ST DAVID'S HEAD

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Introduction

The St David's Head area in north Pembrokeshire, comprises chiefly Ordovician gabbroic and closely related rocks, forming the St David's Head Intrusion. The intrusion is broadly sheet-like in form and, as a result of Caledonian folding, occurs as two linear, near continuous outcrops, up to 2 km in length, on opposing limbs of a tight NE-trending syncline. Where present, an igneous layering dips steeply (50–80°) to the SE and NW on opposing limbs of the syncline. A maximum thickness of 570 m is seen on the south-eastern (Carn Llidi) limb, while only *c*. 385 m is exposed on the north-western (St David's Head) limb.

The intrusion invaded sedimentary rocks (mudstones to fine-grained sandstones) of Ordovician, probable Arenig, age prior to Caledonian (end-Silurian) folding. Contact metamorphic effects are seen in manganiferous siltstones, with the development of spessartine and cordierite porphyroblasts (now pseudomorphed).

The earliest studies on the St David's Head Intrusion were those by Elsden (1905, 1908), who described the presence of various norites, quartz-norites, and enstatite diorites, noting interbanding between and a regular distribution of the different rock types. Roach (1969) elaborated on the earlier work, identifying seven major petrological types in the intrusion orientated parallel to the contacts, in addition to minor, cross-cutting aplite veins. Roach (1969) considered that the two outcrops represent two separate sheets, while Bevins and Roach (1982) suggested that the two sheets are, in fact, opposing limbs of a synclinal structure. Bevins *et al*. (1991) presented geochemical data, highlighting the petrogenetic link between the basic and silicic rocks. Most recently, Bevins *et al*. (1994) provided a detailed petrological and geochemical description of the major rock types present in the intrusion, arguing for a complex evolution, linked to multiple magma injection and in-situ crystallization.

This is one of only two layered intrusions in the Caledonian sequences of Wales, and illustrates the complex nature of processes involved in the development of a layered intrusion, as well as providing critical evidence for the origin of contemporaneous, closely related silicic lavas and pyroclastic rocks.

Description

The St David's Head Intrusion is magnificently exposed in sea cliffs and adjacent exposures in the area to the north of Whitesand Bay. It occurs as two NE-trending outcrops, the north-western forming the coastal section from St David's Head to Penllechwen, the south-eastern forming the less well-exposed section between Penlledwen and Trwyn Llwyd, best exposed on the crags of Carn Llidi. Seven major petrological types are recognized in the St David's Head Intrusion (Figure 6.20), in addition to the relatively minor, cross-cutting aplite veins.

