

FAULT AND LINEAMENT PATTERNS IN THE SOUTHERN HIGHLANDS OF SCOTLAND

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ABSTRACT

Johnson, M.R.W. & R.T.C. Frost (1977). Fault and lineament patterns in the southern Highlands of Scotland. *In*: R.T.C. Frost & A.J. Dikkers (eds.): Fault tectonics in N.W. Europe. Geol. Mijnbouw, 56, p. 287-294.

This paper discusses the mapped faults and photolineaments (observed on Landsat images) in part of the Scottish Caledonides. The prominent NNE-SSW to NE-SW trending wrench faults, including the Great Glen Fault, were active in the Upper Palaeozoic. In addition, recent studies have suggested Mesozoic/Tertiary activity along the Great Glen Fault. The Highland Boundary Fault, which forms the southeastern margin of the metamorphic Caledonides was an active reverse fault in Devonian times, and later transcurrent movements along it have been postulated. Another conspicuous fault set trends NW-SE; some of these faults were active in Mesozoic/Tertiary times. A minority of the faults trend roughly N-S or E-W.

A map of lineaments from Landsat images has been constructed. The lineament pattern is shown to correspond closely to the fault pattern. Although by no means all mapped faults were observed on the satellite imagery, it is considered that some previously undescribed fractures and extensions to known faults were detected.

INTRODUCTION

This paper deals with the geologically mapped faults and the lineaments observed on satellite photographs in an area, measuring approximately 300 × 95 km, composed mainly of Late Proterozoic to Devonian rocks. These from a *block*

roughly bounded by the Great Glen Fault on the northwest and by the Highland Boundary Fault in the southeast. The main rock formations within the block are *Moines*³⁾ (Late Proterozoic metasediments) overlain by *Dalradian* (Late Proterozoic to Early Ordovician metasediments with minor meta-igneous rocks). The "Moines" and Dalradians were orogenically deformed and regionally metamorphosed in early Ordovician times, with the development of Alpine-type structures. Following most of the deformation, the rocks were intruded by large amounts of granitic magma in early Devonian times, during which there were also periods of dyke intrusion and lava eruption, notably in the southwest part of the block. The Devonian sediments are molassic, deposited in intermontane basins and upon the deeply eroded "Moine" and Dalradian metamorphic rocks.

Only insignificant amounts of late Paleozoic, Mesozoic and Tertiary rocks are present in the block; among the post-Devonian rocks perhaps the most noteworthy are the swarms of Tertiary dykes which cut across the southwest area in a NW-SE direction.

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³⁾ Perhaps in deference to modern views (Brook et al., 1976; Johnson, 1975), these should be called "younger Moines" to distinguish them from "Moines sensu stricto" which lie to the north of the Great Glen Fault. However, in this paper and on Encl. 1, "Moines" refers to all the pre-Dalradian and post-Lewisian rocks on both sides of the Great Glen Fault.

FAULTS

General fault pattern and distribution

The 1 : 250 000 scale fault map (Enclosure 1) depicts the trends of major and minor faults in the block and in the adjacent terrains. The data have been collected from 1"-1 mile (1 : 63 000) geological maps⁴⁾ which are available for most of the region studied here. In addition, reference has been made to many published papers which postdate the maps and normally deal with small areas. A search through Geological Survey Memoirs has been made in the hope of obtaining more detailed insights into the various faults recorded.

Where indicated on the source maps, or where it can be inferred from stratigraphy, the downthrow of a fault has been shown. There are virtually no records of fault attitudes in the literature. Only one published study (Smith, 1961) dealt statistically with minor faults (in the southwestern part of the block). Therefore, care was taken to estimate fault dips from the outcrop pattern: all examples shown in the map are steeply dipping, i.e. more than 65°. Many of the major faults, and some of the minor ones, have obvious topographic expression, giving prominent valleys.

