Chapter 7 Late Ordovician to mid-Silurian alkaline intrusions of the North-west Highlands of Scotland

Introduction

I. Parsons

A group of small alkaline igneous plutonic complexes and a suite of associated dykes and sills of late Caledonian age occur in a belt roughly parallel to the Moine Thrust in the NW Highlands of Scotland (Figure 7.1). This alkaline magmatism represents the NW edge of the otherwise overwhelmingly calc-alkaline Caledonian Igneous Province north of the Highland Boundary Fault. Radiometric ages show that the alkaline activity was protracted, spanning the period 456–426 Ma (Table 7.1). The rocks were thus emplaced concurrently with the earlier members of the 'newer granite' suites, although most of these intrusions are a little younger, with a peak of activity around 410–400 Ma (Brown, 1991). The earliest alkaline pluton, the Glen Dessarry syenite (Richardson, 1968), was penetratively deformed by late orogenic events, while the younger intrusions are deformed only locally. The Loch Loyal intrusions were emplaced after the regional metamorphism of the enclosing Moine and interleaved Lewisian rocks. The intrusions in Assynt occur in all the thrust sheets, including a minor development in the Moine, and also in the unmoved Foreland, the only incursion of Caledonian magmatism into that structural unit. The reader must bear in mind that what is now a relatively compact area of alkaline rocks in Assynt includes rocks which must have been emplaced in a belt extending perhaps of the order of 50 km towards what is now the ESE, that has been shortened by movements on the lower thrusts.

Alkaline magmas were available during several other phases of igneous activity in the British Isles (for example in the Carboniferous magmatism in the Midland Valley, and in the British Tertiary Igneous Province) but no highly evolved plutons occur. Many of the rock types in the NW Highlands are therefore unique in a British context, and all are rare in a world context. The ultrapotassic rocks of the Loch Borralan intrusion (Figure 7.1), in particular, have extreme compositions matched at only a handful of localities worldwide. Like most alkaline suites, that of the Scottish Caledonian Province has its own distinctive character. Reviews of the alkaline suite have been provided by Sutherland (1982) and Brown (1991).

Because of the early recognition of their unusual mineralogy, the Caledonian alkaline rocks were prominent in the evolution of ideas in igneous petrology in the early part of the 20th century. The province provided type localities of many rock types named by these early workers (Table 7.2), some of which have remained in widespread use. Adoption of a modern terminology for the suite makes much of this classic early work very hard to follow and in the text the old names have been used, but with their newer equivalents, and rather clumsy mineral-based names, added where appropriate. Credit for the first chemical recognition of the alkaline character of the rocks appears to be due to Heddle (1883a; see Teall, 1900, p. 26) who analysed an albitite from Assynt. Murchison and Cunningham made earlier references to 'syenite' and described Ben Loyal (Ben Laoghal) in some detail (see Heddle, 1883b). These early workers regarded syenite as differing from granite only by 'a mineralogical accident'. The first descriptions of the alkaline rocks with a modern ring are those of Horne and Teall (1892) and Teall (1900), who introduced the name 'borolanite' for the exotic melanite-garnet nepheline-pseudoleucite-syenites for which the Loch Borralan intrusion is most famous.

For more than thirty years, Shand (1906–1939) maintained the province at the forefront of the developing science of igneous petrology by his introduction of the important concept of 'silica saturation' and his assertion that the silica-undersaturated character of some alkaline rocks (in his view a good example being the Loch Borralan intrusion) was a result of the extraction of silica from granitic magmas by reactions with limestones, precipitating calcium silicate minerals and releasing carbon dioxide. The idea was taken up by Daly (1914) and became known as the Daly–Shand hypothesis'. The hypothesis has fallen out of favour, not least because it is now recognized that the carbonate rocks often associated with nepheline-syenites are themselves intrusive igneous carbonatites. The discovery, as recently as 1988 (Young *et al.,* 1994), of a carbonatite body slightly outside the Loch Borralan intrusion, rounds-off a long diversion in petrological thinking, and shows the potential for continuing field research in the province.

(Table 7.2) Glossary of uncommon or varietal rock names employed for members of the alkaline suite in the NW Highlands.