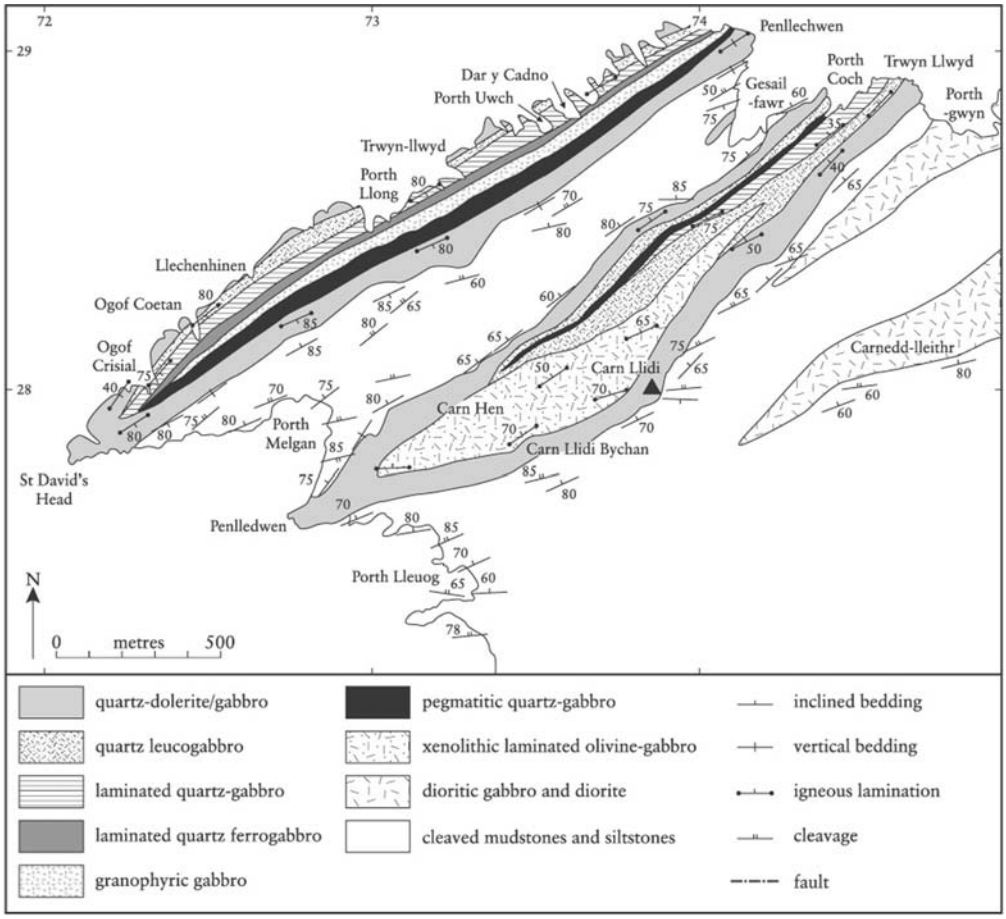

Figure 6.20: Map of the St David's Head Intrusion (after Bevins et al., 1994).

Quartz-dolerite and quartz-gabbro

Quartz-dolerite and quartz-gabbro form an outer unit to the intrusion, up to 100 m thick and best exposed in cliffs at the south-western extremity of the St David's Head outcrop. Here, intermittent centimetre-scale microrhythmic felsic–mafic segregations occur, passing in places into irregular pegmatitic patches. Mineralogically, the gabbros are dominated by plagioclase (max An_{65}) and clinopyroxene (cores $Ca_{40}Mg_{49}Fe_{11}$ to $Ca_{40}Mg_{43}Fe_{17}$; rims $Ca_{40}Mg_{47}Fe_{13}$ to $Ca_{40}Mg_{36}Fe_{24}$) along with minor altered olivine, orthopyroxene and ilmenite, and a quartz-feldspar mesostasis. Texturally, the gabbros are subophitic.

Xenolithic laminated olivine-gabbro

The xenolithic laminated olivine-gabbro unit is up to 200 m thick, being exposed only on the south-eastern limb of the intrusion and with the best exposures present in the steep crags of Carn Llidi. This unit is characterized by the presence of mafic and felsic cognate xenoliths up to 1 m in length. The host gabbro is poorly laminated and is characterized by plagioclase, clinopyroxene, orthopyroxene (typically pseudomorphed), altered olivine and minor Ti-rich biotite and hastingsitic amphibole. The mafic xenoliths are predominantly composed of clinopyroxene, pseudomorphed orthopyroxene and pseudomorphed olivine. Clinopyroxenes are the most Mg-rich in the intrusion, with compositions in the range $Ca_{2}Mg_{47}Fe_{11}$ to $Ca_{40}Mg_{45}Fe_{15}$; orthopyroxenes show very restricted compositions, from $Ca_{4}Mg_{72}Fe_{24}$ to $Ca_{4}Mg_{68}Fe_{28}$. Plagioclase compositions reach An_{71}, the most Ca-rich feldspars in the intrusion.

Quartz-leucogabbro

Quartz-leucogabbro units are present in both outcrops of the intrusion. These gabbros are characterized by relatively high modal proportions of plagioclase relative to the mafic minerals. Clinopyroxenes are similar in composition to those in the xenolithic laminated olivine-gabbro unit, while plagioclases reach An_{61}, although generally they are albitized. Minor ilmenite and quartz are also present.

Laminated quartz-gabbro

Quartz-gabbros showing a pronounced mineral lamination are best exposed in the vicinity of Ogof Crisial. Locally, these gabbros are interlayered with laminated quartz-ferrogabbros (Figure 6.21). The lamination is due to the alignment of the major mineral phases, namely tabular plagioclase, elongate, prismatic clinopyroxene (and rarer altered orthopyroxene) and elongate ilmenites. Clinopyroxenes show a restricted range of compositions from $Ca_{43}Mg_{39}Fe_{18}$ to $Ca_{42}Mg_{33}Fe_{25}$. Plagioclase compositions reach a maximum calcic component of An_{88}. Commonly, the plagioclases show strong compositional zoning.

