THE CORNISH "GREENSTONES"

J. ROBSON

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The dark green basic intrusives of S.W. England (excluding the Lizard), known locally as greenstones or "blue elvan," occur in numerous outcrops and have been quarried extensively for walls, road metal, tarmac and concrete aggregate, on account of their tough, angular character. Unfortunately most of the quarries, especially the excellent ones run by the County Council, have closed in recent years, and supplies are got from a few large concerns. Study of the geology of the greenstones is thus restricted to natural (coastal) exposures in a large measure, and most attention has, with very good reasons, been devoted to the north coast of Land's End and other headlands, where classic papers have been written.

The "greenstones" include igneous ophitic dolerites, micro-gabbro, diabase, proterobase, amphibolite, and picrite: and also metamorphic epidiorite, meta-dolerite hornfels and many special rarer products.

I. DISTRIBUTION, AGE AND ORIGIN

1. **Superficial outcrops** of these rocks, as laid down by H.M. Geological survey, total over one hundred, many perhaps repeated by folding. Topographically, the greenstones never show prominent landmarks (tors) like granite, due to their small size, small irregular joints and Tertiary planation under the sea: they may give slight hills or ridges (Clicker Tor is exceptional: serpentine), but generally no superficial features indicate outcrops, apart from a few weathered (whitish) boulders or where narrow valleys cut the rock. They weather to a rich heavy brown soil: weathering grades down to an irony clay can be well seen at Porthleven beach, in all stages and prominently spheroidal. On the coast, the hard greenstones usually form headlands and if rapidly alternating with slate, coves and a crenulate

coastline develop, e.g. N. Land's End coast (Kenidjack to St. Ives), Penlee, Marazion to Praa (reefs normal to coastline). Good examples of headlands and fine exposures/contacts are at St. Ives, Gurnard's Head, Botallack, Kenidjack, Tater-du, Cudden Pt.; Park Hd., Dinas Hd., Trevose Hd., Stepper Pt., and Cliff Castle, Pentire. The first five, being in the granite contact-zone, are of special interest.

The greenstones occur in groups or zones or as isolated bosses, and largely disconnected. The two main groups are in S.W. Cornwall around the Lands End-Falmouth granites, and in N. Cornwall-West Devon in a broad west/east zone between the Camel estuary and Okehampton and Plymouth. Smaller groups occur around St. Austell and in the Teign valley. Central Cornwall, and the greater part of Devonshire are apparently devoid of these rocks, and in no case do they cut or appear in sandy rocks (i.e. the Gramscatho, Staddon grit, or Upper Culm series).

The linear sill-like trend of the outcrops is usually apparent. In most cases, proximity to the granite domes is marked: greenstones often occur in a zone round the granites, and where this is not so, they strike west/east between the granites, with the slates, and like the slates and porphyry-dykes, tend to be diverted in strike and veer according to the slate-structure and granite uplifts: excellent examples occur around Penzance, Ponsanooth, St. Mabyn, Altarnun and Okehampton.

2. Structure in Section

The basic rocks are massive intrusive sheets (sills) or small bosses, generally thin (from 1-70 ft.): rarely do they form dykes. They tend to follow the bedding horizons, though locally they cross them and pinch out: this is well seen in the smaller sheets, e.g. Porthleven, Marazion. Where the rock is a lens, or laccolite, the slates are domed and curved round the igneous rock, though locally transgressed or torn. Xenoliths of slate/hornfels are frequent in places, e.g. Helsbury, Botallack; confused but beautiful intersheared masses of greenstone and slate hornfels occur, e.g. Botallack, Lowertown (Helston), St. Ives, and Tater-du are perhaps the best examples. The sills are bent, domed and folded with the enclosing slates, as is well seen at Cudden Point (the largest example), Marazion, and Cataclews. At Trevone, limestone is included. They induce limited contact metamorphism on the slates (a pale grey hornfels) adinole and may show a porphyritic or microcrystalline chilled margin (as on the upper contact at Parc-an-als, Porthleven—a very instructive exposure).

The more massive " greenstones ", whether they were intrusive sheets or lavas, have in general suffered little from the Post-Carboniferous deforming movements by which the slates have been so greatly disturbed, so that they may wrap round the igneous mass and the adhering hornfels may be torn off. Where parts (edges) of these masses are sheared, there are usually other parts which have escaped crushing, particularly the coarser facies (Mousehole, St. Ives Is., Tolpetherwin), and served as phacoids around which the adjacent slate was compelled to flow. These cores show the original igneous texture and rock type and enabled it to be classified.

There is little major alteration in structure or minerals, by shearing. Secondary green hornblende (uralite) is invariably formed except in the coarsest types, but rarely do they approximate to schist or gneiss (as in the Lizard schists, which are of similar composition).

3. **Age and origin**

The above facts indicate the probable concordant intrusive nature (sills or small laccolites) of the greenstones. A few may be lavas, e.g. Kenidjack (Tilley 1935), Carn Moyle-St. Ives (Lacey 1958), Tubbs Mill, Gorran, and Nare Head (Hendriks 1925), but in general the characteristic flow, vesicular or pillow structures are lacking and the features of intrusives are present.

