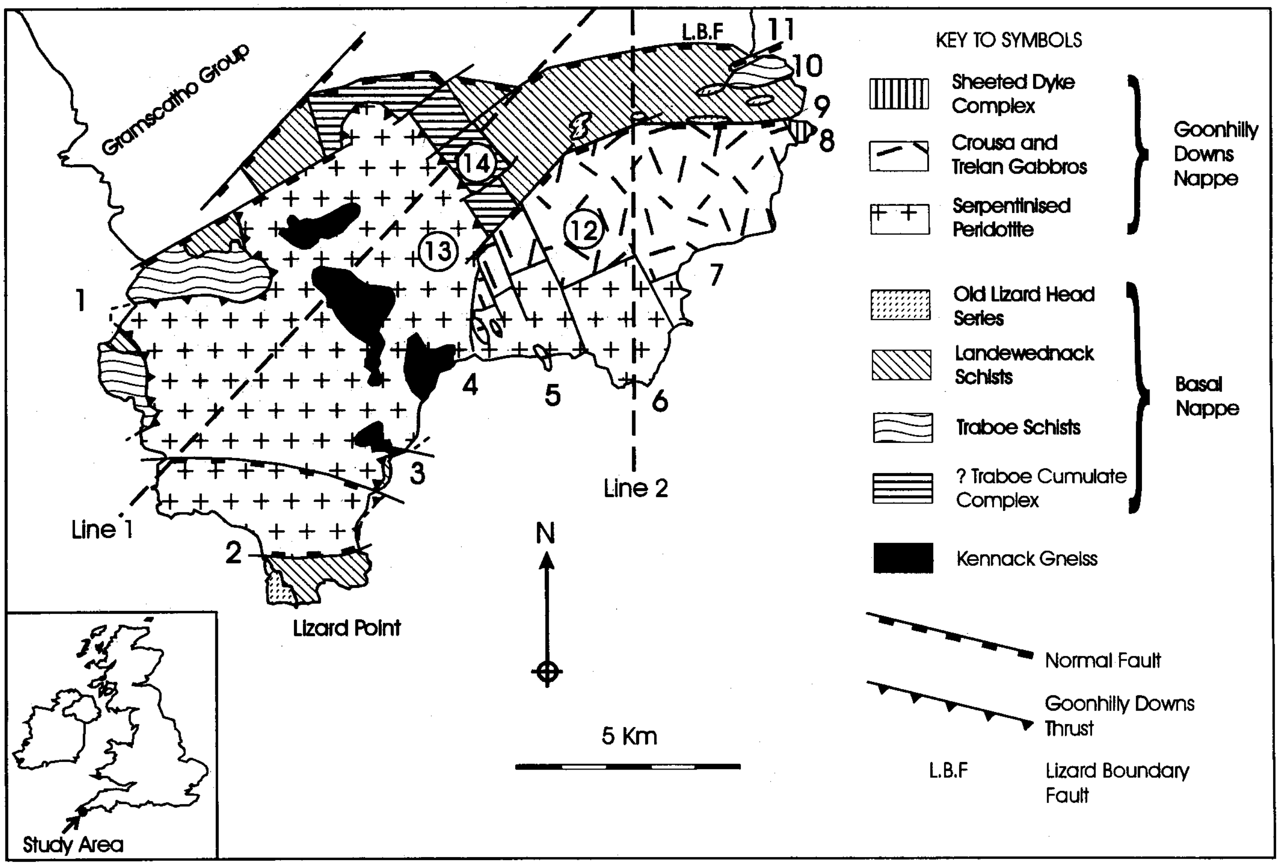


*Fig 2. A simplified geological map of the Lizard Complex modified after Leake et al. (1992). (1) Mullion, (2) Pentreath Beach, (3) Cadgwith , (4) Kennack Sands, (5) Carrick Luz, (6) Black Head, (7) Coverack, (8) Manacle Point, (9) Porthoustock, (10) Porthkerris, (11) Porthallow, (12) Crousa Downs, (13) Goonhilly Downs, (14) Traboe Cross.*

Geophysical data also support the evidence for downfaulting. Gravity modelling (Rollin, 1986) shows that the Lizard complex is considerably thicker beneath Crousa Downs than it is under Goonhilly Downs (Figure 4a, b). A cross-section through Crousa Downs, constructed from geophysical data (Rollin, 1986), suggests a half-graben type structure (Figure 4b). It is apparent from field (Bromley, 1979) and map evidence that there has been some degree of hanging wall rotation during faulting since progressively lower stratigraphical levels are exposed towards the south. It is therefore proposed that the Crousa Downs Unit represents the downfaulted upper levels of the Goonhilly Downs Unit, as shown in Figure 4c.

### *Revised Basal Unit stratigraphy*

If, as we suggest, the Crousa Downs Unit represents the downfaulted upper levels of the Goonhilly Downs Unit, then the Upper Landewednack Schists, Traboe Schists and Old Lizard Head Series to the north must belong to a lower tectonic unit.

