Palaeogene and Neogene deep weathering and soil development, Cainozoic of north-east Scotland

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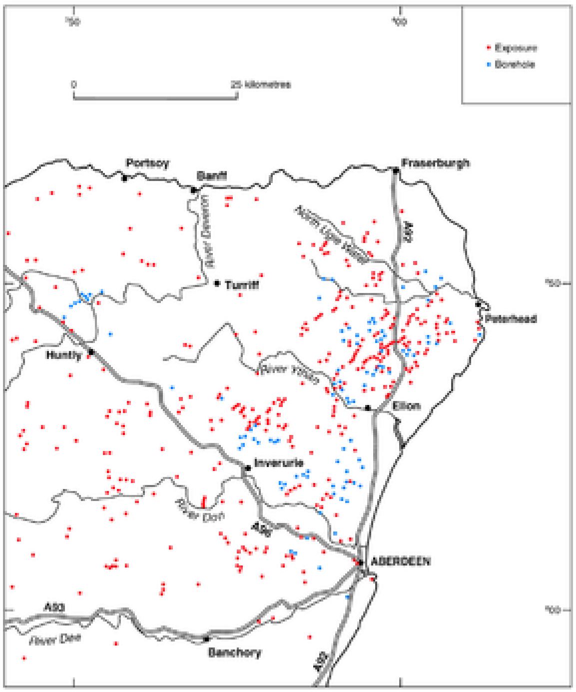
Contents

Introduction

An important feature of the landscape of the lowlands of north-east Scotland is the extensive development of deeply weathered rock (Wright, 1997). Although deep weathering is known from other parts of Scotland, it tends to be relatively restricted in its depth and distribution. In Buchan, in particular, it is common to find extensive areas with few, if any fresh rock outcrops. Boreholes show the weathering commonly extends to depths of 10 to 20 m and may exceed 50 m. The characteristics of these saprolites (in situ weathered rock) and weathering profiles are now quite well known. Investigation of the deep weathering is important for understanding the long-term evolution of the landscape, the variable impact of glacial erosion and the origins of soils. The deep weathering is also of importance in engineering geology, for the weathering reduces rock mass strength in a complex manner, varying in depth and degree of alteration over short distances. Finally, the disaggregation that accompanies weathering allows certain types of weathered granular rock to become a source of aggregate (Bulk mineral resources).

Distribution



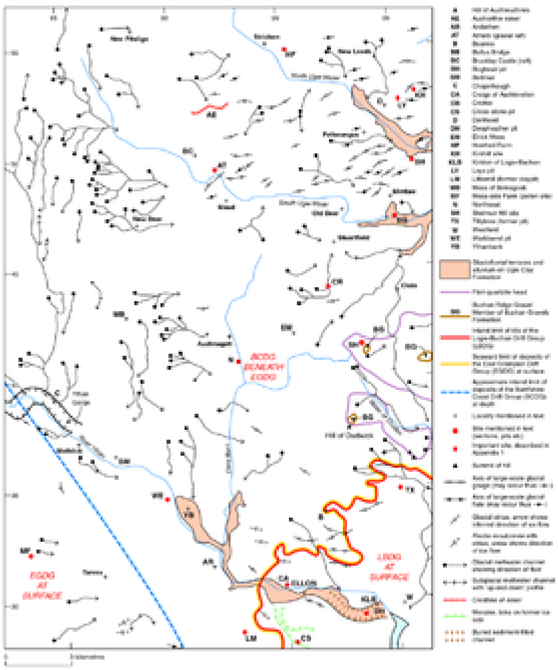
Deep weathering sites in north-east Scotland. P915270.

Deep weathering is common throughout the lowlands of north-east Scotland, but varies in its frequency and depth (FitzPatrick, 1963; Hall, 1986). Information on weathering sites comes from exposures, both long-term and temporary, and from boreholes. Commonly, weathered rock has been wrongly identified as drift in borehole logs. A point distribution map of weathering sites (P915270) is useful in showing the widespread distribution of the 500 or so sites known in north-east Scotland. However, data on the degree of rock weathering are unevenly distributed, and it is likely that many areas that lack fresh outcrops and with a thin drift cover also conceal extensive zones of weathered rock. One such area lies around the headwaters of the River Ythan, where smooth, valley-floor slopes developed across pelite are mantled by periglacial slope deposits (Galloway, 1958), but may also hide pockets of deep weathering. In addition, a point distribution map may give a false impression of the importance of weathering in an area, as small pockets of weathered rock commonly occur in areas of dominantly fresh rock. Nonetheless, it is clear that rock type is a basic control over the distribution and degree of weathering.