The fault pattern is dominated by *major NNE-SSW to NE-SW (020° - 045°) trending faults* roughly following the Caledonoid "grain" in the block: Great Glen Fault, Laggan Fault, Erich-Laidon Fault, Tyndrum Fault, Garabal Fault, Killin Fault, Loch Tay Fault. In addition, there is the Highland Boundary Fault, which trends roughly ENE-WSW. Except for the latter, all these are accepted wrench faults with substantial (sinistral) displacements. Smaller NE-SW trending faults probably belong to this wrench-fault regime, but normally there is no evidence to prove this (where evidence for strike-slip displacement along a minor fault has been found, this is indicated on the map).

Among the minor faults, many trend NW-SE (310° - 330°). While it is tempting to regard these as the complementary set to NE-SW wrench faults in a conjugate shear system (cf. Smith, 1961), there is very little evidence for the strike-slip along the northwest trending faults. One clear example of a northwesterly dextral fault, with a few hundred metres slip, occurs near Loch Laggan (Anderson, 1956). On the other hand, many of these minor faults show vertical throw, but probably never more than a few hundred metres.

⁴⁾ Published by the Geological Survey of Great Britain, which is now the Institute of Geological Sciences.

⁵⁾ The significance of this arc-like trend is not apparent. Possibly it means that displacement on the Great Glen Fault was controlled by a pole of rotation (sited to the NW of the British Isles) to which the fault defines a small-circle trace (cf. Woodford & McIntyre, 1976). Alternatively, the Great Glen Fault may be an indentation response to the collision of continents with irregular margins, and therefore possibly analogous with the structures in Asia described by Molnar & Tapponier (1975).

Commonly these faults can be traced for only short distances, e.g. a few kilometres. A study of the southwest part of the block shows a general SW and WSW dip for the minor faults.

A few faults have NNW-SSE to N-S trends, e.g. the prominent fault in the extreme northeast part of the block, and the faults which displace Tertiary rocks near the volcanic centre of Mull.

Except in the northeast part of the block, where exposure is extremely bad, the distribution of faults on the map is probably a fairly accurate reflection of occurrence and density of the fractures. Another factor affecting the pattern is the lack of lithological control in the "Moines", which is composed of a thick and monotonous psammitic sequence. This may explain the apparent scarcity of minor faults in the "Moines" which occupy most of the north-central and northeast parts of the map. It is also interesting to note the apparent lack of major NE-SW wrench faults in the northeast. The major faults in the block seem to terminate before reaching the Moray Firth coast, where there is a marvellous coast section. The Laggan Fault has been traced northeastwards as far as a graben, in which Devonian rocks are dropped down against "Moines"; the Erich-Laidon Fault gets "lost" in an area of "Moines", and the Loch Tay Fault disappears in an area of large granite plutons.

In south-central parts of the Dalradian, Smith (1961) records minor E-W trending thrust faults. It is unlikely that any of the roughly E-W trending faults shown on the map are thrusts, in view of their steep inclination.

Bounding faults

Great Glen Fault - This is part of a fault line that can probably be traced for *at least* 700 km. It appears to trend from 038° in the SW of the map, swinging gradually to 035° in the NE⁵⁾. Its submarine extension has been traced north-eastwards to the Shetlands, where it is probably represented by the Walls Boundary and Nesting fault systems (Flinn, 1961, 1969). To the southwest, the main fault appears to pass north of Colonsay (McQuillan & Binns, 1973) whilst a southern branch, the Loch Gruinart fault, may pass through Islay (Dobson & Evans, 1974, 1975). From Colonsay the main fault may continue west or southwest for at least 150 km (Bailey *et al.*, 1975). According to Riddiough & Max (1976), it continues as far as the Porcupine Bank.