The intrusions penetrate all the formations of Lower and Upper Devonian, and Lower Carboniferous (Culm slates) series. They rarely appear in the Middle Devonian or Upper Carboniferous (Culm), and never in their sandstones. Maximum development is in the Mylor slates (S.W. Cornwall) and Upper Devonian slates (N. Cornwall).

The main outcrop groups are confined to:—

LOWER ? DEVONIAN—St. Ives, Penzance, Camborne, Penryn: St. Austell, Lanivet: Kingsbridge.

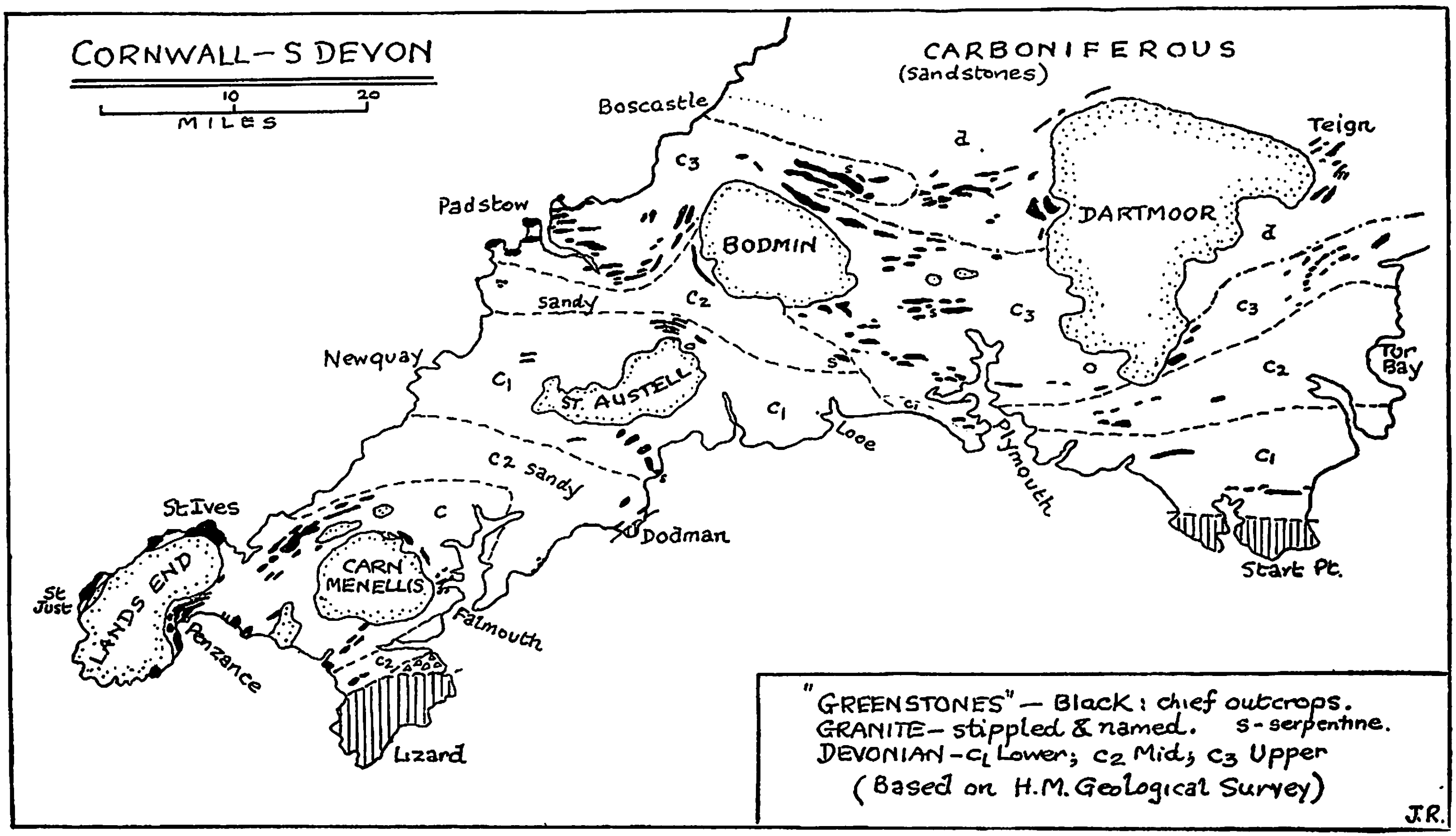
UPPER DEVONIAN—Padstow, St. Mabyn, Altarnun, North Hill, Mornick, Callington, Saltash, Newton Abbot.

LOWER CULM—Milton Abbot, Lydford, Okehampton, Tavistock, Teign Valley.

The greenstones are pre-granite in age; the granite alters them locally (forming pyroxene, garnet, biotite, axinite and tourmaline); its lodes and quartz veins pass into or through them. They are frequently domed by the granite masses and dip away from them, though seldom coming in contact: thus they appear to follow the granite margins. Vast areas away from the granite are free from greenstones, or they are too deep to be exposed without granite uplift: thus mine shafts may cut greenstone where none outcrops.