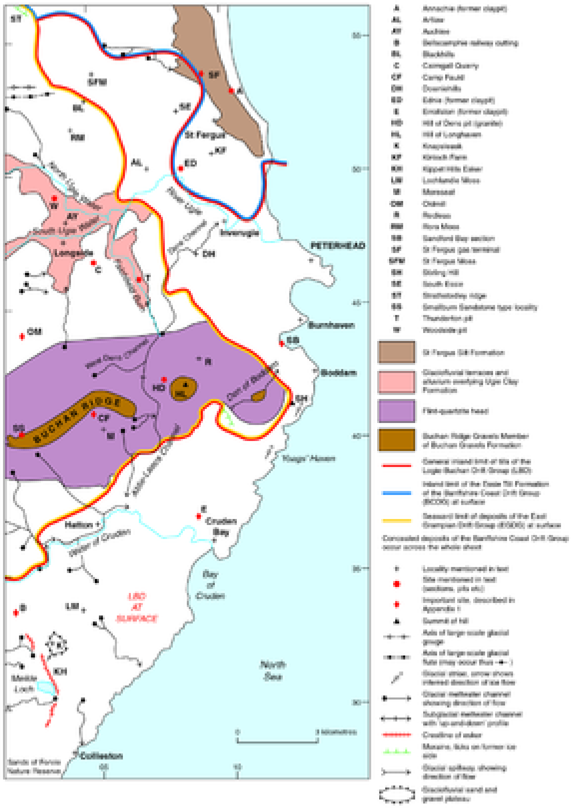
Deep weathering is most commonly developed on biotite granites, basic igneous rocks and in feldspathic psammite bands within quartzites (Hall, 1986). It affects a wide range of metamorphic rocks, but is comparatively uncommon on pelites, although data on weathering in areas underlain by slate is sparse. Deep chemical weathering also has not been noted widely on the Devonian sandstones and conglomerates (Hall, 1986), although geophysical surveys suggest weak alteration on the Turriff outlier down to 10 m in places (Ashcroft and Wilson, 1976). Decomposed conglomerates occur in the Elgin district (Peacock et al., 1968) and between Stonehaven and Inverbervie (Auton et al., 1990).

Depths of weathering are recorded in deep quarries and in boreholes. Weathering to depths of more than 5 m is common in eastern Buchan: for example in the quartzites at the western edge of Mormond Hill (NK 950 568), in quartz-mica psammite at Northseat (NJ 930 408), near Auchnagatt, and in granites at Cairngall, Longside (NK 053 471) and at Hill of Longhaven (NK 084 423). Weathering to a depth of over 60 m is recorded in a borehole south-west of the Hill of Dudwick (NJ 979 378) and in this part of the Buchan, depths of weathering exceed 20 m in numerous boreholes (Hall, 1985). A similar depth is recorded from a fracture zone in the Peterhead Granite (Edmond and

Graham, 1977). Leaching of Permo–Triassic sandstone reaches depths of more than 50 m near Lossiemouth (Peacock et al., 1968). Seismic profiles indicate alteration to depths of 50 m on the sheared margins of the Arnage and Insch basic masses (Leslie, 1984). Weathering depths of 10 to 20 m or more are known from boreholes from the Huntly, Knock and Maud basic masses, the Skene and Peterhead granites and schists near Aberdeen, but these depths tend to be exceptional and normally correspond to fracture zones (Hall, 1983, 1986). Similar depths of weathering are expected to occur along the northern margin of the Insch depression and beneath the floor of the Drumblade depression (Ashworth, 1975).



Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 87W Ellon. P915376.

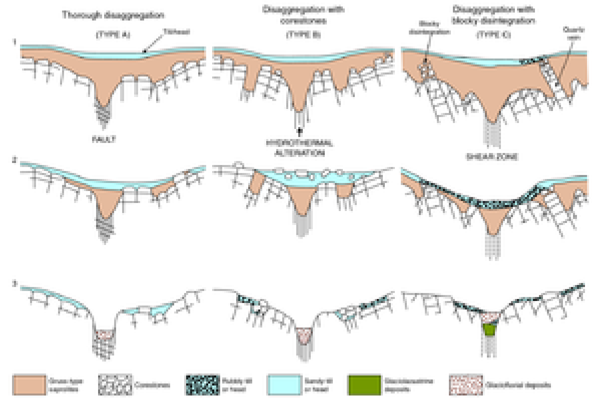


Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 87E Peterhead. P915377.

Many sections and boreholes reveal rapid lateral variations in weathering depths. In sections at Northseat (Hall, 1986; P915376), Cairngall (Hall, 1983), Kirkhill (Hall, 1983; P915377) and Ythanbank (Hall and Sugden, 1987; P915376), zones of weathering lie adjacent to fresh outcrops, yet extend more than 15 m below the surface. Very closely spaced boreholes at Cuttlehill (NJ 499 473), near Ruthven, and Lumphart (NJ 769 269), near Oldmeldrum, demonstrate variations in depth of more than 20 m over distances of less than 100 m. (Hall, 1983, fig. 5.3.ii). Boreholes in the Knock basin in the area east of Ruthven show local development of 20 to 30 m of weathered basic igneous rock, but again weathering depths are highly variable (Hall, 1983, fig. 12.6.iv). These variations are associated with fractured or hydrothermally altered rocks and with sequences of rock of widely different resistance. Rocks of more homogeneous composition tend to show more gradual changes in weathering depths. In general, however, lateral variations in weathering depths of over 5 m can be expected over short distances in most areas.

