IMPROVEMENT OF GEOLOGICAL MAPPING IN NORTH-WEST SCOTLAND

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Abstract

Geobotanical remote sensing techniques have been applied in the improvement of geological mapping in the Assynt and Loch Tay areas of Scotland. Landsat MSS and Airborne Thematic Mapper (ATM) data have been used to evaluate the geobotanical utility of the multispectral information recorded in the visible and reflected infra-red bands. A close relationship has been identified between vegetation and geology in both study areas using band ratios, band ratio composites and principal component analysis techniques.

Several small-scale previously unrecognised lineaments which run NWW-SEE, parallel to other known basic dykes in Lewisian Gneiss, occur south of Loch an Leothaid and south-west of Ben More Assynt in Cambrian-Ordovician quartzite have been recognised. A fault which is very distinct in ATM data of the Assynt area trending NW-SE, has also been recognised. Many previously unidentified dykes and sills which are associated with different types of vegetation have been mapped. In the Loch Tay area a new NNE-SSW trending fault which runs almost parallel to other major faults of the Loch Tay area has been identified using available geobotanical information.

1.0 Introduction

The application of remote sensing in geological studies faces difficulties when a study area is covered by vegetation. Some times the masking effects of vegetation become so severe that well-established conventional methods for geological mapping cannot be applied directly. In these difficult circumstances the only answer to this masking problem of vegetation is to find out the relationship between vegetation and bedrock geology. The effect of bedrock geology on vegetation is not always direct. Some times it involves many interrelated factors, for example soils and climate which affect the vegetation and its spectral properties. But on a regional scale, and even sometimes on a local scale, close relationships have been identified (Cole 1984). The geobotanical technique in remote sensing has been widely applied in geological mapping and mineral exploration. But this technique has been applied mainly in semi-arid, humid tropical and temperate climatic areas. Little work has been reported from Scottish areas. In the present study an attempt has been made to detect the relationships between vegetation and bedrock geology using remote sensing in parts of Scotland.

Successful use of geobotany for geological mapping frequently depends on the ability to detect the relationship between vegetation and bedrock geology and sometimes detect stress in vegetation. Vegetation anomalies are plant community responses to unusual, and almost always stressful, environmental conditions. Therefore, an understanding of plant community response to stress is of critical importance for evaluating the significance of vegetation anomalies. This is particularly important when remote sensing techniques are employed. For completely vegetated areas, airborne and spaceborne sensors gather spectral data for mixed assemblages of plant species, i.e., plant communities; only rarely are single species responses measured. This means that our understanding of spectral characteristics of individual plants and leaves, and their physiological, anatomical, morphological, and ecological causes, cannot be applied directly to the interpretation of remotely-sensed vegetation data. The contribution to the spectral signature due to the structure and composition of plant communities must also be considered.

Plant ecologists have described a generalized vegetation response pattern which seems to result from a wide variety of stresses. This response can be summarized as follows. Community structure is simplified (stratification and species diversity are reduced), the ratio of gross biomass production to total respiration decreases, percent vegetation cover is reduced, trees may be stunted or absent, species composition changes (often evergreen shrubs, perennial grasses, xeromorphic growth forms, or stress-tolerant taxa increase in dominance) and phenological patterns may be altered (Wickland 1984). None of these responses is specific to a particular type of stress, although certain changes in species composition can be characteristic of certain soil conditions. This explains why remote sensing techniques have not been used successfully to identify uniquely the environmental factors causing stress in vegetation. It is possible, however, that certain combinations of these general community responses may produce a characteristic, or diagnostic, spectral signature for a particular type of stress.

In Britain the objectives and constraints are somewhat different, however, and the impact of remote sensing imagery has consequently been rather less. Here the main requirement is for detailed geological maps, such as those produced by the British Geological Survey (BGS), of areas that are often comparatively poorly exposed, highly vegetated and strongly affected by man's influence (Greenbaum 1987). Previous geologically-based experiments in the U.K. using airborne multispectral scanner data have been carried out over low-lying cultivated areas and have not proved notably successful (Greenbaum 1987). In this regard, the moderately high spectral and spatial resolution of the Daedalus AADS 1268, 11-channel multispectral scanner offers the possibility of improved discrimination capabilities.