It seems that the basic rocks are not greatly earlier in time to the granites: they occur at all " horizons " from Lower Devonian to Lower Carboniferous. The granites affect all rocks up to Upper Carboniferous (Culm) including greenstones, which like the granites, appear to have a common origin:—

(a) independent basic (gabbroic) intrusives or differentiates of Post-Carboniferous—pre-granite age, Butcher (1958) regards a group of doleritic greenstones near Tavistock as differentiated intrusive sills of Lower Culm age; two trends are found, (i) potassic, giving oligoclose dolerites and " trachyte " sills, and less common, (ii) albite dolerites and spilites, Mg metasomatism is represented by much tremolite,


CORNWALL – S DEVON
10
20
MILES
CARBONIFEROUS
(sandstones)
Boscastle
Padstow
BODMIN
DARTMOOR
Teign
Newquay
ST AUSTELL
Looe
Plymouth
Tor Bay
St Ives
St Just
LANDS END
CARN MENELLIS
Penzance
Falmouth
Dodman
Lizard
Start Pt.
c2 sandy
sandy
"GREENSTONES" – Black: chief outcrops.
GRANITE – stippled & named. s – serpentine.
DEVONIAN – c1 Lower; c2 Mid; c3 Upper
(Based on H.M. Geological Survey)
J.R.

(b) basic fronts of the acid " magna ", which resulted in the " granitisation " of parts of the slate by (Ca, Mg, Fe) ions, with a separation according to ionic radius thus:—

K (1.33)	Na (0.98)	Ca (0.98)	Fe (0.83)	Mg (0.78)
Alkaline	Intermediate		Basic	Ultrabasic

Granite — Proterobase — Diorite — Dolerite — Picrite

This sequence (variety) is in fact found in the greenstones which may be classified by their relative richness in Ca/Na : Mg. Their distribution in space is less convincing: the picrites are few and far from the granite; the sodic types are distant (Padstow) an anomaly due to their autometamorphism (albite) and association with spilites; those in the Teign Valley are near the granite and resemble syenites. Epidiorites near the granite are less sodic (e.g. Newlyn). The majority of the rocks show an excess of lime over soda irrespective of location. D. L. Reynolds (1947) suggested the greenstones were formed by replacement of calcareous slates or limestone. In support of the "replacement" theory, the calc-flinta at Gaverigan, St. Dennis, figured by Harker (1950, p. 90) is remarkably like greenstone: the slate is partly replaced by felspar and actinolite. At Woodland, Lostwithiel, a rock mapped as calc-flinta proved to be a fine schistose greenstone, as seen in thin section. This conversion may occur if the slates were lime rich or if considerable (Ca, Mg, Fe) ions were added to reduce silica by 10% and alumina by 6% on average. Calcareous slate (now calc-flinta) may be so converted since " metamorphosed " impure limestones can be remarkably like " basic igneous " rocks: the Cornish calc-flinta areas are however free of greenstone. The usual type of slate, e.g. Delabole, has the following composition:—SiO_2, 58.3; Al_2O_3, 21.9; Fe_2O_3, 7.05; FeO, 2.57; MgO, 1.09; CaO, 0.39; Na_2O, 1.18; K_2O, 2.45%. (J. Setchell, Esq., personal communication.) This is in contrast to the greenstones; thermal action develops quartz (67-76% SiO_2), biotite, muscovite, and andalusite, and apart from the dubious source of (Na, Ca, Mg, Fe), it is difficult to admit any heat sufficient to crystallise such minerals as plagioclase and augite in situ far away from the granite,

(c) migration of metal ions, especially alkalies (K, Na, Ca) is now considered very important in the formation of varieties of Greenstone-hornfels during metamorphism (q.v.) by causing variable concentrations of metals/Si in parts of the intrusive and/or in relation to the granite (contact), which may also contribute mineralising agents directly.

The greenstones are fairly consistent in composition and character; their field relations to the slate country rock are always clear and sharply defined in form, textures and minerals, and are distinguishable on sight whether at a main contact, an intersheared mass of both, or with xenoliths—of normal slate, spotted types, pale grey hornfels or biotite hornfels. The evidence provides no reasons to doubt their " igneous " origin.

II. COMPOSITION

1. Chemical

A number (24) of analyses of Cornish greenstones have been published by Phillips (1876), Tilley and Flett (1930) and Tilley (1935). They show the following range:—

	% Range	Average		Gabbros	Basalts
SiO_2	35.66—59.84	44.62	...	48.2	48.8
Al_2O_3	10.54—21.64	17.12	...	17.9	15.8
Fe_2O_3	0.87—14.56	3.62	...	3.2	5.4
FeO	7.03—15.88	10.76	...	6.0	6.3
MgO	1.37—10.72	6.23	...	7.5	6.0
CaO	3.71—14.82	10.12	...	11.0	8.9
Na_2O	1.06— 6.52	2.82	...	2.5	3.2
K_2O	0.10— 2.69	1.04	...	0.9	1.4

The figures refer to the so-called " epidiorites " and some proterobase, mostly from W. Cornwall. Picrites are rich in magnesia (22-27%), poor in silica (35-39%) and negligible in soda, by comparison. There is a considerable range in each oxide, due to the difficulty of taking representative samples of rocks which may vary—in one quarry or even specimen—from white felspathic to green hornblendic types. Microsections and chemical analysis may be necessary to classify the rock.