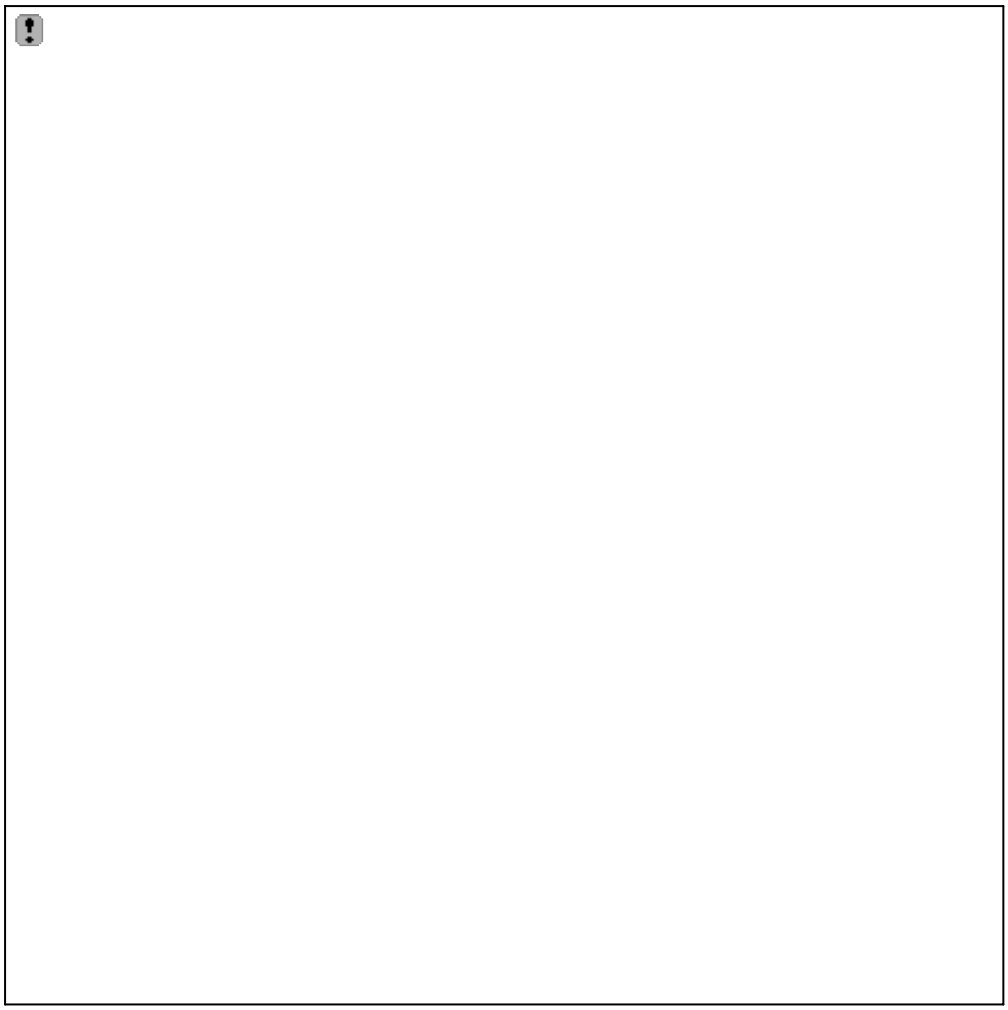

Figure 6.21: Macrorhythmic layering between laminated quartz-gabbro (lighter bands) and laminated quartz-ferrogabbro (darker bands), looking to the NE across Porth Llong, St David's Head Intrusion. (Photo: R.A. Roach.)

Laminated quartz-ferrogabbro

A relatively thin unit of laminated quartz-ferrogabbro in the St David's Head outcrop is best exposed on the north-eastern side of Porth Llong. Towards the south-western end of the outcrop laminated ferrogabbros, up to 1 m thick, are spectacularly interlayered on a macrorhythmic scale with laminated quartz-gabbros. The lamination is similar to that in the laminated quartz-gabbros, except that ilmenite is more abundant in the ferrogabbros. Mineral compositions are nearly identical to those in the laminated quartz-gabbros.