Geobotany, the association of particular plants or plant morphological aberrations with rock types, has been used in mineral exploration for hundreds of years. However, on a large scale prior to the introduction of remote sensing there was no satisfactory way of obtaining synoptic views of gross vegetation patterns over extensive areas to allow the detection of vegetation anomalies. During the past twenty years there has been an increasing use of remote sensing of vegetation for geological mapping and mineral exploration. Early work utilized black and white infrared and false colour infrared photography, taken from aircraft platforms. The work of Cole (1976) in South Africa and Western Queensland, Australia, is a good example of the experimentation phase of exploration remote sensing which successfully located geobotanical anomalies on photographic imagery. Studies of multiband photography to detect changes in vegetation reflectance caused by soil geochemical anomalies were also conducted by Canney (1975) in the Philippines, Thailand, Brazil and the United States.

Little success has been reported in the use of Landsat -1,-2,-3 and -4 multispectral scanner (MSS) imagery for geobotanical purposes because its 79 m resolution is a severe limitation. Nevertheless, several workers (Lyon and Lee 1970, Lyon 1975, Bolviken et al. 1977, Lefevre 1984, Lyon and Lanz 1984, Saraf et al., 1987) have successfully used Landsat digital data for geological mapping and to examine some geobotanial anomalies.

2.0 Geology of the areas

2.1 Assynt area, N-W Scotland

In the Ordnance Survey National Grid the Assynt area comes on the sheet number 15 (Scale 1:50000) between 115000 to 235000 Easting and 907000 to 935000 Northing. The area contains many lochs but the major loch of the area is Loch Assynt.

Apart from bare outcrop and active screes, the area is completely vegetated, the dominant cover being a mixture of ericaceous heaths, *Molinia* and *Juncus* sedges, fescue grasses, sparse thyme bushes and variable proportions of *Sphagnum* mosses. Grasses only dominate well-drained areas underlain by carbonated, fluvioglacial and Recent alluvium and sandy solifluction debris. Stands of bracken are restricted to areas of coarse stabilised scree. The notable green swards are associated with Cambro-Ordovician feldspathic pelites and carbonates but do not extend over the whole area of their known subsurface extent. Whereas vertical rock faces are bare and thinly weathered, the low-angle surfaces observed by remote sensing are infested with a variety of lichen species. More than 50% of the observable bare rock surface is masked.

The Assynt area of Sutherland is dominated by a large antiformal stack within the duplex of the Moine Thrust Zone. It comprised one of the largest tectonic culminations and associated erosional windows in the Scottish Caledonides. Together with the rocks of the Caledonian foreland, onto which the duplex has been thrust, and the local intrusive complexes of various ages, the Assynt area provides a local diversity of rock types and structures that is unsurpassed in Britain (Figure 1). Structural features include simple homoclinal sequences in the foreland cover of Torridonian and Cambro-Ordovician, a wide variety of thrust sheets, imbrications and folds in the Caledonian duplex and complex oblique-slip shear belts in the Lewisian basement of the foreland.

2.2 The Loch Tay Area

The Loch Tay area of the Grampian highlands (Figure 2) is located between Loch Rannoch in the north and Loch Earn in the south. In the Ordnance Survey National Grid this study area comes on the sheet number 51 (Scale 1:50000) between 250000 to 290000 Easting and 730000 to 760000 Northing.

The three main lochs of the area, Loch Rannoch, Loch Tay and Loch Earn are controlled by four main ridges, which form the watershed areas between these major glaciated valleys. The ridges have steep profiles with a number of distinct peaks, namely Schiehallion, Meall Luaidhe and Carn Mairg etc.The highest point of the areas is Schiehallion, 1084 m above mean sea level.

Exposures are limited and consist of approximately 5% to 10% of surface area. They are mostly restricted to the main ridges. The area of interest is mainly covered by extensive tracts of peat resting upon locally transported glacial tills. The soils support a varied vegetation cover of grasses and heather which are in places periodically burnt for the grouse industry. The varied vegetation cover with its burnt "quilt" appearance together with transported till and peat soil combine with the steep slopes of the lithologically controlled ridges to produce a complex heterogeneous surface spectral reflectance pattern which is difficult to interpret in terms of the underlying geology.