Given the irregularity of many rockhead profiles, stripping of saprolite should have resulted in slopes with upstanding rock knobs and ribs. In fact, slopes generally show a marked homogeneity in weathering patterns. Lowland areas north of the Don valley show gentle convexo-concave slopes with few rock outcrops. In section, smooth slopes are developed across thin drift covers resting on rocks at various stages of alteration. Bosses of fresh rock have protected adjacent pockets of weathering from erosion, yet these ‘risers’ commonly fail to have any topographic expression. This discordance seems to be largely a result of glacial and periglacial activity. Although glacial erosion has been generally moderate to low in its intensity, it has been sufficient to remove small, upstanding rock forms. Frost shattering has reduced rock knobs and solifluction has contributed to the smoothing of slopes (Hall, 1986).

Characteristics of the weathering profiles



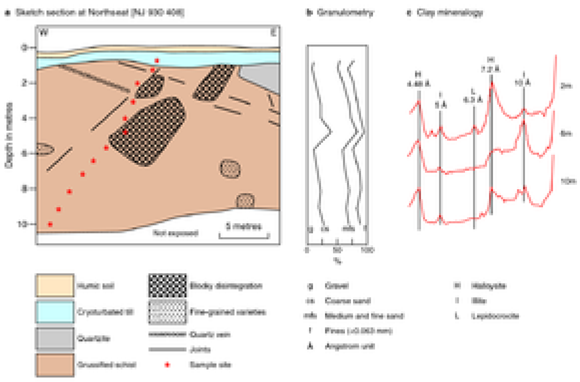
Slope development and the progressive removal of different types of weathering profile. P915271.

Three basic types of weathering profile have been identified in north-east Scotland (Hall, 1983; P915271). The first, type A, is characterised by thorough disaggregation, with a gradual downward increase in coherence to hard rock. These profiles are typically associated with coarse-grained granites and other homogeneous or closely fractured rock types (P104104). A good example is seen at Hill of Dens quarry (P915377) on the Hill of Longhaven (Hall, 1993c). The second type of profile (B) shows an upper zone of thorough disaggregation and a lower zone of corestone development, where kernels of fresh rock are isolated by penetrative weathering along joints (P104105). Profiles with corestones are typical of most widely jointed acid and basic igneous rocks. Good examples were formerly exposed in quarries to the south-east of New Pitsligo. Corestones occur widely on the Knock, Huntly and Insch basic masses and to the east of the Strichen granite. The third type of profile (C) is characteristic of weathered metamorphic rocks. At the base of the profile the metasedimentary rocks break up into angular blocks separated by thin seams of decomposed rock. The blocks become progressively reduced in size up-profile and are surrounded by weathered rock. The heterogeneous composition of many metamorphic rocks in the district means that zones of blocky disintegration persist even in the upper zones of weathering profiles.

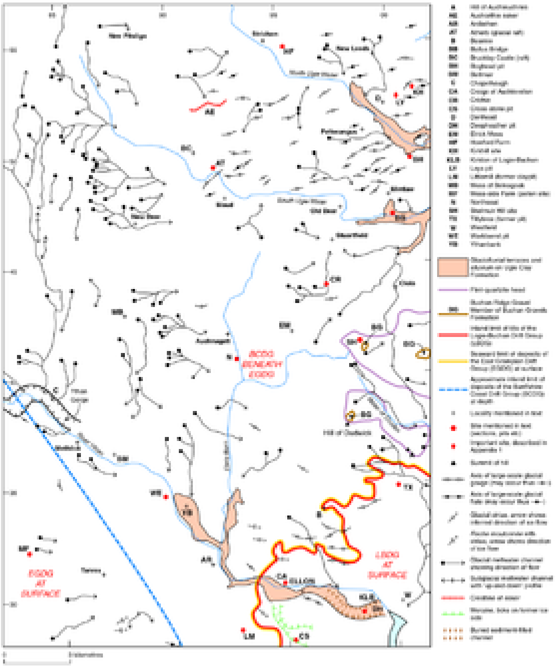

Weathered megacrystic Crathes Granite in Littletown quarry. P104104.

Corestones developed in weathered gabbroic rock near Maud. P104105.