Rock name	First use in NW Highland's literature	Modern equivalent(s)	Petrography and mineralogy	Comments
Assyntite	LB. Shand (1910) NW of Cnoc na Sroine	Socialite nepheline-syenite	Trachytic texture; alkali feldspar, interstitial nepheline, both enclosing sodalite, with biotite, magnetite and titanite	Obsolete name. An exotic rock hut poorly exposed
Borolanite	LB. I tome and Teall (1892) from SE end of intrusion	Melanite-hiotite (pseudolcucite-) nepheline-syenite	Alkali feldspar-nepheline intergrowths (both in pseudolcucite and matrix), well-formed melanite and biotite. Pseudoleucite not always present	The original name is still occasionally used informally
'Canisp Porphyry'	MI. Adopted by Sabine (1953) from early usage	Porphyritic quartz-microsycnite	Alkali and plagioclase feldspar phenocrysts in a groundmass of turbid feldspar and quartz	Forms major sill complex
Cromaltite	LB. Shand (1910) from Bad na h-Achlaise. After Cromalt IBM	Melanite-biotite pyroxenite	Diopsidic pyroxene and ilmenomagnetite enclosed by biotite and replacive melanite	Obsolete name. Similar pyroxenites without melanite at LA
Groruclite	MI. Sabine (1953)	Peralkaline rhyolite Comendite	Alkali feldspar and aegirine phenocrysts in fine wary-feldspar matrix full of aegirine needles	Dykes. Equivalents are strictly volcanic
Hornblende porphyrite	MI. Sabine (1953) following Bonney (1883)	Hornblende microdiorite Spessartite	Phenocrysts of hornblende and plagioclase, sometimes biotite, in fine feldspathic groundmass	Many sills. C.alc-alkaline
Ledmorite	LB. Shand (1910), from Ledmore River	Melanite-augite nepheline-syenite Melanocratic nepheline-syenite	Equigranular, medium grained with closely intergrown melanite, diopsidic augite, biotite. Alkali feldspar intergrowths with nepheline	Name occasionally used informally
Nordmarkite	LA. Phemister (1926), after Nordmarken, Norway	Quartz-syenite	Leucocratic syenites made of alkali feldspar and interstlal quartz with variable aegirine-augite and/or alkali amphibole	Main rock of BL. Also occurs as deformed sills

Perthosite	LA. Phemister (1926), main syenite unit	Alkali feldspar-sycnite	Nearly monomineralic alkali feldspar rock. Name refers to microperthitic texture	Name still widely used
Pulaskite	LA. Phemister (1926) after Pulaski Co., Arkansas	Pyroxene syenite Melasyenite	Similar to 'nordmarkites' and 'perthosites' but with more aegirine-augite. Some variants have melanite at LA, with minor nepheline and melanite at LB	Type example is nepheline-bearing so use at LA is incorrect
Shonkinite	LA. Phemister (1926) after Shonkin Sag, Montana	Pyroxene (nepheline-) melasyenite	At LA diopside and biotite, sometimes hornblende occur in glomeroporphyritic clusters set in alkali feldspar. Nepheline-bearing at LB	Nepheline usual hut not essential. Associated with ledmorites at LB
Sövite	LB. Young *et al* (1994)	Calcite carbonatite	Porphyritic sövite has large calcite rhombs set in finer calcite matrix. Phlogopite sövite has small phlogopite crystals together with apatite set in calcite matrix	Small body with xenoliths from LB outside southern contact
Vogesite	MI. Sabine (1953) after Vosges mountains	Vogesite Hornblende-rich lamprophyre	Hornblende phenocrysts set in fine-grained matrix of euhedral plagioclase, alkali feldspar, hornblende and minor warm. Diopside occurs as glomeroporphyritic clots and rare phcnocrysts	Many sills. Calc-alkaline
Vullinite	LW Shand (1910), from Ails a'hihulllin	None	Fine-grained, sometimes schistose rock, with altered plagioclase set in matrix of alkali feldspar, plagioclase, diopside, hornblende and biotite	Obsolete name. Shand considered it probably metamorphic

LB: Loch Borralan intrusion; LA: Loch Ailsh intrusion; BL: Ben Loyal intrusion; MI: Minor Intrusion.

Rock names in bold were named from type examples in Assynt. Historical details are from Holmes (1920) and Brögger (1921). Note that many of the old varietal rock names are used in the text, between quotation marks, for clarity when referring to earlier publications..