The Loch Tay area is comprised of rocks of the Dalradian Supergroup, a succession of up to 25 km of marine meta-sedimentary and meta-volcanic rocks of late Precambrian to Cambro-Ordovician age. The distribution of rocks in the study area is illustrated in Figure 2. The depositional history of the Dalradian Supergroup is believed to comprise several large-scale basins of deepening and shallowing sequences which represent an increase in tectonic instability. The formations consist mainly of metamorphosed sedimentary rocks but "green beds", epidiorites, probably of volcanic origin, are found in the Sron Bheag schist and Ben Lawers schist. The Dalradian stratigraphy was subjected to metamorphism and structural deformation during the Caledonian Orogeny and these rocks were thrown into a major recumbent fold (the Tay Nappe) and in this area the succession is inverted. The core of the fold is situated in Glen Lyon.

3.0 Data

3.1 The ATM Instrument and ATM Imagery

Digital data which have been used in this study for the Assynt area comprise N - S overlapping swaths from the Daedalus AADS 1268 line scanner flown on behalf of the Natural Environment Research Council (NERC) and characteristics of the instrument which we describe as the Airborne Thematic Mapper (ATM) are described by Williams (1984). The dates of data acquisition in this area were 28 and 29 May 1984 and the data are almost cloud-free. It is not difficult to get a totally cloud-free scene of a particular area because there are two swathes, with about 30-40 percent overlapping northward and southward swathes. If clouds create a problem on northward swaths then there is a possibility that they may not be a problem on southward swaths.

Shadow due to Sun angle becomes severe only where the terrain is very rugged. East facing slopes have severe shadow problems as in the area around Loch na Gainim. Although snow cover imposes some problems, particularly in high-altitude areas, at some places it has been found useful particularly for structural interpretation of the images. Agricultural activity in some parts of the study area has largely destroyed the natural signatures, but this is restricted to small parts of the area.