The following principles seem to apply:—

1. Silica low (35-39%); MgO high (22-27%); (Ca Fe)O moderate ——} Olivine and Pyroxene (Picrite).
2. Silica low (35-40%); CaO high (11-15%), and Iron high (21-24% oxides); Na_2O low (1-2%)——} Hornblende chiefly (Amphibolite).
3. Silica high (43-51%); CaO low (4-10%); Iron oxides low (8-13%); Na_2O (2-5%) ——} Plagioclase and Hornblende/Augite (Dolerite, Meta-Dolerite or Proterobase).

The type of felspar is indicated roughly by the lime/soda ratio: lime is usually far in excess of soda since it occurs in both the chief minerals: the ratio ranges from 13 : 1 to 1 : 1 (average 7 : 2). If present the felspar is usually a lime-rich plagioclase (Ab_1 An_2 — Ab_1 An_1), but oligoclase, albite and orthoclase occur in some rocks.

The wide variation in chemical and normative mineral composition is no doubt influenced by the isolated nature of the many forms, to differentiation or migration, to shear, and in some degree by the horizon (strata) at which they occur. The average composition indicates a rock of the gabbro clan: the Lower Devonian group tend to be more basic; those in the Upper Devonian/Lower Carboniferous area are more sodic, and occur in association with spilite. All are intruded into slates poor in (Ca, Mg, Fe)O.

2. **Mineralogical**

Whether the original rocks be intrusive, dolerites, lava or " granitised " sediments, the present mineral composition is fairly simple, if widely variable in proportion and texture.

There are two essential minerals in the usual type of " greenstone ":—

FELSPARS: Square or lath-shaped, with lamellar twinning, but rarely fresh enough to determine; soda-lime species ranging from albite to labradorite. In the finer rocks, small laths are at times parallel, or in ophitic relationship to the ferromagnesian mineral (pyroxene). In section they are generally turbid; and white, grey or pale green in the rock. Veins of felspar occur in some cases. The type of felspar varies with locality: Labradorite is typical of the S.W. group (Lands End-Penryn); albite occurs in the Padstow-Teign valley group; albite-oligoclase at Newlyn-St. Austell; at Trusham (Devon) orthoclase occurs with albite and the rocks are essentially " syenite " (e.g. the Crocombe " granite " quarries).

HORNBLENDE: Secondary (uralite) or actinolite, of dark or bright green colour; occurs as fibrous shreds, bands, patches, lenses or veins: it forms the colouring of " greenstones " and its matted texture makes the rock tough. Primary brown hornblende may occur, e.g. in proterobase.

The two dominant minerals occur in all proportions and give a felspathic (white) or amphibolite type of rock: a relation best shown at Botallack where the rocks are beautifully banded (gneissic).

Other minerals which occur are:—

PYROXENE, pale augite, rarely purplish, occurs in the coarser rocks which resisted stress; or as kernels, knots or bands enveloped in green uralite which develops from it (a relation also clearly seen by eye in Lizard gabbro). Pale pyroxene (diopside) may also re-crystallise during thermal metamorphism.

CHLORITE forms by weathering, or in proximity to lodes (quartz, tin, copper ore). In either case the hard greenstone forms a green, grey or brown clay-mass. These effects are well shown at Porthleven, Molingey and Chipponds (St. Austell).

Accessory minerals, vary in kind and amount:—

APATITE, invariably present.

SPHENE, after leucoxene, associated with ilmenite or replacing it.

ILMENITE, frequently, alters to leucoxene.

MAGNETITE, bands of " iron ore ", occasionally: small segregations have been recorded at Botallack, Rosehill, Tolcarne (Penzance); Rosudgeon, and Ponsanooth.

PYRRHOTITE and PYRITE.

Special minerals are formed by metamorphism in the so-called dolerite-hornfels.

In general, the " greenstones " contain only two essential minerals (plagioclase and augite/hornblende), but according to the type of felspar, the femic mineral and kind of metamorphism, the rocks include dolerite (diabase), metadolerite, epidiorite, proterobase (minverite) and odd types akin to syeno-gabbro and syenite; in addition, a few are ultrabase intrusions (picrite) with much OLIVINE.

The rocks are dark green, greyish, variegated (ophitic or banded), and rarely bluish (e.g. Trengongeeves, St. Austell). The S.G. ranges from 2.89-3.35 (average 3.1) which is near gabbro or dolerite.

III. METAMORPHISM

The greenstones, mainly doleritic sills or lenses, have been subjected to two degrees (grades) of metamorphism:—

1. **Variscan folding** caused shearing and stress-minerals (chiefly hornblende), but not productive of a schistose texture, though banded rocks tends to develop at Botallack and Lanivet by segregation of the two main minerals: the more massive forms have not yielded except to strain and granulation: a complex irregular joint system is developed (making the rock unsuitable for building stone). Crush breccias with veins of hornblende, epidote and garnet are known. The typical stress minerals are hornblende, tremolite, actinolite, anthophyllite (radiate) and cordierite. The fibrous minerals are in nests, lenses, shreds, veins or matted bands: the adjoining slate hornfels may be veined with green amphibole (e.g. Cape Cornwall). Zoisite is occasionally present in isolated prisms or veins (e.g. Helsbury, bordering felspar).