The ultimate source of the alkaline magmas, and the processes that have affected them on their rise through the crust and during their final crystallization, remain topics of intense research. The modern view of alkaline magmatism is that it is initiated by small degrees of partial melting in the Earth's mantle, which has sometimes been subject, before it melts, to a metasomatic process that enriches it in alkalis and certain other elements characteristic of alkaline magmas. These elements, particularly potassium, titanium, phosphorus, barium, strontium, uranium, thorium and the rare-earth elements, are normally present in very low concentrations in mantle rocks but reach high concentrations in alkaline magmas. The carrier that introduces these elements may be melts related to the carbonatites that are commonly associated with alkaline silicate magmas. Whatever the ultimate sources, basic alkaline parental magmas fractionate strongly as they ascend to give rise to a vast range of alkaline igneous rocks. The relative importance of variation arising during mantle metasomatism, partial melting of the mantle, crystal–liquid fractionation during uprise through mantle and crust, and reactions with wall-rocks, remain contentious, and no doubt vary from one instance of alkaline magmatism to another, accounting for the extraordinary diversity in the final consolidated products. The field relationships described in this chapter provide evidence of differentiation prior to emplacement, fractionation during final solidification, reactions with country rocks, and subsequent metasomatic reactions during cooling. It is necessary to take account of all these processes when attempting to deduce the ultimate sources of the magmas using sophisticated geochemical and isotopic techniques.

The structural setting of the Scottish alkaline suite is somewhat unusual in that its emplacement overlaps, both in time and space, a period of intense crustal shortening. Worldwide, the greatest upwellings of alkaline magma are in environments of major crustal extension, often preceded by large-scale doming, such as in the present-day East African rift system. Much early discussion on the rocks of the NW Highlands centred on this established correlation. For example, van Breemen *et al.* (1979a) suggested that the Scottish alkaline magmatism was related to arching on the scale of the entire NW Highlands Moine outcrop. They noted that the alkaline rocks formed a zone at the edge of the Caledonian mobile belt (Figure 7.1), close to or on, the rigid older crust of the stable Foreland, which could withstand differential stresses provided either by orogenic compression or in compensation for isostatic sag produced by the weight of the thrust sheets.

More recently it has become accepted that alkaline magmatism can be associated with small degrees of melting in the deeper parts of subduction zones, or with regions of the mantle that contain relics of earlier, now inactive subduction zones. This type of igneous association, known as shoshonitic magmatism, includes members with calc-alkaline affinities (like the granites that dominate Caledonian igneous activity) but includes some members with a strongly potassic, silica-undersaturated character, like the pseudoleucite-syenites in the Loch Borralan intrusion. Other members may be oversaturated and strongly sodic, like the late quartz-syenites at Loch Borralan or the 'grorudite' (comendite) suite of dykes in the Ben More thrust sheet. Shoshonites themselves are basaltic rocks unusually rich in potassium so that sanidine occurs as rims on plagioclase phenocrysts and in the groundmass.

Recent contributions dealing with the ultimate origins of the NW Highlands alkaline magmas are based largely on the trace element and isotopic chemistry of the rocks and can be touched on only briefly here. Thompson and Fowler (1986) were the first to apply the association between rocks of shoshonitic affinities and subduction to the Caledonian alkaline suite. Thirlwall (1981a) had postulated the existence of a NW-dipping subduction zone beneath the Scottish Caledonides from the chemistry of Old Red Sandstone lavas. Basing their work primarily on the trace element chemistry of the leucocratic syenite members of the major intrusions, Thompson and Fowler suggested that the parental magmas of the Caledonian alkaline rocks were ultrabasic shoshonitic magmas developed by deep melting of the asthenosphere with included slabs of crustal rocks, perhaps carried down as far as the seismic discontinuity at 670 km by this subduction zone. Fowler (1988b) later showed that basic members of the Glen Dessarry pluton had been contaminated by reactions with the Moine envelope rocks and later (1992) used isotopic data to support the shoshonite hypothesis for Glen Dessarry, invoking a two-stage fractionation model and a multi-component mantle source.

