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# DEEP WEATHERING IN SCOTLAND - RETROSPECT AND PROSPECT

by

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## PROGRESS

Over the past 25 years there has been a significant increase in our knowledge of deep weathering in Scotland. The Current state of knowledge may be briefly summarised as follows.

### Distribution

Deep weathering is widespread in the Scottish Highlands (FitzPatrick 1963; Godard 1965; Walsh *et al* 1972). Weathering occurs most frequently in areas of limited Quaternary erosion, notably Buchan (FitzPatrick 1963; Hall 1985; 1987) and parts of Caithness (Omand 1975; Hall unpublished). Scattered weathering sites are also known, however, from high-level preglacial plateau in landscapes of selective linear glacial erosion, such as the Cairngorms (Sugden 1968) and the Gaick Forest (Barrow *et al* 1913; Hall and Mellor in press) and even from glacially-scoured terrain in the Outer Hebrides )Godard 1961), Skye (Godard 1965; Le Coeur 1984), Rhum (Ball 1964), Wester Ross (Ballantyne and Sutherland 1987, p.92) and Arran (Godard 1969). Much less is known, however, about the occurrence of weathering south of the Highland Boundary Fault and it is still too soon to produce a distribution map of weathering for the country as a whole.

### Depths and patterns of weathering

Observed depths of weathering are usually less than 5m. There are, however, numerous records of weathering penetrating below 10m, notably in north-east Scotland where maximum depths of weathering exceed 50m (Hall 1986), but also in the Gaick Forest (Barrow *et al* 1913; Hall and Mellor in press), the Strath of Kildonan (Zauyah 1976) and other sites in northern Scotland (Godard 1965). In Buchan there exists sufficient subsurface data to allow weathering patterns to be identified and links between the form of the basal surface of weathering and surface morphology to be established (Hall 1986).

### Characteristics of the saprolites

The clay mineralogy of the saprolites has been studied in some detail. Variations in saprolite clay mineralogy with rock type have been demonstrated by studies of basic igneous (Wilson 1966;

1967; 1970; Basham 1974), granitic (Zauyah 1976; Hall, Mellor and Wilson in press) and metamorphic (Koppi 1977; Hall, Mellor and Wilson in press) rocks, as well as Devonian conglomerates (Wilson *et al* 1971). Changes in clay mineralogy with increasing alteration have been identified (Basham 1974; Hall, Mellor and Wilson in press) but the effects of drainage status remain poorly understood. Few attempts have been made to investigate the geochemistry of weathering profiles (Bain *et al* 1980).

Hall (1985) recognises two main types of saprolite in north-east Scotland on the basis of granulometry, clay mineralogy and geochemistry. The widespread gruss weathering type shows a low degree of chemical alteration, with low clay contents, preservation of primary minerals of limited resistance and heterogeneous clay mineral assemlages whose nature is closely controlled by the primary mineralogy of the parent rock. The spatially-restricted clay grusses show more advanced, kaolinitic alteration. This simple bipartite division has been useful in assessments of the palaeoenvironmental significance and age of the two weathering types (Hall 1985; 1987). The division is arbitrary, however, for there is no clear-cut boundary between the two types, simply an obvious difference between median members of both groups. More significantly, the division ignores the great range in alteration found within the gruss group and which presumably reflects differences in rates of alteration, profile position, age and other factors (Hall, Mellor and Wilson in press).

Age

Early weathering studies gave only the vaguest estimates of the age of weathering, generally considering the weathering to be either Tertiary (Linton 1951; 1955) or Quaternary (Phemister and Simpson 1949) in age. The situation has improved only marginally in recent years. Hall (1985) considers his clayey gruss weathering to date from pre-Pliocene time, probably from the Miocene, and his gruss weathering type to date from the Pliocene and early Pleistocene, as well as interglacial periods. An interglacial age has also been recently argued for shallow weathering in southern Skye (Le Coeur 1984).