Previous interpretations restrict the Basal Unit to the southern tip of the Lizard complex between Pentreath Beach and Cadgwith; only the Lower Landewednack Schists and the Old Lizard Head Series are exposed in this area (Bromley, 1979; Veamcombe, 1980). However, similar lithologies have also been identified from the area around Mullion (Styles and Kirby, 1980; Leake and Styles, 1984). These have the appearance of Traboe Schists but have been interpreted as Landewednack Schists which have undergone dynamothermal metamorphism caused by the overriding Goonhilly Downs Unit (Styles and Kirby, 1980). Borehole (Styles and Kirby, 1980) and geophysical data (Rollin, 1986) indicate that the Goonhilly Downs Unit is a relatively thin, undulating slab which is underlain by amphibolites of the Basal Unit (Figure 4a); this is in broad agreement with Sanders (1955) and Bromley (1979). Small outcrops of Old Lizard Head Series are also present across the Porthallow - Traboe area, allowing further correlations with the Basal Unit exposed in the Lizard Point area.

Petrographical (Bromley, 1979) similarities between the Upper and Lower Landewednack Schists strongly suggest that they are of a broadly similar origin. Geochemical variations between the Uper and Lower Landewednack schists (e.g. Kirby, 1979) may be explained by differentiation effects and hence may relate to the original level in the sequence. Although the Traboe Schists show a considerable chemical variability; this could be due to differentiation. Thus, the chemistry of the Traboe Schists may be related their original stratigraphical position within the oceanic crust.

One problematic area is the interpretation of the structural position of the Traboe Cumulate Complex in the Traboe Cross area. On the basis of borehole investigations, Leake and Styles (1984) consider that the cumulates in this area stratigraphically overlie the peridotite. Equally, however, similar lithologies exposed south of Mullion and in the Porthkerris area could be interpreted as underlying the peridotite. Thus, by inference, we would assign the Traboe Cumulate Complex to the Basal Unit. However, this problem can only be satisfactorily resolved with further detailed investigation.

In summary, we can find no *a priori* reason to suggest that the Upper Landewednack Schists, Traboe Schists and Old Lizard Head Series in the north-east of the Lizard complex belong to a separate tectonic unit from those exposed around Lizard Point. We consequently suggest their incorporation into a revised Basal Unit (Figure lb). Also, we tentatively suggest that the Traboe Cumulate Complex be included within the Basal Unit. The continued division of the Landewednack Schists into upper and lower sub-types is therefore

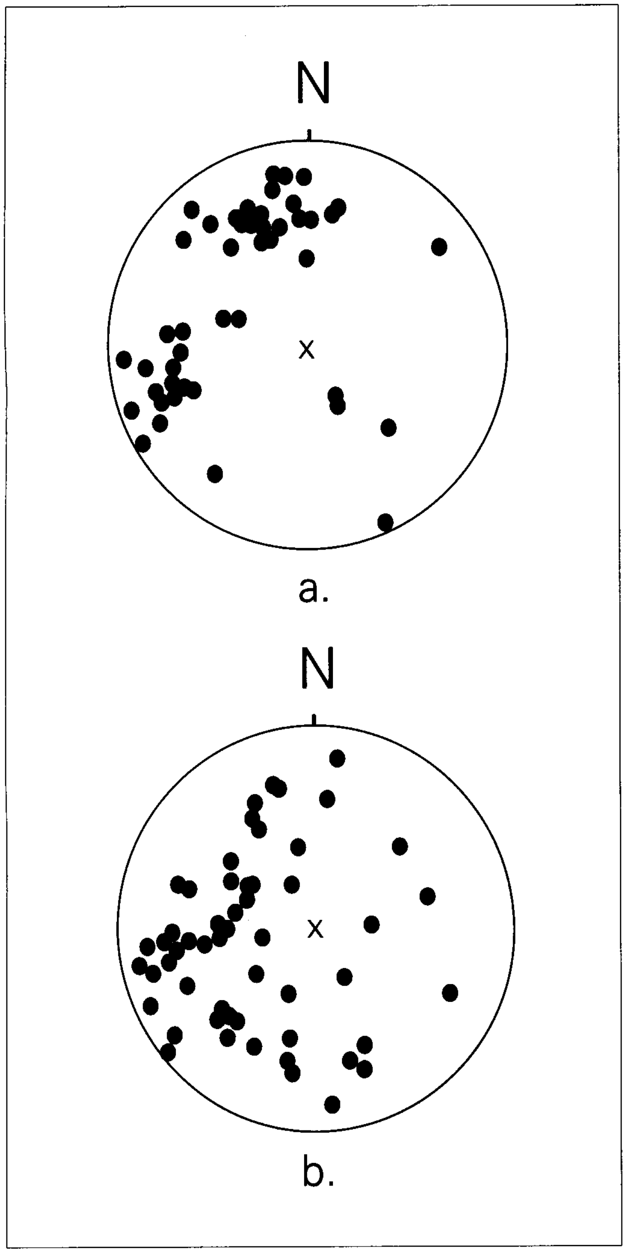


*Fig 3. Stereograms showing poles to major fault planes. (a) from the Porthallow - Porthoustock section. (b) from the Kennack Sands - Black Head section.*

no longer necessary. In addition, we suggest that terminology be further rationalised; we propose that the Basal Unit be renamed the Basal Nappe and the underlying thrust be renamed the Basal Thrust. This terminology is consistent with modern structural usage.