Granophyric gabbro

The principal exposures of granophyric gabbro occur in the north-western outcrop of the St David's Head Intrusion, for example in the cliff-top crags above Porth Llong, although coarse

pegmatitic to granophyric gabbros are also present in the Carn Llidi outcrop. These gabbros are isotropic, dominated by plagioclase (altered), with relatively minor clinopyroxene (the most Fe-rich in the St David's Head Intrusion, reaching $Ca_{42}Mg_{27}Fe_{31}$), orthopyroxene, and ilmenite. Apatite, as stout prisms up to 2 cm long, is abundant and of probable cumulus origin. These gabbros are characterized by interstitial quartz-alkali feldspar granophyric intergrowths (Figure 6.22).

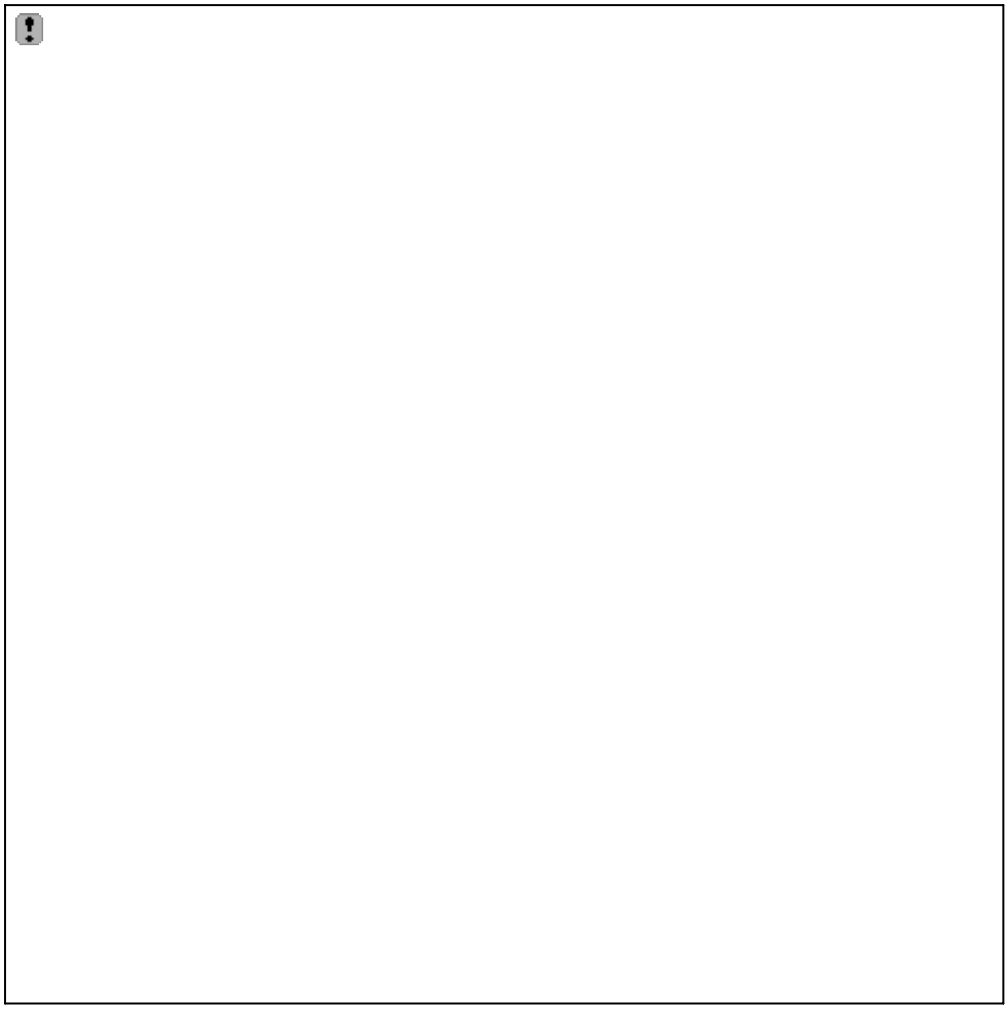

Figure 6.22: Granophyric gabbro from the St David's Head Intrusion, showing slight variations in felsic components, east of St David's Head. (Photo: R.A. Roach.)

Pegmatitic quartz-gabbro

Distinctive pegmatitic quartz-gabbros are present in both outcrops, towards the top of the intrusion. Geochemical evidence presented by Bevins *et al*. (1994) suggests that these gabbros are in fact coarse-grained equivalents of either quartz-gabbro, leucogabbro or granophyric gabbro. Distinctive in these pegmatitic quartz-gabbros are prismatic clinopyroxene crystals up to 12 cm in length.