Three types of " greenstone " develop by dynamic metamorphism:—

(a) The common metadolerite (uralite-dolerite) or epidiorite, a dark green splintery rock of variable texture, with veins of amphibole, e.g. St. Ives, Newlyn, Camborne, Ponsanooth, Chipponds, Helsbury, etc.

(b) The banded, lenticular or spotted types with felspar/hornblende, gneissic and intensely folded perhaps in a semi-plastic state (never as foliated as the Lizard hornblende-gneiss), e.g. Botallack; Marazion: or with spots of hornblende/pyrrhotite in a grey felspathic base, e.g. Trevaylor, Penzance.

(c) The cordierite-anthophyllite rocks of Kenidjack-Botallack are unique types of altered dolerites occurring in the upper parts of a large sill, enclosing, enclosed by or grading into normal banded greenstone (metadolerite). They have been fully described by Tilley and Flett (1930). Several varieties are named, with unusual mineral assemblages. They are best seen on the headlands at Zawn a bal, Kenidjack (in several quarries) and in surface boulders: they are always in close association with metadolerite and do not occur in the altered slates below. The special minerals of interest are dark blue ovoid cordierite, pale grey anthophyllite and brownish cummingtonite. The weathering is characteristic and unmistakeable in its knotted (" ball rock ") or banded ridges of cordierite or excrescences of anthophyllite (" starstones "), with fluted hollows in the softer minerals. Ideal examples are seen on the point and joints of Zawn a bal headland, steeply pitching seaward (caution), and on many boulders seaward of Kenidjack rifle range.

Transitions from the original metadolerite show the development sequence (Tilley 1930). Biotite-cummingtonite-anthophyllite (each replacing hornblende)-cordierite (replacing plagioclase). In all cases, streams of ilmenite pass through the new minerals and a rough gneissic texture prevails. Subordinate minerals are plagioclase, quartz, magnetite, rarely spinel and diaspore, zircon, apatite; white mica and tourmaline may occur: almandine at Zawn a bal.

The rock types are:—

Cummingtonite-plagioclase, plus or minus biotite.
Cummingtonite-anthophyllite-plagioclase-cordierite, plus or minus biotite.
Anthophyllite-cordierite-biotite, plus or minus plagioclase.
Cordierite-biotite-plagioclase, plus or minus anthophyllite, quartz.

Chemically the new rocks range and average, on Tilley's analyses:— SiO_2, 33-58 (49.28); Al_2O_3, 8-20 (15.3); Fe_2O_3, 0.1-11.3 (2.39); FeO, 7.7-26.7 (14.31); MgO, 2.4-15.5 (7.57); CaO, 0.9-7.05 (2.95); Na_2O, 0.9-7.05 (2.95); K_2O, 0.1-4.7 (1.88); TiO_2, 1.8-2.9 (2.01)%.

Compared with the normal metadolerite, there is enrichment in Al_2O_3, FeO and loss of CaO, dependent on the new minerals. In variable parents like greenstones, a range of products and composition is not surprising, and the main problem is loss of lime. This has been attributed to weathering or chloritisation prior to metamorphism; or to leaching by lode solutions in an area highly mineralised. Assimilisation of slate may have occurred yielding *some* cordierite and biotite; whilst potash and iron have undoubtedly been added (metasomatic) in some varieties. Possibly the (upper) plastic dolerite was contaminated by slate during intrusion;[1] intensely sheared, the composite rock would give partly normal metadolerite, partly cordierite, anthophyllite and biotite varieties; followed by contact metasomatism, removing some soda and lime and adding iron and potash near veins, and locally depositing biotite, magnetite, spinel, diaspore, garnet and veins of axinite.

There seems little doubt that these strange rocks are of igneous parentage: they grade into metadolerite, not into sediments; the composition, mineral contents (magnesia—rich amphiboles, cordierite, and plagioclase), and relict textures, are conclusive. They have no real counterpart in sedimentary rocks (though a cordierite-biotite slate hornfels occurs), but in average bulk composition, they compare directly with basic gabbro, or norite, which could yield a mineral assemblage comparable with the Botallack suite.

In recent years, studies have been made on the Lands End greenstones. Between Carnmoyle and St. Ives, Lacy (1958) has extended Tilley's work on the basic hornfelses derived from coarse and fine greenstone, some of which shows " pillow " structure locally, both metamorphosed to cordierite-anthophyllite-biotite rocks. Metasomatic derivation from basic rocks is inferred by redistribution of

[1]It is significant that the norites of Insch and Arnage, Aberdeenshire, described by Read (1935, p.591), carry biotite, cordierite, and spinel; with xenoliths of andalusite-cordierite hornfels.