North-west-dipping subduction was also invoked by Halliday *et al.* (1987) but they pointed out that the alkaline magmatism stayed in a single narrow zone, albeit made even narrower by thrusting, over a period of 30 Ma while the region was a convergent plate margin. They also pointed out that there is a progressive increase in the alkaline characteristics of even the Caledonian granitoids towards the NW (Halliday *et al.,* 1985). They considered that these factors rule out a deep, well-mixed, asthenospheric source and pointed to a source in the lithos-pheric mantle, which had been subject to metasomatic enrichment in the elements characteristic of alkaline magmatism. They considered that the thermal state of the lithosphere, on the edge of the orogen, exercised the main control on the magmatism, with small-degree partial fusion of ancient, cold and dry lithosphere underlying the Lewisian gneisses of the Foreland to produce the alkaline melts. For the most western, most potassic and chemically by far the most extreme complex, Loch Borralan, thcy invoked special, potassium-rich subcontinental mantle, with subduction seen as the trigger for melting. Thirlwall and Burnard (1990) carried out a chemical and isotopic study of this intrusion, and concluded that all its rock types were primarily generated by strong fractional crystallization of mantle-derived, subduction-related shoshonitic magmas closely similar to those that produced the late Silurian Lorn lavas to the south of the Great Glen Fault. The magmas producing the oversaturated syenites were modified, prior to emplacement, by reactions with Lewisian crust. On geochemical grounds Thirlwall and Burnard ruled out the derivation from old, stable lithosphere favoured by Halliday *et al.* (1987), but they were not able to reach a conclusion as to whether the source was in the deep lithospheric mantle or the asthenosphere. In conclusion, it is fair to say that there is much to be done to explain the origins of Britain's most exotic suite of rocks, and in the writer's view solutions will only come when field relationships, petrography, mineralogy and the modern geochemical approach are made to work more closely together.

The alkaline rocks of the NW Highlands also have great importance because of their structural and geochronological implications. They pro vide evidence of the order and scale of movements in the Moine thrust zone, and provide the only exact time markers for events in this internationally famous major structure. A number of workers have discussed the possibility that the igneous rocks in Assynt were responsible for the embayment in the Moine Thrust known as the Assynt Culmination. This interweaving of igneous activity and structural events is an unusual and outstanding characteristic of the province and a number of the sites described in this chapter have been chosen to illustrate not only petrographical types but also critical structural relationships.

Although the early map-makers (Peach *et al.,* 1907) thought that all the igneous activity in Assynt occurred prior to the movements on the great thrust planes, it was Bailey and McCallien (1934) who first pointed out evidence that thrust movements actually overlapped the emplacement of the igneous rocks. They noted undeformed pegmatites cutting pseudoleucite-syenites in the Loch Borralan complex in which the normally rounded pseudoleucites had been flattened. They suggested that the flattening occurred as a result of thrust movements. The origin of this flattening is still controversial, but contemporaneity of igneous activity and thrusting was firmly established in an important paper by Sabine (1953), in which he recognized that particular types of minor alkaline intrusion occurring as dykes and sills were restricted to particular structural units in the thrust region.

(Figure 7.2) is a simplified map of the structure of Assynt, showing the main thrust planes. The development of nomenclature of the thrusts is reviewed in Johnson and Parsons (1979). There are many minor planes of movement, in particular the arrays of high-angle reverse faults joining low-angle thrusts originally known as imbricate structure but called duplex structure by modern workers. In places the sills of Assynt are repeated by such structures. For modern treatments of the structural setting of the igneous rocks in Assynt the reader is recommended to read Johnson and Parsons (1979), Elliott and Johnson (1980) and Coward (1985). The uppermost thrust is the Moine Thrust itself, bringing the metamorphic Moine Supergroup of the Moine Nappe, mylonitized at the base, over the Lewisian, Torridonian and Cambro-Ordovician rocks of the Ben More Nappe, itself carried westward on the Ben More Thrust. North of Inchnadam ph the rocks below the Ben More Thrust were moved on a lower thrust, the Glencoul Thrust, carrying the Glencoul thrust sheet, but west of Inchnadamph the Ben More and Glencoul thrusts join. Sabine (1953) noted that a type of peralkaline felsite dyke, for which he used the name 'grorudite', occurred only in the Glencoul and Ben More thrust sheets and suggested that this meant that both sheets had behaved as a single tectonic unit, for which he proposed the name Assynt Nappe. He suggested that, south of Inchnadamph, the combined Ben More and Glen Coul thrusts be called the Assynt thrust plane. However Sabine's terminology has not been adopted by recent workers and the early terminology of Peach and Horne (in Peach *et al.,* 1907) is retained in this chapter. Sabine located a solitary 'grorudite' in rocks of the Cam Loch Klippe ((Figure 7.2), locality 2), confirming the classic interpretation of Peach and Horne that these rocks were outliers of the Ben More thrust sheet. The lowest thrust sheet, the Sole Nappe, brings thrust rocks over the undisturbed Foreland region.