Borehole records indicate that the transition from fresh to hard rock at the base of weathering profiles is variable in character. Around one third of boreholes examined show a well-developed basal surface of weathering. This abrupt change from weathered to fresh rock is most common where weathering is shallow. However, around half of the boreholes show that fresh rock is overlain by alternating bands of decomposed, weakened, shattered and fresh rock. Such transition zones may persist over depths of 15 m or more. In about one in five boreholes the transition from weathered to fresh, more competent rock is gradational over several metres. Overlying glacial and periglacial deposits generally truncate the weathering profiles, but exposures commonly show pockets of weathering protected by adjacent bands of hard rock.



Vertical changes in a gruss weathering profile in quartz-biotite psammite, Northseat. P915272.

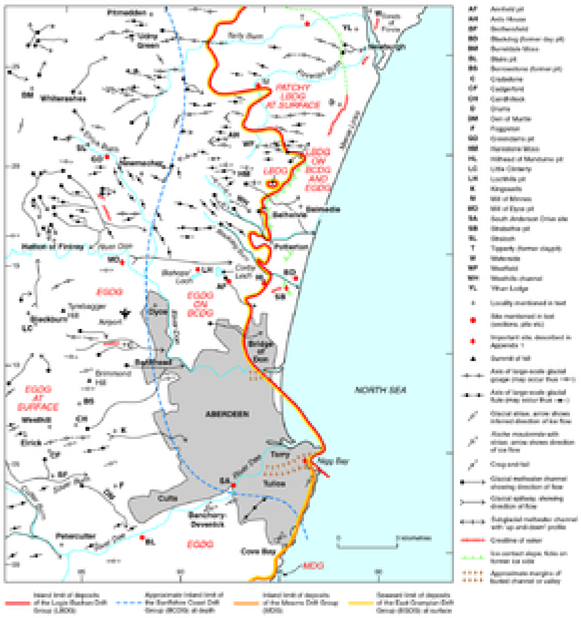


Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 87W Ellon. P915376.

In many deep exposures, such as Northseat (NJ 930 408) (Hall, 1986; P915272; P915376), there are few signs of soil horizon development within the weathering profiles. Colour, grain size and clay mineralogy all change gradually down the weathering profile. Downward translocation of clay is indicated by the presence of clay coatings along joint boundaries and around blocks. However, in more altered saprolites, near-surface zones of kaolinisation and reddening are replaced at depth by less weathered materials. The lateral variations in the degree of weathering of the Moreseat Sandstone on the Moss of Cruden have been interpreted as reflecting the differential truncation of a deep weathering profile (Hall and Jarvis, 1994). Reddening (rubefaction) is associated with saprolites developed on the Peterhead Granite where it probably results from the presence of iron minerals in the granite. Reddened quartzitic saprolites occur at several sites including Sunnyside (NJ 983 372), Drinnies Wood (NJ 973 497) and Howe of Dens (NJ 975 805).

At the base of weathering profiles, staining by manganese or manganese-iron oxides is widespread, especially on rocks rich in mafic minerals. The presence of manganese dioxide, in particular, has been interpreted as an indicator of present or former hydromorphic conditions at, or beneath, the water table (Koppi, 1977). This observation is significant as many weathering profiles that contain these minerals lie well above contemporary water tables, for example at Northseat. The relationship between weathering profiles and water tables is poorly understood, although normally the basal surface of weathering provides a permeability contrast, which corresponds with the level of the water table. On parts of the Buchan Ridge, where weathering depths exceed 15 m, water is not met for 10 m or more below the surface. Several deep quarries in partly weathered rock, such as Cairngall and Hill of Dens, have floors above the local water table. Here it appears that the free-drainage offered by the disaggregated rock allows a lowered water table. However, weathering is known to penetrate deep below the water table in some boreholes indicating that weathering processes must occur locally in the deeper zones of groundwater circulation.

Weathering patterns

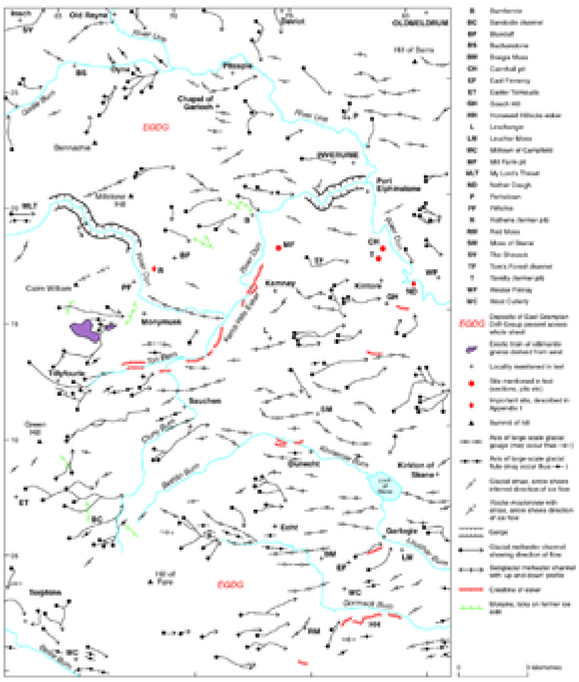


Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 77 Aberdeen. P915379.