Kennedy's (1946) proposal that the Great Glen Fault is a major wrench has been generally accepted, but controversy remains about the age, and sense and amount of slip. Some recent authors have suggested total or partial dextral slip, in opposition to Kennedy's sinistral slip. Sinistral shifts of 115 km (Holgate, 1969), 160 km (Winchester, 1973), 250 km (Storetvedt, 1974; Storetvedt & Winchester, 1974) and dextral shifts of 30 km (Holgate, 1969), 110 km (Garson & Plant, 1972) and 60 - 100 km (Flinn, 1969) have been proposed by

different geologists. In addition, Bacon & Chesher (1975) argue for solely normal faulting along the Great Glen Fault in post-Hercynian times (but see Flinn, 1975). This work has also highlighted the possibility of a prolonged history of movement on the Great Glen Fault, e.g. the proposed displacement of Tertiary dyke swarms (dated at 54 m.y. B.P.) and, of course, earthquakes have been recorded along the fault line (see also Flinn, 1977; Bott & Browitt, 1975). Downthrow of at least 2 km to the southeast has been proposed.

Some workers (e.g. Garson & Plant, 1972; Flinn, 1969) have proposed an initiation of the fault before the mid-Devonian, somewhat earlier than the time envisaged by Kennedy.

It is worth mentioning that new radiometric dating (Brook *et al.*, 1976) suggests that the Great Glen Fault separates different orogens — a Grenville belt (with a Caledonian "overprint") to the north covering the northern Moines (Johnson, 1975), and a wholly Caledonian belt to the south (the block considered here). Previously Garson & Plant (1973) had raised the possibility that the Great Glen Fault follows a subduction zone which was active in the Late Precambrian, during consumption of oceanic crust that was situated to the south of the Great Glen, but this is unlikely because Grenville, or at least late Proterozoic, ages have been reported from south of the line of the Great Glen fault (van Breeman *et al.*, 1976).

The present position regarding the Great Glen Fault can be summarised as set out below.

- (1) Total dextral displacement is improbable.
- (2) Direct evidence for sinistral displacement (Kennedy's disrupted Strontian-Foyers granite complex) is probably unreliable (Munro, 1973; Marston, 1970). The case for sinistral displacement rests on the apparent association (parallelism) between the Great Glen Fault and known sinistral wrench faults (e.g. the Ericht-Laidon and Loch Tay faults); also the Great Glen Fault (or the Loch Gruinard Fault) is in line with the Leannan Fault in W. Ireland, which is a sinistral fault (Pitcher *et al.*, 1964). Sinistral displacement probably occurred in the Palaeozoic.
- (3) Arguments for post-Cretaceous movements are fairly convincing; these movements are most likely dextral in character, perhaps amounting to 30 – 65 km. Evidence includes displacement of Tertiary dykes, of ancient river systems and of Jurassic strata in NE Scotland. A postulated 65 km dextral displacement on the supposed continuation of the Great Glen system in the Shetlands is supposed to be partly of post-Jurassic age, and a similar dextral displacement on the Helmsdale Fault, which is parallel to the Great Glen Fault, has been suggested (Flinn, 1977).

Highland Boundary Fault — This constitutes the southern limit to the Midland Valley Graben. It can be traced for

about 400 km through Scotland and it certainly extends beyond there into the North Sea and into Ireland. In the block studied, it trends c. 045°/046° in the SW, switching to c. 058°/059° NE of the junction with the Loch Tay Fault. The fault is well exposed at Stonehaven on the east coast. Everywhere the Highland Boundary Fault is a high angle fault (70° dips to NW are recorded), usually separating Dalradian from Lower Devonian rocks. At Stonehaven, however, low-grade Dalradian metasediments are faulted against schistose Arenig spilites and black shales: the fault zone is about 15 m wide and is occupied by dolomite. To the south, the Arenigian is covered unconformably by steeply dipping Downtonian sandstones.