Geomorphological significance

Following Godard (1965), several studies have shown that deep weathering is of fundamental importance in understanding the nature ofpreglacial relief and its style of evolution. The presence of deep weathering has been used widely as an indicator of the preservation of preglacial landforms (Linton 1951; Godard 1965; FitzPatick 1963; Walsh *et al* 1972; Hall 1985). More significantly, it has been demonstrated that there is often a close correspondence between the preglacial morphology, levels of rock resistance to chemical alterations (Godard 1962) and deep weathering patterns (Hall 1986). The Tertiary in Scotland was a period of warm to cool humid climates favourable to the deep penetration of weathering when most, if not all, of the country remained above base level. The preglacial relief of the

Highlands is now increasingly seen as the product of prolonged differential weathering and erosion throughout this period (Godard 1965; Hall 1987).

The survival of weathering of preglacial age implies that glacial modification of relief has been modest (Godard 1962). Recently, patterns of weathering in north-east Scotland have been combined with evidence from landforms of glacial erosion to examine the amount of processes of landscape modification by Quaternary ice sheets (Hall and Sugden 1987). The contribution of reworked weathered rock to the matrix of glacial deposits has, however, not been investigated in detail, although the widespread existence of inherited clays in Holocene soils indicated that this contribution in significant (Wilson and Tait 1977; Wilson, Bain and Duthie 1984).

**THE PROBLEM OF AGE**

At the core of many geomorphological studies of deep weathering lies the question of the age of the weathering. In Europe, saprolites have been dated in two main ways. Firstly, at some sites saprolites are overlain by sediments (Coincon, Tardy and Godard 1976) or lava flows (Roaldset 1983) which provide a minimum age for the weathering. Often, however, saprolites extend to the surface or are overlain only by materials which are or are presumed to be much younger than the underlying weathering profiles. In this case, the characteristics of the saprolites, particularly the clay mineralogy and granulometry, are compared with those of other saprolites whose age is more or less known. It is then assumed that saprolites of similar characteristics must have evolved under similar environments and be of similar age. Alternatively, relict saprolites of unknown age are compared with saprolites forming at present under different, generally warmwer, climates. Again, if the two sets of saprolites have similar characteristics then it is assumed that the relict saprolite formed under similar climates in the past (Bakker 1967).

This methodology was been adopted in attempts to date weathering in Scotland (Hall 1985; Hall, Mellor and Wilson in press) but has allowed only very broad age estimates. There are a number of reasons for this. One major problem is the lack of correlative deposits, due to the scarcity of sediments in Scotland which are known to predate the Devensian cold stage. This difficulty has been offset to some extent by mineralogical comparisons with Tertiary sediments in the North Sea (Hall 1985), but these offshore sediments are as yet little studied. The shortage of correlative deposits has lead to long-range correlation, using mineralogy and granulometry, with saprolites south of the limits of glaciation (Hall, Mellor and Wilson in press), saprolites which are themselves often of uncertain age and which have evolved under rather different climates than those which have affected Scotland in the Cenozoic.

There are also particular problens in dating relict kaolinitic saprolites, such as the clayey grusses of Buchan. From the

Palaeocene to the Late Miocene, climates in Britain seem to have remained warm and humid and suitable to the production of kaolinitic regoliths (Isaac 1983). Hence, relict kaolinitic saprolites, may have formed at any time during this long interval and dating often relies on insecure geomorphic evidence. Furthermore, the possibility of inheritance of Mesozioc kaolins deserved attention in view of the Mesozoic age of kaolins in other glaciated crystalline terrains, such as southern Sweden (Lidmar-Bergstrom 1982), and the evidence of very low long-term rates of erosion in parts of Scotland, such as Buchan (Hall 1987). Finally, it has become almost axiomatic to relate the kaolinisation process to warm and humid climates. This assumption has recently been challenged by oxygen isotope studies of Permian kaolins in Australia (Bird and Chivas 1988a) which indicate kaolinisation under cold climates. Little is known about the products of prolonged alteration under humid temperate climates, such as those which prevailed for perhaps as long as 7Ma at the end of the Tertiary in Scotland, and it remains possible that some kaolinisation may date from this period. It is notable in this context that older Quaternary arenes in the Massif Central (Godard 1972; Seddoh 1973) show a style and degree of alteration comparable to that of the clayey grusses of Buchan.