Mg, Fe concentrated near granite and/or mineral veins possibly by the agency of F and K added from granite. The field relations and textures oppose the origin from calc-sediments (Reynolds 1947). Hawkes (1958) has described the petrology of the greenstones in the above area: the sodic dolerites have been recrystallised during metamorphism to andesine, hornblende and sphene. Migration of Ca is shown in four trends:—replacement of hornblende by diaspore, chlinochlore and spinel, by cummingtonite, anthophyllite and cordierite, by biotite (metasomatic K from granite), and by diopside, the latest mineral. The igneous texture is preserved. Retrogression is shown by sericite and chlorite.

Floyd (1962) has made a petrochemical study of the Tater-du greenstones, sheared sill like dolerite intrusives, laminated with slate hornfels and adinole contacts. Five groups of rock are cited originating from dolerite; hornblende/cummingtonite, biotite, biotite/amphibole, hornblende/biotite/dropside/garnet, and calc silicate hornfels, all with or without plagioclase. Two trends are recognised: increasing Ca and K; and again internal metasomatism chiefly by movement or exchange of Ca during contact metamorphism is said to produce lime poor (Fe Mg rich) rocks with anthophyllite-cummingtonite-cordierite, or lime rich rocks with hornblende-diopside-grossularite, zoisite, scapolite, axinite. A suggestion of zoning in the aureole is made, desilication increasing towards the contact: Fe Mg-Ca-Si. The background rock is doleritic and igneous intrusive origin is supported.

2. **Contact metamorphism** by the granite is quite a subsidiary process, and produces the so-called dolerite hornfels. A variety of textures is still evident and the proportion of minerals variable, but only a few species occur: prolonged search is required to find " contact " minerals, and in general the effects of thermal action are not conspicuous.

Hornblende is still the chief colouring mineral, but here may attain a brownish-green or pale brown colour; in large bladed crystals or acicular masses.

Augite/Diopside in pale green granules or streaks is fairly plentiful, alone or bordering pink garnet (notably in the Camborne-Redruth area). It may be surrounded by green hornblende.

Biotite is found in the contact zone, abundantly.

Plagioclase forms a groundmass carrying the above minerals: it ranges from oligoclase to labradorite.

Pink orthoclase occurs in places.

Garnets, pink (grossular) or brown (andradite), occur as veins or pockets, rarely well crystallised: notably at Camborne-Redruth, Botallack and Helsbury, and are of early formation, enclosed by calcite, augite or hornblende. The yellow or brown garnet-hornblende-hedenbergite rocks from Gt. Retallack, is of interest and may be a greenstone found in the mine. Locally the greenstones show rarer modifications due to the effects of borate and fluoride solutions: usually in the form of veins or pockets may be found epidote, yellow, prismatic; axinite in purple wedges or massive; and fluorspar. Tourmaline is rare in these rocks (on joints).

Where the greenstones are cut by tin-copper lodes, mineral sulphides and cassiterite may be introduced, and chlorite is developed, e.g. a microsection from

Pendeen cliffs shows a mesh of chlorite, coarse colourless pyroxene, quartz and cassiterite: a mineralised band at Carrick Dhu (St. Ives), shows a mesh of actinolite, banded and sheared chlorite-ilmenite, and pockets of axinite, epidote, calcite, and chalcopyrite.

Granite veins and lenses of orthoclase cut the rocks near the contact. A remarkable example of a " composite " rock was described by Daniell (1925) from the headland between Pendour and Porthglaze Coves, where folded slates and greenstones are cut by veins (zawns) of quartz and granite, the latter injected into greenstone (mixed magma rock); a dark green and salmon coloured product. A section shows bright green hornblende, orthoclase and pale cassiterite.

Barren milky quartz veins are frequent in greenstones: they often have no effect on the wall rock, or may soften and bleach it, e.g. Chipponds. Quartz veining is beautifully shown at Porthleven where thirteen dolerite sills in various stages of decomposition and size can be easily studied in all aspects.

IV. TEXTURES

The basic rocks of S.W. England, composed essentially of *two* minerals, show a surprising range of textures and appearances, even within the same mass or quarry; dependent on the original rock type, size of intrusion, the grade and kind of metamorphism.

The larger intrusions, or those distant from the intensely sheared contact zones, are less altered from their original ophitic or coarse holocrystalline mineral constitution (pyroxene + plagioclase). The smaller bodies near the granite, are sheared and banded, but never attain a schistose texture.

The range of textures, typical localities for sudy and some features of microsections, are as follows:—

(i) Holocrystalline-coarse: appearance of gabbro, grey-green or green and white, e.g. Mousehole, Marazion (Venton), Helsbury, Tolpetherwin; Dinas Head, Cataclews, and Rock. In the central part of some masses, the rock approaches a pegmatite in texture: " gabbroic " veins occur, also pale veins of felspar, e.g. St. Ives Is., Helsbury.

A felted (mesh) pattern occurs in this group, and yields a very tough though coarse, rock, e.g. Marazion, Trehane, Trecollas, Tintagel.

Mottled greens characterise the rock at Trevose Head.