Most authors (e.g. Anderson, 1947; Ramsay, 1964) regard the fault as a reversed fault, with slip of roughly 3 km. It is also complex and possibly fundamental. Lambert & McKerron (1977) have suggested that the Highland Boundary Fault marks a subduction zone but this is at variance with the identification of probable continental basement to the Midland Valley (Upton *et al.*, 1976). The main displacement, by reverse faulting, occurred in Middle Devonian times. On tenuous grounds (perhaps because of the allochthonous serpentines which line the fault), several authors propose late Cambrian or early Ordovician slip along the Highland Boundary Fault. The conclusion is based on the existence of fragments of serpentine in Lower Devonian conglomerates, but this merely implies that serpentines were at erosion level in Devonian times — they may have been derived from, say, an obducted ophiolite complex rather than from the Highland Boundary Fault zone (cf. Church & Gayer, 1973). Post-Devonian slip, with downthrow to the north, is shown by the displacement of the Lower Carboniferous across the fault (Anderson, 1947). However, the fault line cannot have moved significantly since that time because Carboniferous-Permian dykes cross it without deflection.

Anderson (1947) has postulated sinistral slip on the Highland Boundary Fault during the Carboniferous movements, perhaps influenced by the rough parallelism between the Highland Boundary Fault and the wrench faults; evidence is slight, e.g. horizontal slickenside lines.

Major faults in the block

Laggan Fault (030° – 040°) — this can be traced for about 110 km, traversing "Moines", Dalradian (?), Middle Devonian rocks and granites. No estimate of slip. Northeast termination is a graben; southwest termination is within a granite.

Ericht-Laidon Fault (040°) — this can be traced for 140 km, traversing "Moines", Dalradian and granites. Up to 10 km sinistral slip has been calculated from the displacement of granite contacts.

Tyndrum Fault (030°) — this can be traced for 60 km, across "Moines", Dalradian and granites. It is clearly seen as a high