The problems of dating gruss type weathering are perhaps even more intractable. Grusses contain large amounts of little-altered, but non-resistant primary minerals and represent an immature weathering type. The mineralogy of grusses is mainly controlled by lithology (Tardy *et al* 1973; Dejou, Guyot and Robert 1974; Hall, Mellor and Wilson in press) and the controls of climate and age are poorly understood and may be masked by other factors, such as drainage. Hence comparisons between gruss weathering profiles are difficult and isolation of the climatic and age controls on clay mineralogy requires careful sampling to minimise variation in lithology, drainage and other factors (Basham 1974; Hall, Mellor and Wilson in press). Moreover, clay minerals are not diagnostic of weathering environments and are insensitive to climatic change (Singer 1980). Gibbsite, for examples, occurs in alpine soils (Gardner 1972), in the early stages of weathering of granitic and gabbroic rocks (Green and Eden 1971; Hall, Mellor and Wilson in press), as well as in the final stages of weathering under humid tropical conditions. Hence inferences about climate and age based solely on clay minerology are of doubtful value.

Gruss weathering profiles are also often demonstrably trucated and it may be unclear whether a particular saprolite represents the roots of a formerly deep and relatively old weathering profile or the product of renewed and relatively recent weathering. A related problem is that of superimposition of alteration products related to different weathering periods within a single profile, as suggested by micomorphological studies (Koppi 1977). Superimposition may be more widespread than is currently appreciated as grusses often retain large amounts of partially-altered feldspar and biotite, susceptible to renewed alteration. Moreover, grussification must have operated more or less continuously under the humid temperate climates which prevailed in Scotland from the end of the Miocene to the beginning of the Pleistocene. Finally, the weathering of non-resistant clasts in Middle and Late Pleistocene sediments indicated the further continuation of the grussification process, albeit probably at reduced rates, in interglacial periods. The combined effects of truncation and superimposition present major difficulties for dating grusses.

Questions of the age of saprolites are further complicated by the fact that weathering profiles are vertically diachronus, becoming younger towards the base of the profile as weathering extends downwards into unaltered rock. Rates of weathering are also highly variable, and decrease with time (Colman 1981), and this means that depths of weathering are only a very crude guide to the time period required to produce a weathering profile of given depth. Rates and depths of weathering vary with rock type (Hall 1986). Weathering can be greatly accelerated by minor hydrothermal alteration (Samuelsson 1973), by intense microfissuration and by stress release during rock breakdown (Dejou and Pedro 1976; Folk and Patton 1982). With regard to the latter, silt and clay contents in certain coarse-grained granite and gabbro granular grusses in north-east Scotland are so low (<10%) as to raise the question as to whether rock breakdown is a result of chemical alteration or chemical alteration has followed disaggregation by purely mechanical means as a result of stress release. In summary, gruss weathering profiles are internally diachronous and may be truncated and polycyclic and form at different rates by a combination of physical and chemical processes.

The difficulties outlined above mean that relative dating of saprolites based on comparisons of mineralogy, granulometry and geochemistry can, at best, offer only a broad indication of age. New methods are needed to provide better age estimates for weathering. Fortunately, at least three methods already exist which have potential for dating saprolites.