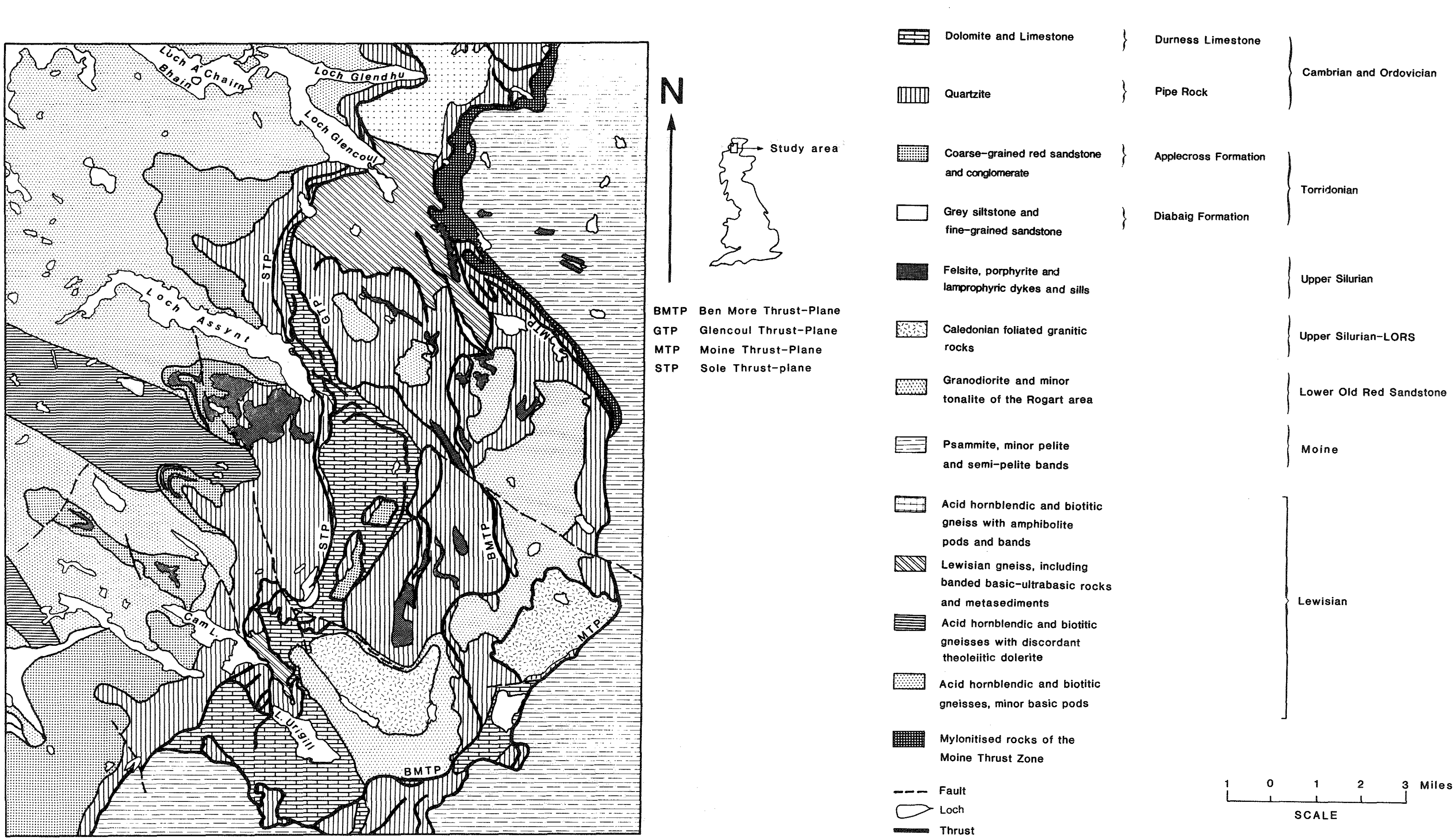

Figure 1. Geological map of the Assynt area, N-W Scotland

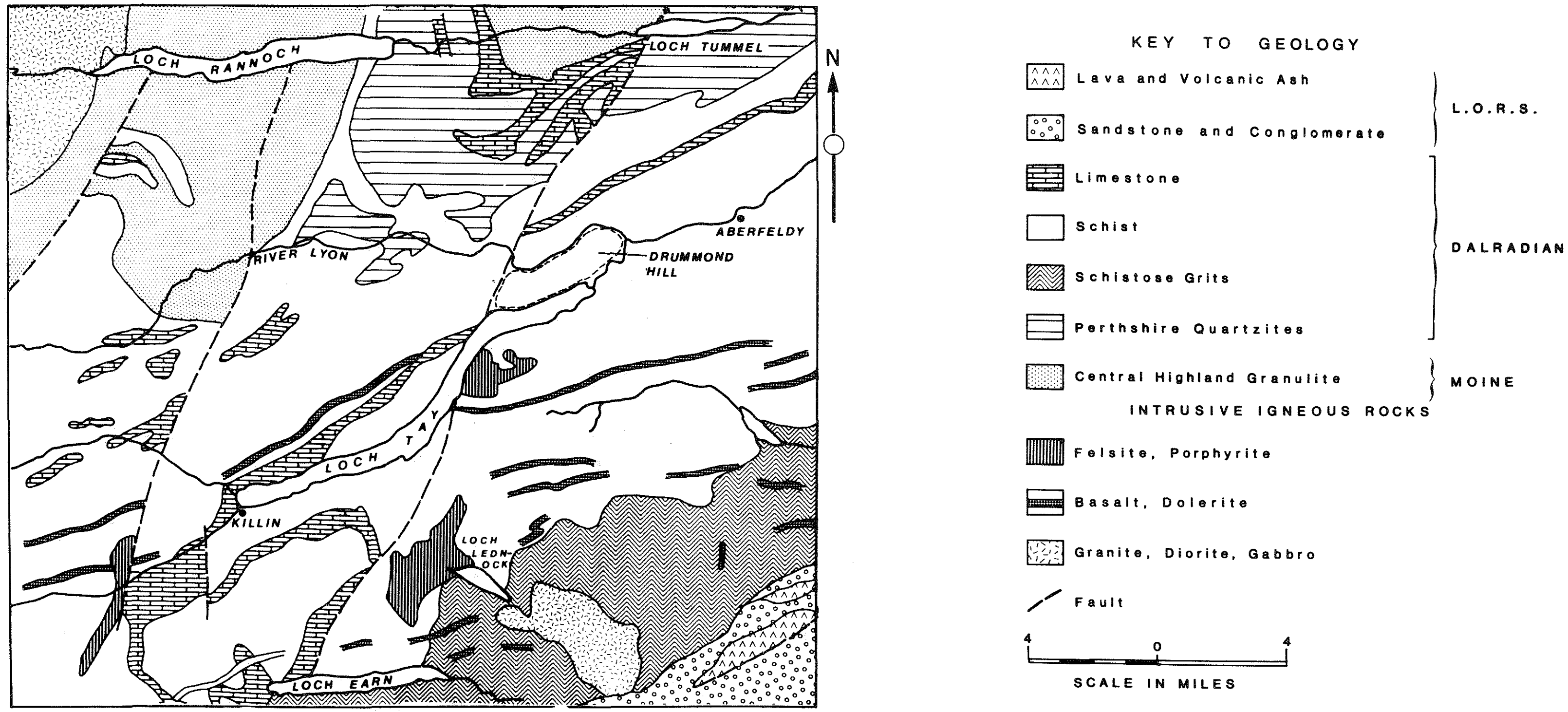

Figure 2.Geological map of the Loch Tay area, Grampian Highlands, Scotland

3.2 The Landsat MSS data

In this paper we also present the results of some work carried out for the vicinity of Loch Tay using multispectral scanning data received from Landsat and aerial photographs. The number of completely cloud-free Landsat scenes which are available for any given area is very small. Typically the National Point of Contact, at R.A.E., Farnborough, for Landsat products hold CCTs for only two or three scenes for each area of the United Kingdom. Of 10 CCTs (Path 221, Row 20) obtained from R.A.E. Farnborough, only two were sufficiently cloud-free to be useful (22 September 1979 and 28 March 1981).

4.0 Methods

To identify areas of interest on a regional basis it is neccessary to create hard copy image sheets as an interpretation base. These are false-colour composites from spectral bands which have been empirically selected to improve lithological and vegetation discrimination.

4.1 Image Processing and Interpretation

4.1.1 ATM data

The most appropriate image processing techniques depend on the geological parameters of the site, but if the whole area is covered by vegetation then conventional image processing techniques for highlighting the lithological discrimination and the presence of alteration zones cannot be applied. Martin-Kaye and Bird (1986), have demonstrated that colour composites formed from channels 10, 9 and 3 and from channels 10, 7 and 3 can be used to map accurately the location of alteration zones in certain parts of Saudi Arabia which do not have any vegetation.

No two problems are necessarily solved by the same image-processing technique. The essential quality of the ATM is its adaptability to many different circumstances. In the present study it has been established after many trials of combinations of channels for colour composites that the colour-composite of channels 5, 7 and 9 is the best combination of channels for geobotanical studies. High reflectance of vegetation between 0.75µm to 1.25µm in the electromagnetic spectrum suggests that the combination of channels 5, 7 and 9 covers the high reflectance of vegetation and if there is any shift in the reflectance of stressed vegetation from the infrared to the visible bands then this combination will also identify that shift.

The geological interpretation of the ATM imagery was carried out in a number of inter-related phases.