### *Revised Goonhilly Downs Unit Stratigraphy*

The lithologies, originally assigned to the Crousa Downs Unit, are now re-assigned to the Goonhilly Downs Unit. We therefore consider virtually all peridotite exposed within the Lizard complex to be part of the Goonhilly Downs Unit. The distribution of recrystallised hydrous and anhydrous peridotite assemblages (Flett, 1946; Green, 1964) may be controlled by intense deformation and high temperature hydration of peridotite in close proximity to the underlying thrust. The transition to the primary assemblage may be a function of increased distance from the thrust. In summary, we would incorporate the majority of the peridotite, the Crousa Gabbro and the Porthoustock Sheeted Dyke

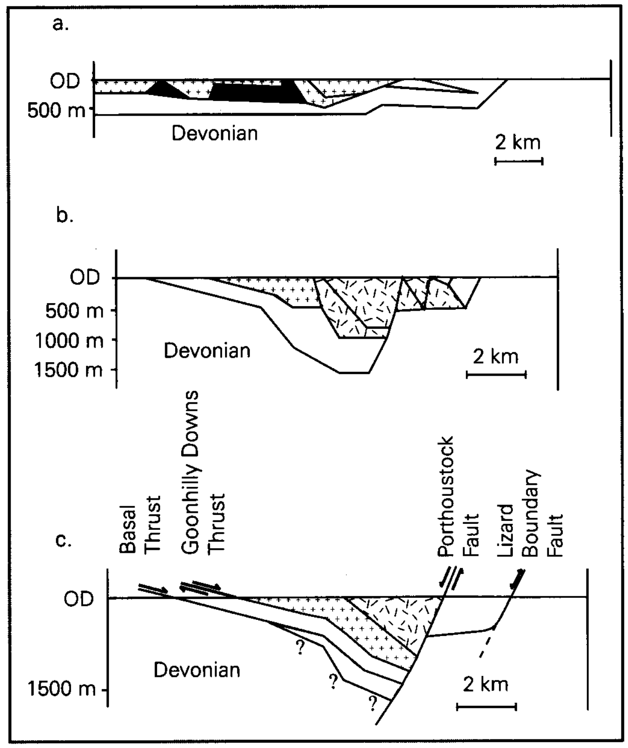


*Fig 4. (a, b) cross-sections constructed from geophysical data (from Rollin 1986); (c) a simplified schematic cross-section (after Rollin 1986). (a) follows line 1, Fig. 2. (b, c) follow line 2, Fig. 2. Ornament as for Fig. 2.*

Complex in the Goonhilly Downs Unit (Figure lb). We propose that the Goonhilly Downs Unit be renamed the Goonhilly Downs Nappe and that the underlying thrust be renamed the Goonhilly Downs Thrust.

## DISCUSSION

We contend that extensional faulting has adversely influenced perception of the immediate post-obduction geometry of the Lizard complex ophiolite. Extensional faults are common within the Gramscatho Group metasediments to the north of the Lizard complex and developed at various times from the late Carboniferous to Triassic (Shall and Wilkinson, 1994; Alexander and Shail, 1995; 1996). Early north-north-west — south-south-east extension is characterised by the reactivation and extensional cut-out of earlier thrust faults, e.g. Carrick Thrust (Leveridge and Holder, 1985; Shail and Wilkinson, 1994). The orientation and high-angle nature of the Lizard Boundary Fault (e.g. Bromley, 1979; Barnes and Andrews, 1984) suggests it cuts out the Basal Thrust in an identical manner, and by analogy with similar faults is probably late Carboniferous to early Permian in age (Alexander and Shail, 1996). Later east-north-east — west-south-west extension brought about the reactivation, and formation, of north-north-west striking faults, such as those exposed around Kennack Sands. These were probably associated with Triassic rifting (Alexander and Shall, 1996)

## CONCLUSIONS

The Lizard complex comprises two tectonic units: the Goonhilly Downs Nappe, underlain by the Goonhilly Downs Thrust, and the Basal Nappe, underlain by the Basal Thrust.

The Crousa Downs Unit of previous workers is regarded as the downfaulted upper levels of the Goonhilly Downs Nappe.

The Traboe Cumulate Complex, Traboe schists and Upper Landewednack schists are re-interpreted as belonging to the Basal Unit.

Variable hydration of the Goonhilly peridotite may be attributable to deformation related to internal stacking in close proximity to the Goonhilly Downs Thrust.

The Lizard complex ophiolite, in common with much of the Variscan basement in south west England, preserves a record of late Palaeozoic to Mesozoic extensional faulting.

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