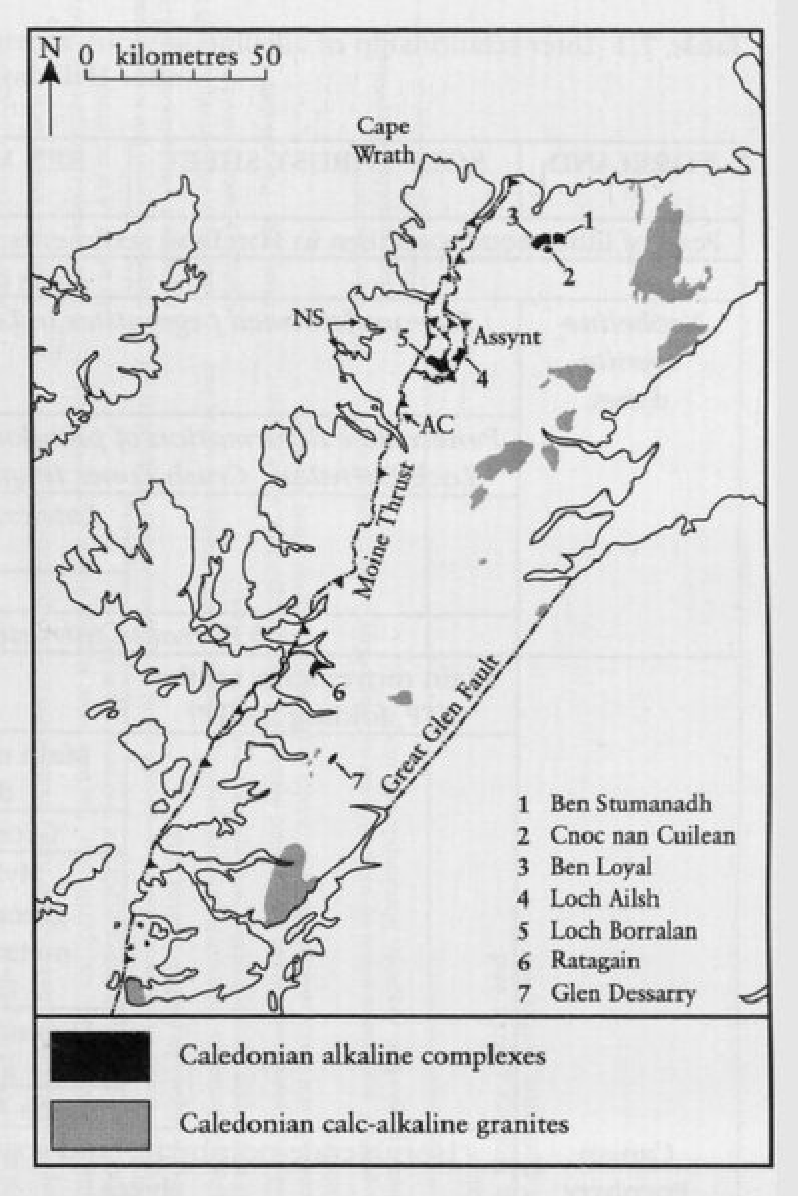
Sabine noted many other striking restrictions on the distribution of the alkaline dykes and sills in Assynt. These can be used to make important deductions concerning the order of events in the thrust belt, and together with radiometric ages obtained on the plutons, to provide brackets for the ages of the main thrust movements. (Table 7.1) is the most recent interpretation. Although some workers (e.g. Macgregor and Phemister, 1937) regarded the thrust sequence as propagating upwards, lower thrusts being truncated by higher ones, the modern view is that thrusts normally evolve downwards, with older thrusts riding piggy-back on younger lower ones. This picture is compatible with the distribution of igneous rocks in Assynt, although all workers agree that late movements on the Moine thrust plane must have occurred.