At scales of 1 to 10 km^2, rockhead profiles show three main features:

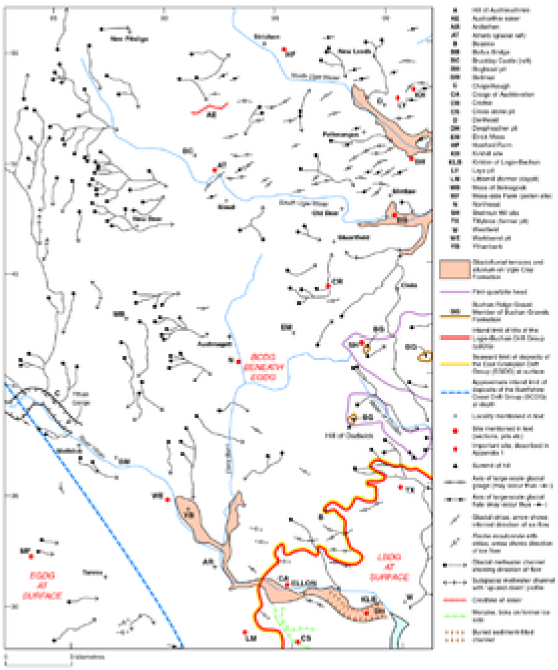
- alternating low risers and depressions
- linear zones of deep alteration
- scarp-foot weathering zones

Each of these distinctive weathering patterns may have topographic expression.

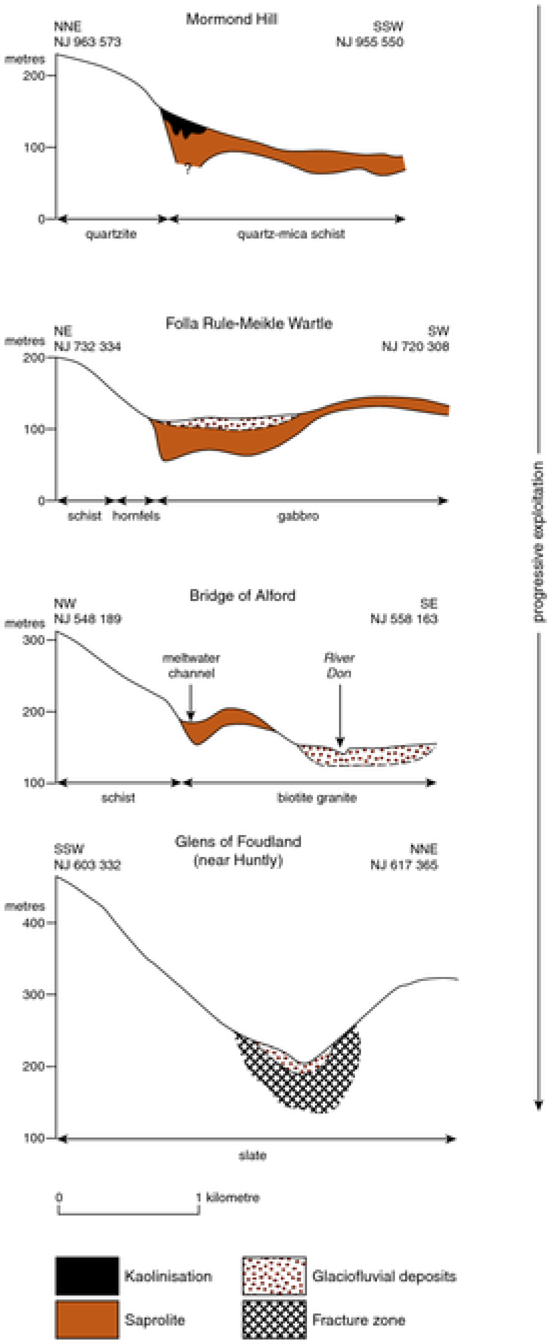


Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 76E Inverurie. P915378.

In the lower Ythan valley, topography appears to reflect the progressive stripping of saprolites from a gently undulating rockhead surface (Hall, 1986, fig. 4). The intensity of glacial erosion increases towards the axis of the valley, where ice-moulded bedrock surfaces are locally developed (Hall and Sugden, 1987). The formation of the Barra basin, one of a series of small basins along the lower Don valley (Hall, 1983, fig. 12.5.ii), has involved the removal of weathered rock by a combination of fluvial and glacial processes. The lowest part of the basin floor corresponds with a zone of intense shearing and is underlain by deeply weathered rock. In contrast, the adjacent mass of Hill of Barra (P915378) is composed of dislocated, but relatively unsheared, basic cumulates and is comparatively little weathered (Ashcroft and Munro, 1978).