1. Selection of the most suitable false-colour composite combination to suit the principal objective by examining selected combinations over known areas of interest.
2. Production of hardcopy imagery using the chosen colour composite combination.
3. Initial interpretation of hard copy to identify geology and vegetation and stressed vegetation (if present) and to locate new areas of exploration interest.
4. Interactive processing of imagery over selected areas of interest to improve the interpretation.
5. Application of more complex image processing techniques, such as principal component analysis and band ratios composite, to particular areas of interest.

Geometric correction of data was attempted using 1:50,000 Ordnance Survey maps but it proved very difficult to remove all the variations in scale, due to variations in the flying height and to ground elevation effects. After unsuccessful attempts to correct two scenes, no further corrections of this form have been undertaken.

4.1.2 Landsat MSS data

Tapes of the two cloud-free scenes have been processed and a number of hard-copy images generated. Many images are false-colour composites (FCCs) and these are contrast enhanced. In each of the scenes we have taken the data from three of the four spectral bands, usually 4, 5 and 7, and assigned them to the three colours blue, green and red. The grey values have been suitably colour coded so that no absolute significance should be attached to shades of the false colours. The shades change from one scene to another and also, for a given scene, when the contrast enhancement is altered.

Band ratioing: In the visible and near infra-red spectral region (0.35-1.1µm), ferric oxides and vegetation exhibit strong absorption features. In the short wavelengths infrared region (1.1-2.5µm), various phyllosilicates, carbonates and sulphates have characteristic spectral responses. However, both dry and green vegetation also affect this spectral region.

Band ratio analysis is an effective method for detecting spectral differences between bands of image data. The pixel brightness values of two spatially co-registered bands are expressed as a ratio and the resulting values rescaled for display purposes. In this project we have used the band ratio of infrared/visible (band 7/band 4) and the results are quite useful particularly for vegetation/lithological interpretation.

Principal Component Analysis: In principal component analysis the first principal component contains approximately 90% of the information of the studied scene, the second principal component contains around 8% and principal components three and four contain about 1% each. The first principal component is therefore very useful.