A final important point is the possible role of the alkaline rocks in Assynt in giving rise to the Assynt Culmination. This embayment in the Moine Thrust (Figure 7.2) is actually a broad upwarp or bulge in the Moine thrust plane, and between it and the almost perfectly planar Sole Thrust is a thick lenticular complex of thrust rocks. Several early workers (Phemister, 1926; Bailey 1935; Sabine, 1953) suggested that there was a causal connection between this thickening and the presence of the minor and major bodies of igneous rocks, and their view was supported by Elliott and Johnson (1980). The connection would not be a direct one, because the thickness and volume of the igneous rocks is far less than the thickness and volume of the culmination. But it is plausible that the igneous rocks and their thermal metamorphic aureoles increased the resistance to slip of the Cambro-Ordovician horizons on which most of the thrusts moved, roughening the slip surfaces, and causing duplication and doming.

Three of the sites selected for this Geological Conservation Review are relatively large and complex, and an extended description of each is given. These are the major intrusions at Loch Borralan and Loch Ailsh in Assynt, and the group of intrusions around Loch Loyal, 40 km to the NE (Figure 7.1). Localities have been chosen within these sites that illustrate the great range of unusual rock types, internal and external contact relationships, and structural implications.

The remaining 12 sites are much smaller and of a different character. Examples have been selected of each rock type represented in the extensive suite of dykes and sills that occur in Assynt, on the grounds of typical character, accessibility, and where appropriate, their relationship with the major structures in the thrust belt. The exposures arc individually important because of the relatively rare rock types represented, and also important as a suite, because of their petrogenetic, structural and chronological implications. A common introduction to each of the rock types is provided, setting out their petrography and structural implications. Peralkaline rhyolites ('comendites', the 'grorudites' of Sabine, 1953) are described cutting the Loch Ailsh syenite in Glen Oykel, south, illustrating an important relative intrusive age relationship, and from the Cam Loch Klippe at Craig na h-Innse Ruaidhe, east of the Cam Loch, exemplifying the restriction of this rock type to the Ben More thrust sheet. Porphyritic quartz-microsyenite (the Canisp Porphyry), is described from a large and physiographically important site on Beinn Garbh, from the Laird's Pool GCR site near Lochinver (which demonstrates its extension into the Foreland), and from a structurally important site west of Loch Awe (Cnoc an Leathaid Bhuidhe). Calc-alkaline hornblende microdiorite sills (so-called 'hornblende porphyrites') are extremely common in Assynt and examples of these are described from intense swarms on Cnoc an Droighinn, east of Inchnadamph and Luban Croma, north of the Loch Borralan intrusion. More mafic but other wise similar hornblende lamprophyres (vogesites) are also common and are described from Allt nan Uamh and from Glen Oykel, north where the vogesite is associated with a remarkable diatreme with a carbonate matrix. A set of sills of quartz-microsyenite ('nordmarkite') occurs near the Moine thrust plane (usually just above) and an example from Allt na Cailliche, SE of Loch Ailsh, is described. Finally, two examples of melanite nepheline-microsyenite ('ledmorite') cutting Torridonian and Lewisian rocks on the west coast, at Camas Eilean Ghlais and An Fharaid Mhór show that the source of the most strongly alkaline magmatism was beneath the Lewisian Foreland, and also have important implications for late movements on the Sole thrust.

References



(Figure 7.1) Map of NW Scotland showing localities of alkaline intrusions, aligned roughly parallel to the Moine Thrust. Many alkaline dykes and sills occur in the Assynt district and also near Ullapool in the Achall Culmination (AC). GCR sites exemplifying nepheline-syenite dykes in the Foreland are indicated by NS. Caledonian calc-alkaline granites NW of the Great Glen are also shown. The Ratagain intrusion is largely calc-alkaline in character but has minor syenitic members (after Halliday et al., 1987, fig. 1).