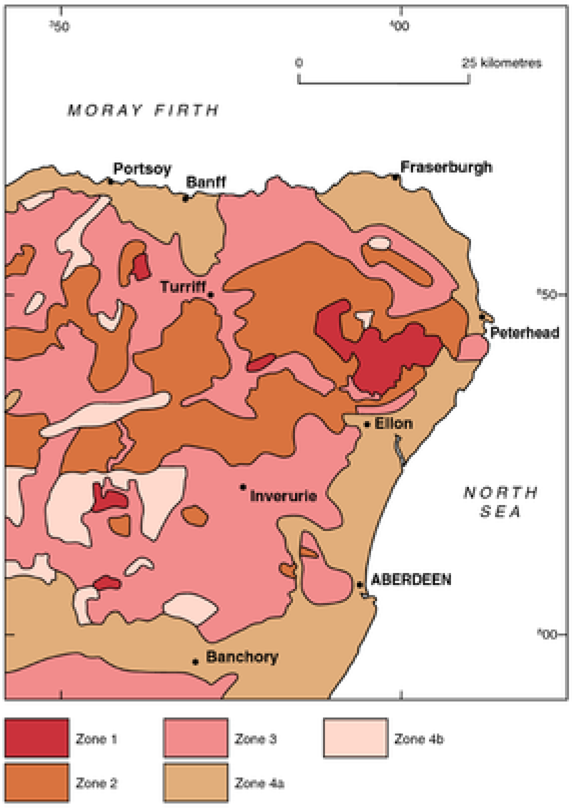


Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 87W Ellon. P915376.

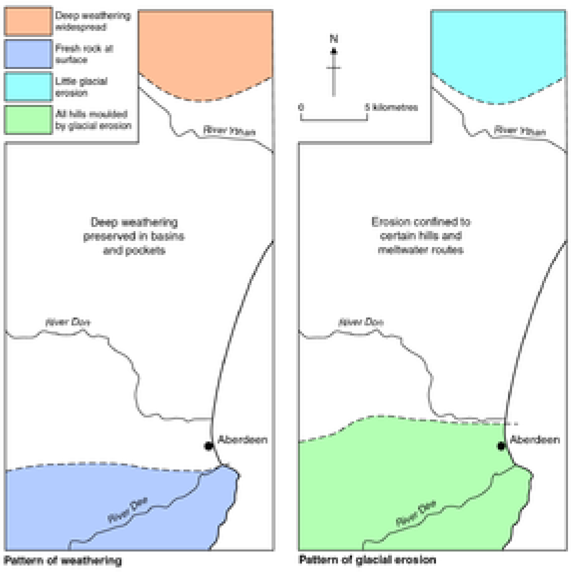


Scarp-foot weathering zones and their progressive exploitation. P915273.

Zones of deep linear alteration exist at a variety of scales. Trenches up to 300 m wide in the weathering front at Crichie (NJ 970 440) (P915376) and Minnes (NJ 944 237) (P915379) appear to relate to localised fracturing. Both have been partly excavated by meltwater. Boreholes for a bypass site investigation south-west and west of Keith, to the west of the district, showed that weathering beneath the floor of Strath Isla penetrated to depths exceeding 30 m in schists. Adjacent metalimestones showed cavities, presumably resulting from solution, down to depths of 20 m (Ove Arup and Partners, personal communication, 1993). These linear zones of alteration generally reflect fracturing or shearing (Leslie, 1984).



Regional weathering patterns. P915274.



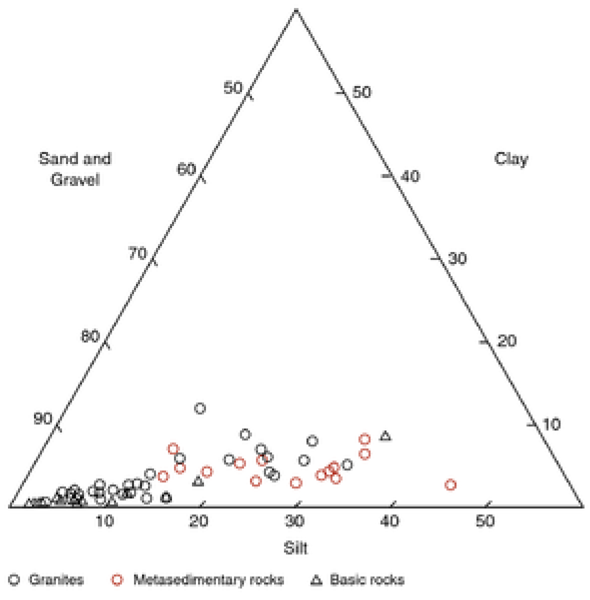
A comparison of the patterns of weathering and glacial erosion in eastern Aberdeenshire. P915268.