All images have been rectified using Ordnance Survey National Grid co-ordinates and an accuracy of better than the edge of one pixel has been achieved.

5.0 Results and discussion

The ATM imagery reveals major structural features such as faults and dykes but in comparison it is less sensitive to variations of lithology. Nevertheless because vegetation is often closely related to the composition of underlying rock types on a local scale it is often possible to differentiate outcrop patterns of differing materials.

Growth patterns of vegetation along many small-scale faults near Loch Feith Leothaid differ from those upon the adjacent country rocks. Similar fault-based topographically negative lineaments occur near Loch A Chairn Bhain, as identified using density slicing giving a distinct colour to the vegetation and also using the band 7/band 3 ratio. In the same Loch Feith Leothaid area topographically positive lineaments also showing vegetation anomalies are related to ultrabasic dykes. The differences in plant assemblages are related to the high percentage of bases released into the soils from the intrusions. Both on the eastern side of Loch Assynt and south of Inchnadamph towards Stronchrubie lamprophyre sills intrude the Sail Mhor Group of the Durness Limestone. As the layers of these intermediate igneous rocks alternate with the dolomite limestones so the vegetation shows a pattern of alternating bands with grasses on limestone and bracken on the lamprophyres.

Differentiation between the gneisses of the Lewisian basement and the overlying Torridonian sequences may be achieved on the basis of vegetation type and density. The former is often grassed whereas the Torridonian rocks commonly support a dense growth of heather. On the false-colour composites used, the heather is manifest by dark tones whereas the grasses produce lighter features. The distinction is readily observed in the ground between Loch Assynt and Loch Veyatie where the sinuous unconformity circles each hill ridge in turn.

Using band ratio 3/7 it has been possible to identify the contact between the Basal Quartzite and the Pipe-Rock of Cambrian age, around Loch Urigill and south of Loch Cam. This may be the result of local reddening of Pipe-Rock. A shift of reflectance peaks from the infrared region into the visible part of the electromagnetic spectrum over the Basal Quartzite suggests stress in the vegetation above this almost entirely siliceous rock formation.

The Cambro-Ordovician sediments exposed to the north of the Skiag Bridge junction are dominated by alternations of Serpulite Grit (Salterella Grit) and Fucoid Beds within a substantial duplex zone to the north-east of which lies the Durness Limestone. In the field it is recognised that the upstanding Serpulite Grit ridges have thin soil cover and are heather dominated whereas the intervening hollows support more dense grasses and bracken. The characteristic striped ground of limited extent is readily identified on the ATM images and corresponds with the duplex zone mapped by Elliott and Johnson

(1980).

In the case of Landsat MSS data of the Loch Tay area, in spite of their low spatial resolution (79 m) these data are very useful for this type of study. Band ratio composites of bands 4/5, 5/7 and 7/4 have been found helpful for the identification of linear features. Several linear features which had previously remained unrecognised have now been recognised (Figure 3). Most significantly we have identified a new NNE-SSW trending fault which runs almost parallel to the Loch Tay Fault. The name Loch Lednock Fault has been given to this new fault which extends from Loch Tummel in the north to Loch Earn in the south.The Loch Lednock Fault comprises small-scale faults east and south-east of Loch Tay. Small segments of NNE-SSW trending faults on this line are plotted on the British Geological Survey 1:63,360 scale maps (sheets 47 and 55). Irregularities in lithological boundaries occur in the Dalradian sequences immediately east of Loch Lednock and in the southern boundary of the Perthshire Quartzite south of Loch Tummel. Principal component analysis has proved very important in the detection of various types of vegetation. Major lithological units of the area and their boundaries have been identified on this basis, although on the ground this is sometimes difficult due to vegetation cover.