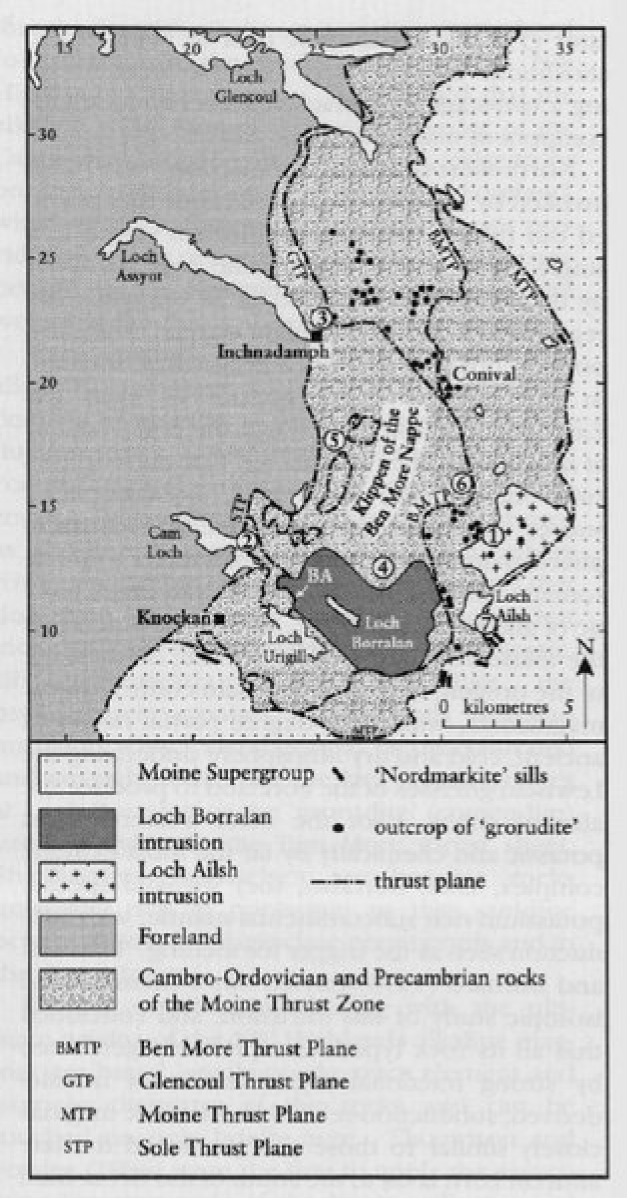
Table 7.1 Inter-relationship of alkaline igneous activity and major tectonic events in the Moine thrust zone (after Halliday *et al.*, 1987).

FORELAND	SOLE THRUST SHEET	BEN MORE NAPPE	MOINE NAPPE	AGE (Ma)
Peak of illite metamorphism in Foreland sediments				*c.* 408[1]
		Ross of Mull Granite cuts Moine thrust plane		414±4[2]
Nepheline-syenite dykes	*Late undeformed pegmatites in Loch Borralan*		*Cnoc-nan-Cùilean intrusion*	426±9[5]
	Penetrative deformation of pseudoleucite rocks at Loch Borralan. Crush Zones in quartz-syenites		*Final movements on the MTP*	
		Late crushing in Loch Ailsh		
		'Nordmarkite' sills near the MTP		
	Loch Borralan intrusion			430±4[3]
	Main movements on the STP, folding BMTP?			
		Main movements on the BMTP		
		'Grorudite' dykes		
		Mylonites and greenschist-facies metamorphism in Loch Ailsh	Moine mylonites and 'D1' Main movements on MTP	
		Sgonnan Mór folds and fabric		
		Loch Ailsh intrusion		439±4[5]
Canisp Porphyry	'Hornblende-porphyrite' and vogesite sills and dykes			
			'D3' of Glen Dessarry Moine. Deformation of syenite	
			Glen Dessarry intrusion	456±5[4]

Events in italic were essentially synchronous. MTP: Moine thrust plane. BMTP: Ben More thrust plane. STP: Sole thrust plane. The radiometric ages are from the following sources: 1. Johnson *et al.*, 1985. 2. Halliday *et al.*, 1979a. 3. Van Breemen *et al.*, 1979a. 4. Van Breeman *et al.*, 1979b. 5. Halliday *et al.*, 1987.