(ii) Ophitic texture is less common than expected, though it often shows in section: it is characteristic of normal dolerites, and is well seen in the rock of St. Ives island as an intergrowth of coarse felspars and pyroxene, with veins of plagioclase. Fine ophitic patterns occur in the rocks of Clodgy Point and Gurnards Head. A very coarse type appears at Parc-an-als, Porthleven—the margins are porphyritic and microcrystalline. Many portions of coarse unsheared greenstones-dolerites (diabase) or proterobases, show this texture: it is best recognised on weathered surfaces.

(iii) Porphyritic greenstones are unusual. They occur in the St. Austell-Black Head area, and good examples with white soda-felspar phenocrysts are in the hard blue rock at Tregongeeves; at Molingey; and at Tubbs Mill (Gorran) (Reid 1907, pp. 53-54), where two mixed types occur, grey-green porphyritic and microcrystalline. The marginal parts of sills of other textures are occasionally porphyritic.

(iv) Microcrystalline: semi-ophitic rocks are usual in the granite contact zones, e.g. Newlyn, Carrick Dhu, Camborne-Redruth, Lanner, and Chipponds. They are dark grey-green, compact and often lustrous; much sheared or granulised. They form excellent road metal. They range from amphibolites-epidorite-metadolerite to more felspathic types, e.g. Penlee, with microcrystalline uniform soda felspar, strained by shearing; shreds of amphibole, and pyrite. The usual type is of fine turbid felspar, semi-ophitic hornblende; ilmenite and apatite: coarser hornblende veins, pyroxene and garnet may occur.

(v) Spotted rocks at Trevaylor, Penzance, and Botallack (in part) are pale grey felspathic types of turbid plagioclase completely enclosing round, ovoid or lenticular spots of hornblende alone or with kernels of pyroxene or pyrrhotite.

(vi) Banded (gneissic) types are beautifully developed in the Kenidjack-Botallack cliffs: grey plagioclase (Lb) and bright green hornblende alternate in varying degrees and are intricately folded and sheared. The rocks are well exposed in the cliffs and quarries from Kenidjack, to Crowns, and Botallack Head: much of the rock is the usual dark green metadolerite. At Botallack Head quarry a synclinal section, with slate contact, is exposed. Lenses of purple slate-hornfels are included, making a very ornamental stone. At Kenidjack, the quarries afford sections of contorted types with thick alterations of felspar and hornblende-rich types, cordierite rocks and quartz veins. Garnet occurs rarely: tourmaline on joint faces.

A less obvious banded type occurs in some of the Penzance rocks: in the Camborne area, apparent banding occurs due to veins or lenses of garnet and pyroxene; this is very evident in the weathered rock. A distinctly schistose character is found in the rocks at Lanivet, Tretoil and Woodland, where igneous structures are absent and the rocks show very fine grain, felspar-hornblende banding, and a platy fracture like slate. They are near the granite and strongly folded.

(vii) Recrystallised (dynamothermal): the Kenidjack types with cordierite-anthophyllite-biotite, etc., are essentially gneissic in mass and granulose in section: the final products show large areas of cordierite (multiple twin), tufted anthophyllite or cummingtonite; biotite, quartz and streams of iron ore round or through the larger crystals. The mineral bands (or veins) tend to be segregated as in the (replaced) parent dolerite and this is clearly shown on the weathered rock masses as hard blue cordierite knots or ribs, in a softer meshwork of anthophyllite, biotite, and cummingtonite.

(viii) Recrystallised additive variants are always coarser than the normal greenstone, and occur usually well crystallised, with veins and pockets of hornblende or actinolite carrying red garnet, calcite, axinite, epidote, quartz, sulphides, mica, tourmaline (black) as local extreme modifications by the granite. In addition orthoclase felspar veins are not unusual, sometimes, as at Levant, Tater-du, and Pendour Cove, forming thin repeated injections in the basic rock.

V. TYPES OF "GREENSTONE"

It is obvious that the vague term "greenstone" covers a variety of rocks, what may now be logically classified as follows:—

Felspar	Normal (Igneous) PYROXENE	Metamorphic AMPHIBOLE	SiO_2, Na_2O increase; (Mg, Ca)O increase
Albite	PROTEROBASE ALBITE DIABASE		
Oligoclase-Andesine		EPIDIORITE	
Labradorite	DOLERITE = DIABASE	METADOLERITE Dolerite Hornfels	
None:		AMPHIBOLITE	
Ca Mg rich	PICRITE (Serpentine)	CORDIERITE-ANTHOPHYLLITE	

As indicated above the distinction of types (as in igneous rocks) depends on the kind of felspar: a "greenstone" may thus vary over a wide range:

Soda syenite (albite) = proterobase or albite diabase, e.g. Cataclews, Trusham.
Diorite = epidiorite, e.g. Penlee.
Dolerite = diabase, e.g. Mousehole, St. Ives.
Amphibolite, ultra-basic part of dolerites.
Picrite, e.g. Menheniot, Polyphant.

Macroscopically the distinction is rarely evident, except in coarse facies, and resort to the microscope and complete analysis (Na/Ca/Mg ratio) is usually necessary.