In addition to the seven main petrological units, thin (up to 30 cm wide) cross-cutting aplite veins are particularly well developed in the vicinity of Ogof Crisial. The aplites are dominated by albite and quartz, associated with minor ilmenite, amphibole, apatite, titanite and zircon.

Contact relationships and layering

Contacts between the petrological units vary from sharp to gradational, while certain units are interbanded. Relationships are described in detail by Bevins *et al*. (1994). The nature of the contacts is crucial in establishing the history of the intrusive events. In addition, the St David's Head Intrusion shows three types of mineral and compositional layering within the individual

petrological units, namely:

1. Mineral layering in the more evolved laminated quartz-gabbros and laminated quartz-ferrogabbros, related to the parallel alignment of tabular plagioclase, pyroxene and ilmenite crystals.

2. Macrorhythmic modal layering, up to 1 m thick, related to an alternation of laminated quartz-gabbro and laminated quartz-ferrogabbro units.

3. Centimetre-scale, felsic-mafic, microrhythmic modal layering in the quartz-gabbro unit.

Geochemistry

Bevins *et al*. (1994) provided the first detailed geochemistry for the full range of gabbroic and related rocks of the St David's Head Intrusion. Roach (1969) had previously presented major element analyses for a small number of samples from the quartz-dolerites and quartz-gabbros, while Bevins *et al*. (1991) had used the geochemistry of the silicic (aplitic) derivatives of the St David's Head rocks to speculate on the origin of silicic eruptive rocks associated with the neighbouring Ordovician volcanic centres (e.g. the Pen Caer GCR site). The apparent link by fractional crystallization between the St David's Head aplites and the more basic gabbros led Bevins *et al*. (1991) to suggest that many of the rhyolitic lavas and ignimbrites in the adjacent sequences were similarly derived from more basic compositions by fractional crystallization.

Interpretation

The petrological varieties present in the St David's Head Intrusion and their contact relationships reveal a complex origin, thought to relate in part to in-situ fractionation and in part to multiple events of magma injection. For example, interbanding relationships between leucogabbro and laminated quartz-gabbro at Ogof Crisial imply that the leucogabbro was intruded later than the crystal accumulation that gave rise to the laminated quartz-gabbro, indicating separate intrusive events. In contrast, the lamination in the laminated quartz-gabbros and the laminated quartz-ferrogabbros is thought to be of cumulus origin, resulting from the periodic sedimentation and accumulation of ilmenite crystals. The presence of mafic (olivine +orthopyroxene+clinopyroxene) cognate xenoliths in the xenolithic gabbros has been taken as evidence for the existence of high-level magma chambers in which these mafic minerals accumulated, prior to incorporation in later basic magmas and transport to higher crustal levels.

The geochemical data set of Bevins *et al*. (1994) confirmed the earlier proposals of Bevins *et al*. (1991) that the various petrological types are related through crystal fractionation. In particular, strong correlations between highly incompatible elements demonstrate that all the different rock types present in the intrusion, from basic through to silicic compositions, are petrogenetically linked, while plots of highly compatible elements versus incompatible elements illustrate the role of clinopyroxene and olivine in the fractionation process. Not all of the chemical variations determined, however, can be explained by crystal fractionation. Certain major and minor element variations suggest the importance of cumulate processes, in particular accumulation of olivine-orthopyroxene, ilmenite, and of apatite.

Conclusions

The St David's Head Intrusion is one of only two layered intrusions in the Caledonides of Wales, and provides evidence for a variety of high-level igneous processes. A great variety of rock types are present, resulting in a number of different rock units, ranging from basic through to silicic composition. Evidence from the field relationships between these different units, afforded by magnificent coastal exposures, combined with geochemical evidence, suggests that the units are all related to each other magmatically, but that a variety of igneous processes have operated, leading to the variety of compositions exposed today. These include in-situ fractional crystallization, the incorporation of crystalline material (cognate xenoliths) from an underlying high-level magma chamber, and the injection of different magma batches of contrasting compositions at slightly different times. The geochemical variation present in the intrusion provides critical evidence for the origin of rhyolitic lavas and ash-flow tuffs exposed elsewhere

in the Ordovician sequences of Pembrokeshire.

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