

Carboniferous and Permian dykes and sills, Midland Valley of Scotland

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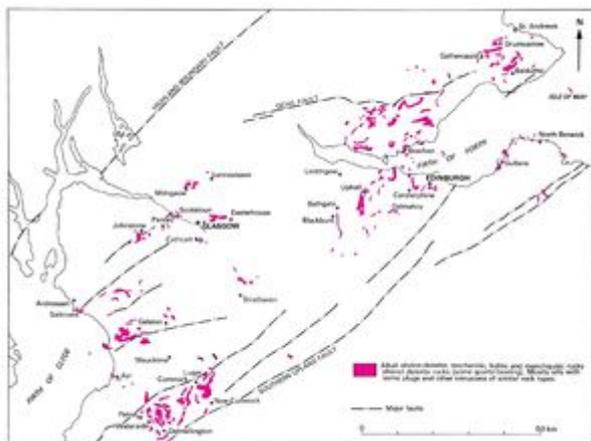
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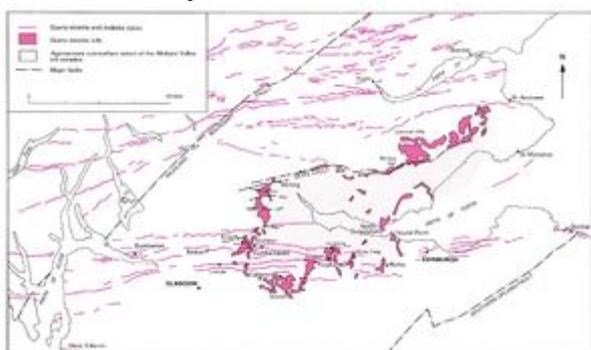
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Alkali dolerite and related sills



Alkali dolerite sills and associated intrusions of Carboniferous and Permian age in the Midland Valley. P915544.



Late Carboniferous quartz-dolerite and theoleitte intrusions in the Midland Valley. P915545.



Base of late Carboniferous quartz-dolerite sill intruded into sandstones of the Calciferous Sandstone Measures, Hound Point, South Queensferry. P219250.

Large sills and sill-complexes of basic alkaline rocks occur within the Carboniferous basins of the Lothians and Fife, in the western part of the Central Coalfield basin around Paisley and Glasgow, and in the Ayrshire Coalfield basin ([P915544](#)). There is no associated dyke swarm. Most are of Silesian to Permian age and may occur at deeper levels in basins of thick sediments, where near-contemporaneous surface eruptions are of a predominantly explosive, pyroclastic nature. In coalfield areas they are known to intrude along coal seams. In such circumstances, the coal may be either totally replaced, 'burnt' or coked, or converted to a higher-grade anthracitic coal and the dolerite is altered to 'white trap'. The sills have been quarried extensively for aggregate throughout the Midland Valley.

Petrography of the alkaline sills

Basic alkaline rocks of the Midland Valley were the subject of numerous early works on the origin and differentiation of basaltic magmas, on account of the wide variety of rock-types often present within a single composite or differentiated body such as the Lugar and Saltcoats sills of Ayrshire and the Braefoot Outer Sill of Fife. Almost all the sills are of olivine-bearing doleritic

rock types which have been divided for descriptive purposes into five groups. Within these groups many individual names have been utilised to describe the more-distinctive rock-types. Composite or differentiated intrusions rarely contain rock-types from two or more groups and many include basic or ultrabasic layers in their lower parts.

1	Kylitic types are characterised by the presence of abundant olivine (10-40%), usually with nepheline and euhedral, zoned, purplish augite. They include essexite, theralitic essexite, theralite, olivine-rich theralite (= 'kylite'), basanite and picrite.
2	Teschenitic types have less olivine (5-15%) than the kylitic types and all are analcime-bearing. They include teschenite, hornblende-teschenite, camptonite, bekinkinite, picrite and peridotite. Most of the rocks described as 'teschenite' in the Midland Valley are strictly 'olivine-bearing teschenites'.

3	Alkali olivine-dolerites and basalts are mildly-undersaturated but with no visible nepheline and little analcime. Textures may be ophitic, sub-ophitic, intergranular or microporphyritic, the latter commonly resembling the Dalmeny lava-types.
4	Monchiquitic types are fine-grained, feldspar-free rocks consisting of phenocrysts of olivine and augite in a mesostasis of glass, analcime or nepheline. Most lack the amphibole, characteristic of true monchiquites and thus are more correctly termed olivine-analcimites or olivine-nephelinites. Similar rocks containing some plagioclase are analcime-basanites, nepheline-basanites and leucite-basanites. Many are xenolithic (p.112).
5	Altered doleritic types include chloritised and serpentinitised olivine-dolerites, some with residual analcime and some with juvenile quartz. Others are altered olivine-free dolerites with traces of quartz.