PROTEROBASE = MINVERITE

Occurs as sills, rarely dykes up to 120′ thick, of syenite appearance; speckled, non-porphyritic, coarse or finely ophitic. Grey-green when fresh, purplish brown on weathering (e.g. Cataclews), like other basic types spheroidal in places (Rock, etc.) The mineral assemblage is unusual: albite, hornblende (barkevikite), biotite, augite, plus or minus olivine, calcite (deuteric ?): accessory ilmenite, apatite, pyrite. S.G. 2.85-2.9.

These rocks are intrusives in the Upper Devonian spilite province of N. Cornwall and Plymouth areas. Around the Camel estuary they occur at Trevose, Cataclews, Trevone, Padstow, Rock, St. Minver and St. Mabyn, and Trethenna (albite, hornblende and augite), all somewhat chloritic. These rocks have been allied to camponites by Dewey (1914) and by Parkinson in his contribution to a paper by Fox (1903, p. 676).

A number of the small intrusions between Liskeard and Plymouth are of this type; at Cartuther, Treluggan, Pope's Mill, Grove, Forder Lake (Saltash) and in Antony Park. They carry brown hornblende intergrown with purple augite, plus or minus biotite; albite-oligoclase; ilmenite and much apatite. They are coarsely crystalline and usually non-ophitic. This type is rare in Devon, being represented only by (partly) a differentiated sill at Bickington.

ALBITE-DIABASE (Soda Dolerite).

Occurs as sills or small bosses of dark green, often much weathered chloritic rocks. They are of variable texture, fine grained or coarse with mottled felspars, may be ophitic.

The chief minerals are augite and albite, with apatite and ilmenite accessory.

Perhaps the best examples are seen in the Teign valley (Ussher 1913, pp. 59-63), Devon; at Trusham (albite, augite, veins or pockets of perthite) and at Crocombe in large quarries in two facies: light (syentic) and dark (doleritic) coarse rocks of pale green or pink felspar, which is invariably albite, plus or minus orthoclase, and may occupy half or more of the rock; as in the spilites, it is believed to be largely secondary. Purplish augite, plus or minus olivine, hornblende (brown), biotite: ilmenite and apatite accessory: calcite, chlorite, perthite and epidote are secondary.

In Cornwall, intrusions of this type occur in the Wadebridge area, at Sladesbridge, Laneast, Egloshayle, Mouls and Cliff Castle, Kestle (albite plus purple augite). At Park Head, Treglinnick, and Black Head the rocks carry quartz accessory.

A fine grained rock of this type occurs at Gwavas, Newlyn, and like the pale rock at Trusham, is a salic (felspathic) facies with 58-60% SiO_2, the highest recorded in a "greenstone". These are the only examples where soda is equal to or greater than lime, the rock being chiefly albite. In the types above the contact altered slates are saturated with soda (albite) to produce adinole (Dewey 1914; Agrell 1939), not unlike a fine "greenstone".

EPIDIORITE, DOLERITE, Metadolerite, (D. Hornfels).

Apart from unsheared massive dolerites (noted elsewhere), this class includes the dynamothermal representatives. Most intrusions in the Lands End, Cury-Helston, Camborne-Redruth, St. Austell, Lanivet, St. Breward, N. Bodmin Moor, and Milton Abbot areas are of this type (the commonest). They often lie near the granite contact zone so are toughened by shearing and baking.

Hornblende predominates; the felspar ranges from oligoclase to labradorite. Textures are highly variable and the rocks are grey, green or black, rarely bluish, relieved here and there by granules, lenses or ramifying vins of pyroxene, hornblende, garnet, felspar, axinite, epidote-zoisite: flaky biotite, and joint-films of quartz, tourmaline and white mica. Fluorite and sphalerite appear at times.

AMPHIBOLITE.

The ultra basic parts of intrusions, free or almost free from felspar, occurring as bright or dark green bands or parts composed of hornblende alone.

In some cases, notably the rocks around Penzance analysed by Phillips (1876, p. 162) the bulk composition closely resembles that of hornblende: silica poor, as low as 35%, and relatively rich in CaO, and FeO. The paucity in SiO_2 and MgO in such rocks indicates that the green mineral is in fact hornblende, and not actinolite.

PICRITE.

Occurs in a few small intrusions in Upper Devonian of ultrabasic type. The rocks are holocrystalline pale to dark green and much serpentinised; initially of augite and olivine, they are of mottled appearance and occur as follows:—

Clicker Tor, Menheniot: a large quarry for rail ballast and block-making.

Polyphant: ornamental (serpentine) and roadstone, but very soft. Has worked at times since 11th century: pale and dark varieties, strong joints; veins of ankerite.

At Trewen, the rock is harder, dark green and speckled; composed of augite, olivine, tremolite, hornblende, chlorite and up to 11% magnetite. Trewen church is built of it.

Castlewitch, Callington; serpentinous: also Trekelland (Lezant).

Molenick: hornblende picrite: brown hornblende; dark green mottled rock, poekilitic (serpentine).

Highweek, Newton Abbot: augite picrite; dark green: also has biotite, some plagioclase, iron ore and apatite: chlorite and serpentine.

Duporth, St. Austell: mottled, pale green spots in a darker matrix poekilitic altered olivine plus pyroxene. May carry brown augite and tremolite outgrowths, chlorite, apatite.

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