Rock name	First use in NW Highland's literature	Modern equivalent(s)	Petrography and mineralogy	Comments
Assyntite	LB. Shand (1910) NW of Cnoc na Sroine	Sodalite nepheline-syenite	Trachytic texture; alkali feldspar, interstitial nepheline, both enclosing sodalite, with biotite, magnetite and titanite	Obsolete name. An exotic rock but poorly exposed
Borolanite	LB. Horne and Teall (1892) from SE end of intrusion	Melanite-biotite (pseudoleucite-) nepheline-syenite	Alkali feldspar-nepheline intergrowths (both in pseudoleucite and matrix), well-formed melanite and biotite. Pseudoleucite not always present	The original name is still occasionally used informally
'Canisp Porphyry'	ML. Adopted by Sabine (1953) from early usage	Porphyritic quartz-microsyenite	Alkali and plagioclase feldspar phenocrysts in a groundmass of turbid feldspar and quartz	Forms major sill complex
Cromaltite	LB. Shand (1910) from Bad na h-Achlaise, After Cromalt Hills	Melanite-biotite pyroxenite	Diopsidic pyroxene and titanomagnetite enclosed by biotite and replacive melanite	Obsolete name. Similar pyroxenites without melanite at LA
Grorudite	ML. Sabine (1953)	Peralkaline rhyolite Comendite	Alkali feldspar and aegirine phenocrysts in fine quartz-feldspar matrix full of aegirine needles	Dykes. Equivalents are strictly volcanic
Hornblende porphyrite	ML. Sabine (1953) following Heddle (1883)	Hornblende microdiorite Spessartite	Phenocrysts of hornblende and plagioclase, sometimes biotite, in fine feldspathic groundmass	Many sills. Calc-alkaline
Ledmorite	LB. Shand (1910), from Ledmore River	Melanite-augite nepheline-syenite Melanocratic nepheline-syenite	Equigranular, medium grained with closely intergrown melanite, diopsidic augite, biotite. Alkali feldspar intergrowths with nepheline	Name occasionally used informally
Nordmarkite	LA. Phemister (1926), after Nordmarken, Norway	Quartz-syenite	Leucocratic syenites made of alkali feldspar and interstitial quartz with variable aegirine-augite and/or alkali amphibole	Main rock of BL. Also occurs as deformed sills
Perthosite	LA. Phemister (1926), main syenite unit	Alkali feldspar-syenite	Nearly monomineralic alkali feldspar rock. Name refers to microperthitic texture	Name still widely used
Pulaskite	LA. Phemister (1926) after Pulaski Co. Arkansas	Pyroxene syenite Melasyenite	Similar to 'nordmarkites' and 'perthosites' but with more aegirine-augite. Some variants have melanite at LA, with minor nepheline and melanite at LB	Type example is nepheline-bearing so use at LA is incorrect
Shonkinite	LA. Phemister (1926) after Shonkin Sag, Montana	Pyroxene (nepheline-) melasyenite	At LA diopside and biotite, sometimes hornblende occur in glomeroporphyritic clusters set in alkali feldspar. Nepheline-bearing at LB	Nepheline usual but not essential. Associated with ledmorites at LB
Sövite	LB. Young *et al.* (1994)	Calcite carbonatite	Porphyritic sövite has large calcite rhombs set in finer calcite matrix. Phlogopite sövite has small phlogopite crystals together with apatite set in calcite matrix	Small body with xenoliths from LB outside southern contact
Vogesite	ML. Sabine (1953) after Vosges mountains	Vogesite Hornblende-rich lamprophyre	Hornblende phenocrysts set in fine-grained matrix of euhedral plagioclase, alkali feldspar, hornblende and minor quartz. Diopside occurs as glomeroporphyritic clots and rare phenocrysts	Many sills. Calc-alkaline
Vullinite	LB. Shand (1910), from Allt a'Mhuilin	None	Fine-grained, sometimes schistose rock, with altered plagioclase set in matrix of alkali feldspar, plagioclase, diopside, hornblende and biotite	Obsolete name. Shand considered it probably metamorphic

LB: Loch Borralan intrusion; LA: Loch Ailsh intrusion; BL: Ben Loyal intrusion; ML: Minor Intrusion.
Rock names in **bold** were named from type examples in Assynt. Historical details are from Holmes (1920) and Brøgger (1921). Note that many of the old varietal rock names are used in the text, between quotation marks, for clarity when referring to earlier publications.



(Figure 7.2) Map of the Assynt district showing the major thrusts, the two major alkaline intrusions, and the distribution of two of the six types of minor intrusive rocks. BA is the critical locality, at Bad na h-Achlaise, where nepheline-syenites and pyroxenites of the Loch Borralan intrusion are intruded into one of the klippen (the Cam Loch Klippe) of the Ben More Nappe. GCR sites in the thrust zone related to minor intrusive rocks are shown by circled numbers. 'Grorudite': 1, Glen Oykel South; 2, Creag na h-Innse Ruaidhe. 'Hornblende porphyrite': 3, Cnoc an Droighinn; 4, Luban Croma. 'Vogesite': 5, Allt nan Uamh; 6, Glen Oykel North (diatreme). 'Nordmarkite': 7, Allt na Cailliche. (After Sabine, 1953 and Johnson and Parsons, 1979, fig. 3.)