A characteristic of both alkali dolerite and tholeiitic quartz-dolerite intrusions throughout the Midland Valley are the zones of 'white trap' in which the normal rock is transformed into a pale white, cream or yellowish brown alteration product. The primary doleritic texture is usually preserved, but the constituent minerals are pseudomorphed by kaolinite, chlorite, leucoxene, amorphous silica and carbonate. Most 'white trap' is associated with fault planes which can contain vein mineralisation (Chapter 16). 'White trap', commonly containing solid or viscous hydrocarbons on joint surfaces, is particularly widespread in dolerites that are associated with carbonaceous shales, coals or oil-shales. It has been suggested that the alteration is caused by volatiles released during the distillation of such rocks by heat from the intrusions.

Dinantian to early Westphalian sills of the Lothians and Fife

Major sills up to 120m thick, in the eastern Midland Valley are mostly of olivinedolerite or teschenitic type, although monchiquitic types occur as smaller bodies in the later Stephanian/early Permian vents of east Fife and East Lothian.

The sills cut mainly Calciferous Sandstone Measures in the Lothians and extend into the Upper Limestone Group in Fife, but are absent from the Passage Group and Coal Measures. It has therefore been suggested that they are of late Viséan to Namurian age, contemporaneous with the volcanicity of the area. Quartz-dolerite dykes of the early Stephanian regional swarm cut teschenite sills on Inchcolm Island and near Linlithgow and hence provide an upper age limit. Some of the olivine-dolerite sills bear a strong petrographic and geochemical resemblance to neighbouring extrusive rocks and may be of Viséan age. The teschenites, however, form a separate distinctive suite and appear to be later, although their fine-grained margins often consist of olivine-basalt or basanite, akin to the Dalmeny type lavas of the Bathgate Hills and Burntisland. Veins of sediment within several teschenite sills were originally taken to indicate intrusion into unconsolidated sediments during the Viséan, but some veins have been reinterpreted as intrusive tuffisites, possibly related to later volcanic activity. Recent K-Ar whole-rock dates suggest minimum ages within the range 313 to 296 Ma (i.e. Westphalian) and hence imply affinities with the Namurian to early Westphalian volcanicity.

Teschenitic sills are widespread in the Lothians, including the sills of Gullane, Salisbury Craigs, Craigie and Blackburn. Altered dolerites form the Corstorphine Sill, Edinburgh and the Stankards Sill, Uphall, both of which contain thick bands of picrite. Rocks from the Lochend Sill, Edinburgh and Craighleith sill, North Berwick have been described as 'essexites'. An olivine-bearing doleritic sill with some tholeiitic affinities in the Dalmahoy and Kaimes area of West Lothian has previously been regarded as an atypical member of the Stephanian quartz-dolerite suite. However, a K-Ar date suggests a minimum age of 320 Ma and supports an earlier interpretation that the sill is contemporaneous with the Dinantian or Namurian volcanic activity.

In Fife olivine-dolerite and teschenite sills are abundant, forming sill-complexes up to 115 m thick which are well known from coal workings and boreholes, as well as from extensive surface outcrops. The distribution of the various types shows a rude zonal pattern in east Fife which is independent of geological structure. Examples of ophitic, non-ophitic and microporphyritic olivine-dolerites occur in major sills at Gathercauld, Drumcarrow and Baldutho. Well-known examples of teschenitic types occur on the Isle of May, on Inchcolm Island and at Braefoot Point. The latter has a layered structure attributable to gravitative sinking of olivine, and consists of picroteschenite, teschenite, dolerite and dolerite-pegmatite within chilled margins of basalt.

Westphalian to Permian sills of the western Midland Valley

Representatives of almost all the rock-types listed occur in extensive sills and sill-complexes in the Ayrshire Coalfield basin and teschenite sills are abundant in the Glasgow-Paisley area. Representatives of all types cut Coal Measures strata and most sills are therefore of late Westphalian age or younger age.

In the Ayrshire Coalfield the kylitic and monchiquitic sills and some teschenites are younger than all major faults of the area. They have strong petrographic and geochemical affinities with the Lower Permian Mauchline lavas, are cut by necks and dykes associated with the lavas, and occur as blocks in vent agglomerates. They are therefore assumed to be slightly older than or broadly contemporaneous with the Permian lavas. Palaeomagnetic measurements support a Permian age and K-Ar mineral dates indicate minimum ages in the range 285 to 276 Ma. The majority of teschenitic sills (including the Lugar Sill), teschenitic olivine-dolerites and a variety of altered doleritic types also cut the Coal Measures and most major faults, but are affected by a set of NW-SE-trending faults. These sills are therefore assumed to be slightly older and separated minerals have yielded K-Ar minimum ages in the range 297 to 286 Ma. Most are probably of late Westphalian or early Stephanian age, but it is possible that some (e.g. the Craigie Sill, south of Kilmarnock) are associated with the Passage Group lavas.