**NEW DATING TECHNIQUES**

Oxygen isotope analysis

The isotopic composition of meteoric waters is largely a function of air temperatures. Oxygen isotopes within kaolinite clay minerals represent a record of air temperatures at the time of kaolinite formation, for later oxygen isotope exchange is limited (Bird and Chival 1988a and b). Hence oxygen isotope analysis of kaolins provides a method by which to estimate palaeotemperatures during weathering. Moreover in areas where temperatures have changed markedly in the Late Mesozoic and Cenozoic, such as Australia, where the continent has drifted northward from 11 to 44 S over the past 95Ma (Bird and Chivas 1988b), or in Scotland, where climates have cooled from tropical to cool or cold conditions over the last 50Ma, comparison of palaeotemperatures inferred from oxygen isotope analysis with the climatic record should allow the age of kaolinisation to be estimated, particularly where a framework of independently-dated kaolins exists (Bird and Chivas 1988a and b). In Scotland such methods could be applied with little apparent difficulty to the kaolinitic clayey gruss weathering type, especially as oxygen isotope data on marine Tertiary palaeotemperatures already exist for the North Sea (Buchardt 1978). Grusses developed on acid rocks also frequently contain clay fractions dominated by kandites Hall, Mellor and Wilson in press), although the application of oxygen isotopes analysis here would be hampered by the small size and heterogeneity of the clay fractions.

K-Ar dating

K-Ar dating is a standard technique for dating minerals in volcanic and metamorphic rocks which are older than 100ka. The method works particularly well on biotite, which retains argon well, but other minerals rich in K are also suitable (Dalrymple and Lanphere 1969). This method has been used to date Carboniferous kaolinites from northern Norway (Sturt, Dalland and Mitchell 1979) and may have potential for dating younger weathering profiles. Kaolinitic saprolites are inherently unsuited to K-Ar dating, however, due to the low levels of K in kaolins. Illite, and to a lesser extent, chlorite are, in theory, more suitable but present formidable analytical problems in the separation of detrital clays, derived from the comminution of primary minerals, from neoformed clay minerals. Recently, however, it has been demonstrated that preliminary K-Ar dates can be determined for diagenetic illites in sandstones by careful sample preparation and thorough analysis of the nature and origin of the minerals present in the clay fraction (Liewig, Mossmann and Clauer 1987; Liewig, Clauer and Sommer 1987). It would seem a small step from the analysis of diagenetic clays to the dating of weathering clays in saprolites, particularly on rocks of intermediate composition where illite and chlorite are dominant compnents in the clay fraction. An alternative approach lies in the comparison of apparent K-Ar ages for fresh and weathered micas, for the systematics of K and Ar loss patterns in micas with weathering are increasingly well understood (Clauer, O'Neil and Bonnot-Courtois 1982; Mitchell and Taka 1984)..

$^{10}$Be analysis

A final method of dating is based on the measurement of levels of $^{10}$Be in soils and saprolites (Pavich *et al* 1985, 1986). Cosmogenic $^{10}$Be is delivered to the earth's surface at a known steady rate and quickly becomes locked in the minerals of the clay fraction. The long half life of $^{10}$Be (1.5Ma) means that the isotope has great potential for dating soils and saprolites. Levelso of $^{10}$Be are first established using accelerator mass spectrometry. Thereafter the theoretical age of the saprolite can be calculated using data on the concentration, delivery rate and decay constant of $^{10}$Be, together with estimates of erosion rates. Application of this technique in the Appalachian piedmont has yielded estimates of rates of saprolite production of 7m/Ma (Pavich *et al* 1985) but the technique has yet to be applied in Europe. One obvious problem in the application of the technique in Scotland would lie in the estimation of the depth of profile truncation by glacial erosion and other processes.

**CONCLUSION**

Studies of deep weathering in Scotland over the past 25 years have established the basic characteristics of the distribution, depth, mineralogy and geomorphic context of the weathering. Estimates of the age of the weathering remain vague, however, and are likely to remain so on the basis of current methodology. New dating methods are needed and oxygen isotope, K-Ar and $^{10}$Be methods appear to offer considerable potential for future dating.

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