Scarp-foot weathering zones occur widely. The acceleration of weathering at the foot of water-gathering slopes has led to the development of deep weathering zones transverse to the scarp-foot, itself generally located on a geological discontinuity. These zones may be found at various stages of development dependent on the present drainage (P915273).

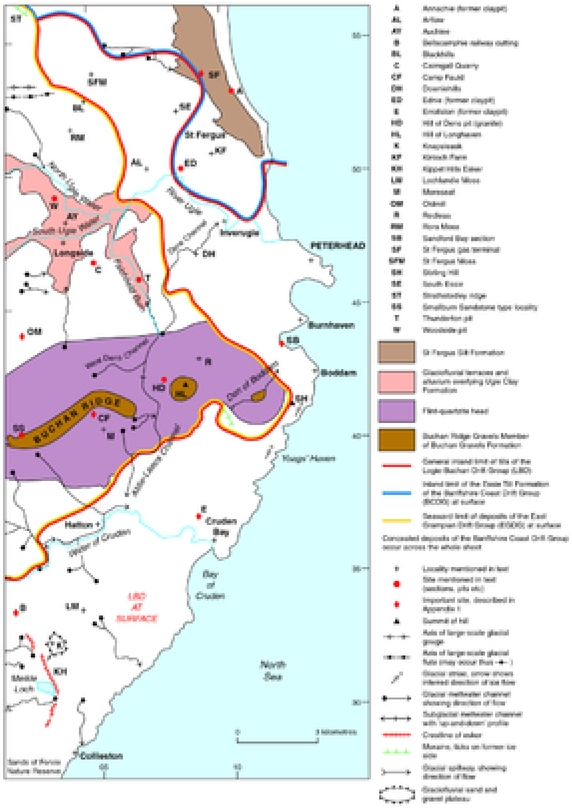
The key controls on the distribution of weathering at the small scale are rock type, structure and topography. At the regional scale (greater than 10 km^2), the varied intensity of glacial erosion is an important factor. Identification of regional weathering zones in north-east Scotland (Hall, 1986; P915274) suggests that weathering is most sparsely distributed in areas of more vigorous ice flow. The most common occurrences of fresh rock typically occur in areas that were eroded by the coastal ice streams and by ice flowing down the Dee valley. This contrast is particularly apparent on a transect northwards from Aberdeen to the Buchan Ridge, where there is a close inverse correlation between the depth and frequency of weathering and the occurrence of icemoulded bed forms (Hall and Sugden, 1987; P915268). These contrasts probably reflect differences in the basal thermal regimes of the ice streams. The coastal areas and the Dee valley were traversed by warm-based ice, capable of significant erosion. In contrast, inland areas were covered by ice that was usually cold-based and frozen to its bed, allowing only limited erosion.

Saprolite characteristics

Saprolites in the lowlands of north-east Scotland vary widely in grain size, geochemistry and clay mineralogy. Grain size within weathering profiles generally does not change systematically with depth and near-surface samples commonly have a similar texture to those at depth (Hall, 1983). Analysis of grain size for 78 exposures of saprolite shows that grain size characteristics vary according to rock type and degree of chemical alteration. It is also significant that grain size characteristics vary widely within a section. At the initial stages of weathering, granitic, basic igneous and metasedimentary weathering profiles form distinct granulometric populations (P915275) and the resultant saprolites possess different mechanical properties. On granites, initial disintegration forms granular grit, with median grain sizes above 1000 µ and very limited development of fines. This style of disaggregation is well displayed on the coarse Peterhead Granite at Hill of Dens quarry on the Hill of Longhaven (P915275; P915377). At that site, total fines (silt and clay) content is usually less than 5 per cent. The granulometry of such immature granite saprolites closely reflects the dimensions of the minerals in the fresh granite, with fine-to medium-grained granites breaking down into saprolites with median grain size of 400 to 500 µ and coarse-grained granites providing median grain sizes of 1200 to 1500 µ (Hall, 1983). On medium- to coarse-grained gabbro and norite, initial breakdown also produces granular sands (P915275). Fines contents are low (generally less than 10%), and median clay content (0.7%) is below that of the weathered granites (2.8%). Quartz psammites produce varied grain size characteristics that reflect the diverse lithology of the weathered, less resistant rock bands within the host rocks and the advanced degree of alteration at these sites. Other metasedimentary rocks produce saprolites with elevated fines (27.4%) and clay (4.5%) contents (P915275). In comparison with overlying soils developed on the saprolites, the soils are greatly enriched in fines and deficient in coarse sand.



Granulometry of weathered rocks. P915275.