Kylitic sills are well developed in the Kyle district of Ayrshire, north of Dalmellington. The Benbeoch sill includes the type 'kylite' (an olivine-rich theralitic essexite) and contains picritic layers. Other picritic sills occur locally and felsic, alkaline segregation veins are recorded from Kilmear Hill. Monchiquitic sills are never more than 2 m thick and are closely associated with volcanic necks of the Mauchline lavas. Notable examples occur in the Waterside area south of Patna.

Teschenite sills are numerous in the area around Cumnock and also between Ardrossan and Galston. Other sills of less-alkaline teschenitic olivine-dolerite occur mainly in the area between Patna, Dalmellington and Cumnock. The Lugar sill is thought to have formed from an initial intrusion of picroteschenite magma followed shortly afterwards by one or more pulses of olivine-theralite or peridotite and later veins of lugarite (amphibole-rich ijolite). There has been much debate as to whether differentiation took place before or after intrusion. Other composite intrusions which include both kylitic and teschenitic rock types occur in the Patna area.

Highly-altered olivine-dolerites, some with secondary quartz, form extensive outcrops near Dalmellington and Cumnock. They include the Craighens-Avisyard composite sill-complex which also contains biotite- and hornblende-bearing teschenitic basalts and picrites.

In the Glasgow-Paisley area, alkali dolerite sills cut strata ranging from Upper Calciferous Sandstone Measures to Coal Measures. K-Ar mineral dates from four sills are tightly grouped in the range 273 to 270 Ma, suggesting contemporaneity with the Permian sills and lavas of the Ayrshire coalfield. All the major sills are teschenitic, although some contain appreciable nepheline in addition to analcime. A notable example of such a rock is the bekinkinite of Barshaw, near Paisley, a

melanocratic theralite with abundant titanite and red-brown amphibole (kaersutite). Essexites occur in a small, boss-like intrusion near Lennoxton.

Four major sill-complexes, some consisting of up to three leaves with a maximum recorded thickness of 36 m, can be traced over wide areas. These occur in the Johnstone–Howwood area; between Paisley and the River Clyde at Scotstoun (the 'Hosie' and 'Hurlet' sills); around Cathcart; and between Necropolis Hill, Glasgow and Easterhouse. Highly altered sills around Milngavie consists of olivine-free dolerite with sporadic, minute patches of quartz. However their mafic minerals (purplish augite, with sporadic red- brown amphibole and biotite) are of the type found in teschenites.

Quartz-dolerite intrusions

Broad, persistent, quartz-dolerite dykes with a general E-W trend cut rocks ranging from Lower Devonian to Middle Coal Measures in the northern part of the Midland Valley ([P915545](#)). The dykes include fine-grained varieties with a glassy mesostasis which have traditionally been called tholeiites. Thick sills in the Firth of Forth area are closely associated with the dykes in terms of field relationships, petrography and geochemistry. They may be regarded as components of a Midland Valley Sill-Complex ([P915545](#)), comparable and contemporaneous with the Whin Sill of northern England.

Quartz-dolerite intrusions commonly follow E-W fault planes and post- date their main movement. Such faults are known to displace the Coal Measures and in the offshore Fife coalfield quartz-dolerite intrusions cut Westphalian B strata. Field evidence of an upper age limit comes mainly from Fife and is inconclusive: Blocks of quartz-bearing dolerite occur in several vents, most significantly in those of Ardross and St Monance which are considered to be of late Stephanian age, but also in those of Viewforth and Lundin Links which are of less certain age. Plugs of olivine-basalt and basanite in the Lomond Hills have been considered to cut quartz-dolerite sills but the relationship cannot be proved. Better evidence is found in northern England, where fragments of Whin Sill have been found in a Lower Permian breccia and in the western Highlands, where quartz-dolerite dykes are cut by dykes of the Permian camptonite-monchiquite suite. Whole rock K-Ar dates range from 295 to 290 Ma and a late Westphalian/early Stephanian age for the suite is now generally accepted. The quartz-dolerites therefore represent an interlude of tholeiitic magmatism, which has no known extrusive equivalent, between the major alkaline volcanic episodes of the Dinantian–Namurian and Stephanian–Lower Permian.