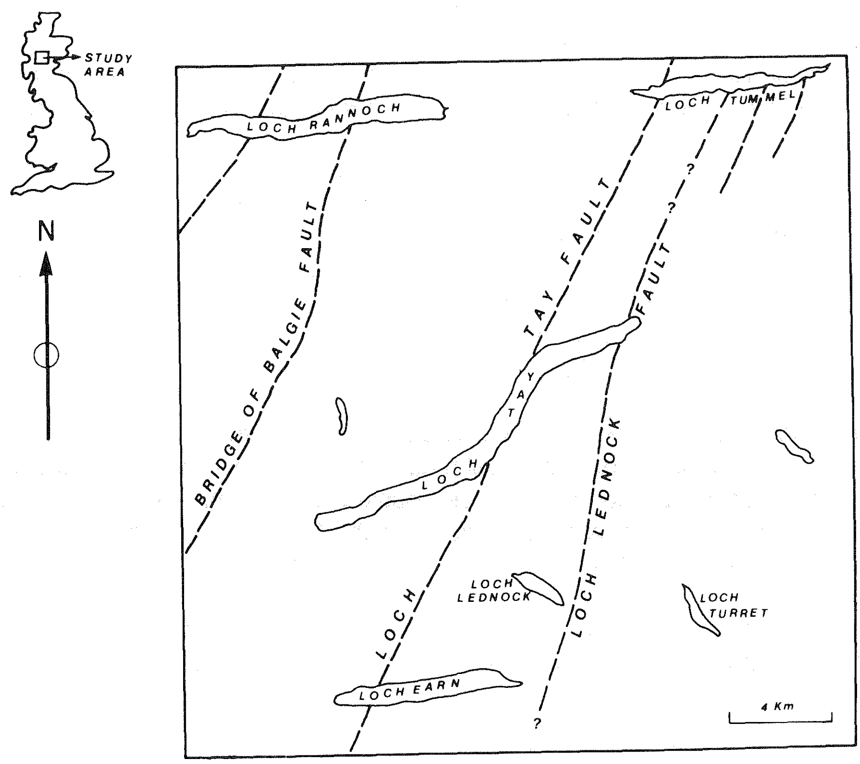

Figure 3. Structural interpretation of Landsat MSS band ratio composite (band 4/5, 5/7 and 7/4)

On Drummond hill, in spite of afforestation, a close relationship has been identified between soil, geology and vegetation. On Drummond hill there are mainly two types of Dalradian sequence rocks (a) Mica Schist, and (b) Epidiorite and Hornblende Schist. The soils on these two rock groups are different in nature. The soils on the Mica Schists are *Brown Forest* soils and soils on Epidiorite and Hornblende Schists are *Peaty Podzols* (Soil Survey of Scotland 1980). The vegetation on these different soils also differs in nature. The plants growing on *Brown Forest* soils are European larch and plants on *Peaty podzols* are Scots pine (Edlin 1969). The different signatures of these plants which have been identified using both Landsat MSS data and aerial photographs confirm the relationship between geology, vegetation and soils.

Comparison of the two available data sets reveals that the September data are much more useful than the March data in detecting relationships between vegetation and bedrock geology.

6.0 Conclusion

Many aspects of the study areas are ideally suited to geobotanical methods for geological mapping. Vegetation and bedrock geology are often closely correlated. For the detection of maximum difference between healthy and stressed vegetation the season of observation is vital. It is most important that data should be obtained in cloud-free and snow-free conditions during those months when the heavy metal cycling in the plants is greatest (Saraf et al. 1987). The month of May, effectively early spring in northern Scotland, is the time when the cycling of heavy metal in plants is normally at its greatest (Guha and Mitchell 1966). However in 1984, there was a severe drought throughout western Scotland from February to early June, with a consequent "knock-back" on new growth (Drury 1986). Despite the drought, good correlations have been identified between the vegetation cover and specific lithological types.

The major advantage of ATM is that it can provide cloud-free and snow-free data which are difficult to get by orbital systems because of the frequent occurrence of clouds. Their other major advantages are the vastly superior resolution and the ability to aquire the data under the most favourable climatic conditions.

In case of the Landsat MSS data neither available scene (March and September) was very useful for the detection of difference in vegetation because of the time of acquisition of data. The greater value of the September data stems from the fact that dieback in vegetation is begining at that time of the year. Nevertheless the Landsat MSS data have been found very useful for structural and lithological interpretation. This analysis confirms many well-known features but also reveals many previously unrecognised lineament systems (Figure 3).

It should be stated clearly that multispectral data of both sets are very useful, but they do not provide the entire answer to the problems of geological mapping using geobotanical concepts. Rather, these data constitute a new element of information to be coupled with existing technology to increase the quality and accuracy of mapping. The vegetation cover of the Earth is dynamic and living, relying for its very existence on a close and flexible coupling to its environment

Narrow bands in the thermal infrared part of the electromagnetic spectrum have the potential to improve geological mapping, but more research is required in the field of geobotanical techniques to established its applicability in geological mapping.

7.0 Acknowledgements

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