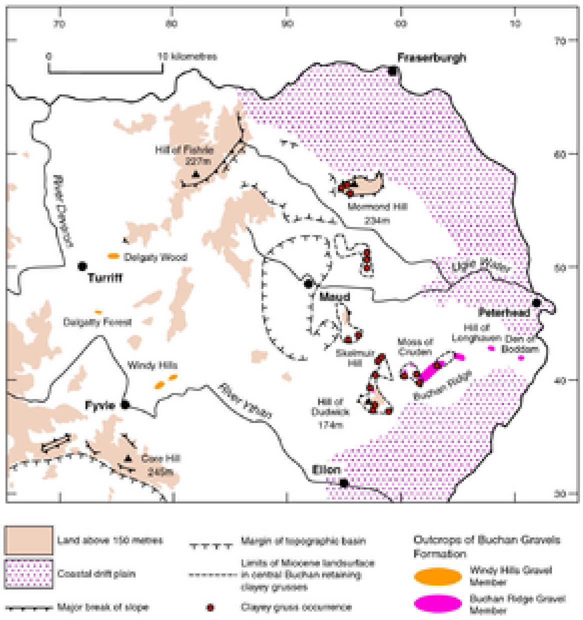


Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 87E Peterhead. P915377.

The grain size characteristics of saprolites developed in the initial stages of breakdown on different rock types indicates a particular style of disaggregation (P915271). The initial breakdown of granitic and gabbroic rocks produces a polymineralic granular gruss (or sand). This process has been termed 'granular disintegration' (Basham, 1974). Metasedimentary rocks first break into angular blocks, a process termed 'blocky disintegration' (Basham, 1974). Alteration then penetrates along the fractures and produces thin seams of decomposition containing significant amounts of fines. These contrasts may reflect the ways in which residual stresses are released from the rock during weathering and unloading. In finer grained metasedimentary rocks, the opening of fractures involved in blocky disintegration largely relieves residual stress. In igneous rocks, stress retained after jointing is relieved by the propagation of micro-cracks, possibly after the modest expansion of certain minerals, notably biotite, in the initial stages of weathering.

With increasing alteration, the granulometric differences between rock types become less clear, although metasedimentary saprolites continue to have a relatively high fines content. The size of the clay fraction ($< 2\ \mu$) is a useful indicator of the degree of chemical alteration. Advanced alteration gives saprolites on all rock types with a clay content of more than 6 per cent, reaching 20 to 25 per cent on metasedimentary rocks.

Weathering types and age



Distribution of Miocene land surface and major topographical features. P915269.

Two distinct types of saprolite or weathered rock mantle are identified in north-east Scotland (Hall, 1985).

A more evolved weathering type, clayey gruss, shows an elevated clay content (>6%), with clay mineralogy dominated by kaolinite and illite, and with small amounts of hematite. Within the district, this degree of weathering is known from only a small number of sites, mainly on the high ground of central Buchan (Hall, 1985; P915269). It is represented by kaolinisation of clasts within, and bedrock beneath, the deposits of the Buchan Gravels Formation. It also occurs within the Mormond Hill Quartzite. Kaolinised granite containing a hematite/layer-silicate clay mineral, macaulayite, is found at the foot of Bennachie (NJ 693 245) (Wilson et al., 1981, 1984; Koppi, 1977). Kaolinistion affects the pelites beneath the quartzite gravels at Windy Hills (P915269) and silicate clasts within the gravels themselves (Koppi and Fitz-Patrick, 1980; Hall et al., 1989). Koppi (1977) also describes a highly weathered feldspar-biotite psammite from Clashindarroch Forest (NJ 435 305), just west of the boundary of the district. Comparison with the mineralogy of North Sea sediments suggests that highly kaolinitic weathering mantles formed prior to the Pliocene in north-east Scotland under warm humid conditions (Hall, 1985).

The vast majority of the saprolites in the district fall within the gruss weathering type. The saprolites are dominantly sandy, with limited development of fines, and the clay mineralogy is closely controlled by rock type. Granitic saprolites contain kaolinite-mica clay mineral assemblages (Hall et al., 1989). Basic igneous saprolites contain a wide range of clay minerals. For example, weathering of the ‘Insch Gabbro’ has left feldspar and hornblende largely unaffected. Pyroxene alters initially to iron oxides and later to vermiculite, while biotite weathers to hydrobiotite and vermiculite and, locally, to kaolinite and gibbsite (Basham, 1974). Acid metamorphic rocks give kaolinite and mica clays, but an increasing content of primary ferromagnesian minerals leads to a reduction in kaolinite and an increase in smectite content (Hall et al., 1989). Altered metalimestones are dominated by smectite, partly inherited from the parent rock (Wilson et al., 1968). Grusses are thought to have formed in north-east Scotland under the humid temperate environments of the Pliocene and warmer periods of the Pleistocene (Hall, 1985).

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