Dykes

Many of the dykes cross the Midland Valley in continuous lengths of up to 80 km or may be traced as en-echelon offsets. To the west they cut the Highland Boundary Fault and Dalradian metamorphic rocks and several dykes may be traced almost continuously for 130 km from Loch Fyne to the Tayside area ([P915545](#)). The more persistent dykes are commonly 20 to 30m wide with some up to 50 m ([P219945](#)). Geophysical surveys have shown that the swarm continues across the North Sea at least as far as the Central Graben.

In the central Midland Valley persistent quartz-dolerite dykes form a 20 kmwide swarm trending due E-W from Dunbar to Dumbarton. To the south dykes are less numerous and the most southerly major representative occurs at West Kilbride, although many narrower E-W tholeiite dykes in the Ayrshire Coalfield may be of similar age. The extensive dyke swarm north of the Ochil Fault gradually assumes an ENE trend closer to the Highland Boundary Fault. Some dykes are deflected locally into a NE trend in the fault zone.

Sills

Quartz-dolerite sills form prominent scarp features such as the Castle Rock and Abbey Craig, Stirling; the Lomond Hills; and Cockleroy Hill and Carribber Hill in the Bathgate Hills. Other well-known sills crop out at North Queensferry, Hound Point ([P219250](#)), Ratho, the Caldercruix-Shotts area and Kilsyth. Many have been quarried for road metal. Extensive sills are encountered in mines and boreholes in the Central and Fife coalfields where their effect on coal seams is similar to that of the alkali dolerite sills (p.112). Many sills consist of several leaves, 25 to 100 m thick, linked by near-vertical dykes or 'step and stair' transgressions, which are often related to pre-existing fault planes. The whole sill complex is up to 150m in total thickness and occupies some 1600 km².

Francis (1982) has shown that the shape of the sill complex approximates to a series of 'saucers', the lowest and thickest parts of which coincide with the centres of syn-sedimentary Carboniferous basins. In detail, many transgressions can be shown to have occurred in a downward sense, often leaving a thin continuation sill at the higher horizon. It thus seems likely that magma was able to 'flow' down gently-inclined bedding planes into the centres of the basins.

There are no indications of feeder dykes or pipes in the lower, central parts of the complex, but various E-W dykes in the southern part of the regional swarm have long been considered as possible feeders, since some are seen to pass locally into sills (e.g. the Lenzie-Torphichen, Dullatur and Cumbernauld dykes). On the northern margin of the sill complex, the Ochil Fault Intrusion, a series of irregular pods in the plane of the Ochil Fault, is also considered to be connected with the sill-complex and is a possible feeder.

Petrography

A complete spectrum of textures exists between various named types of tholeiite and the quartz-dolerites but mineralogical and geochemical differences are slight. All types occur as broad, persistent dykes, but tholeiites predominate among the thinner dykes and also occur on the margins of thick quartz-dolerite dykes and sills. The textural differences may therefore reflect differing rates of cooling and volatile contents of individual intrusions.

The quartz-dolerites consist essentially of labradorite laths, subophitic augite, pseudomorphs after hypersthene, occasional pigeonite, iron-titanium oxides and an intersertal mesostasis of quartz and alkali-feldspar, usually intergrown as micropegmatite. Amphibole and biotite commonly fringe the augite and oxides. Apatite and pyrite are usual accessories.

Tholeiites are distinguished by the presence of intersertal, pale brown, often devitrified, microlitic glass. Augite is more granular than in the quartz-dolerites, pseudomorphs after olivine occur sporadically, calcium-poor pyroxene is absent and skeletal ilmenite often forms reticulate patterns in the glass. Chlorophaeite (an amorphous mixture of green ferruginous silicates which darkens on exposure to air) is a feature of several tholeiites in which it occurs in intersertal areas or as pseudomorphs after fayalitic olivine.

A fine-grained sill at Binny Craig, West Lothian, consists of a distinctive basalt with small phenocrysts of plagioclase and augite, but is otherwise mineralogically and chemically similar to the quartz-dolerites.

Differentiation of the quartz-dolerites is best observed in the thicker sills and to a lesser extent in wide dykes. Sills are chilled at top and bottom with marginal zones of fine-grained dolerite. The central parts consist of a medium-grained, homogeneous dolerite, in the upper part of which a zone of coarse, irregular, crystallisation commonly occurs. Pink quartzo-feldspathic patches within this

zone commonly contain long feathery clusters of augite crystals. Pink aplite veins also occur throughout the sills and quartz-calcite-chlorite veins are abundant in the upper parts. Late stage veins of fine-grained basaltic material, presumably from later pulses of magma, are recorded from both dykes and sills.

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