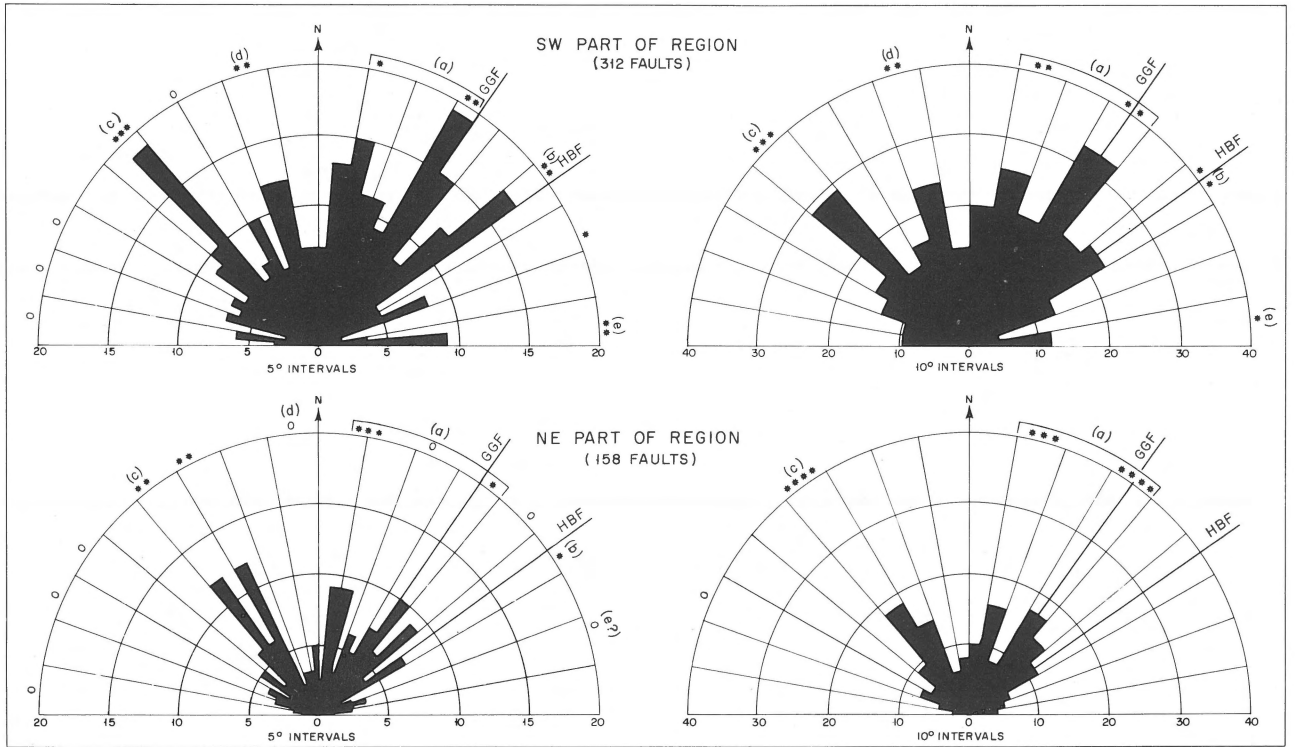


Fig. 1
Rose diagrams of frequency of mapped faults in Southern Highlands of Scotland.

The predominant trends of the major bounding faults are given for reference. Stars represent peak significance following the method outlined in Frost (this volume): - **** represents less than 0.1% chance of peak being randomly produced, *** = 0.1% to 1%, ** = 1% to 5%, * = 5% to 10% and 0 = greater than 10% chance.

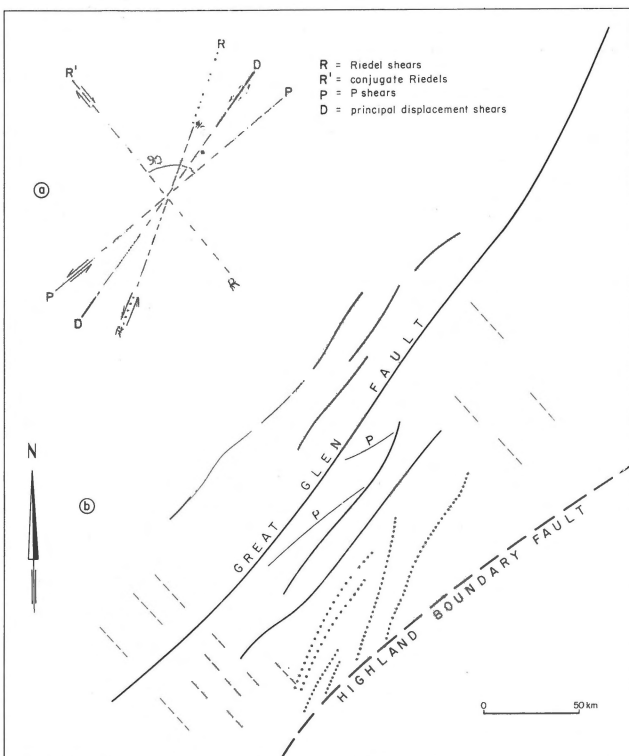


Fig. 2
Comparison of idealised pattern of Riedel shears (a) with simplified fault trends in Southern Highlands of Scotland (b).
Ornaments for D, R, R' & P shears are the same in (a) and (b).

angle fault (c. 70°) on hillsides. No estimates of slip are given. The fault line has been mineralised.

Garabal Fault (030°) – this can be traced for about 50 km. It displaces the Garabal Hill igneous complex (Lower Devonian?) by approximately 3 km. A dip of 75° NW has been measured on the fault which is followed by a crush zone 120 m wide. Horizontal slickenside lines occur in the zone, which is cut by probable Lower Devonian minor intrusives.

Killin Fault (020°) – this can be traced for about 60 km; a dip of c. 70° has been measured. A zone of shattered rock some 100 m across is found along the middle part of the fault. The zone is cut by Lower Devonian intrusives.

Loch Tay Fault (025° – 040°) – this can be traced for 80 km across Dalradian, “Moines” and granites. Estimated slip is 6 – 8 km, sinistral: it displaces fold axes and metamorphic zones. In the northeast this fault terminates in granites. In the southwest, near the Highland Boundary Fault, it passes into a series of “splays”, along which limited sinistral slip is evident (Anderson, 1947).

Faults north of the Great Glen

In a zone extending about 40 km northwest of the Great Glen Fault the influence of NE-SW trending wrench faults is

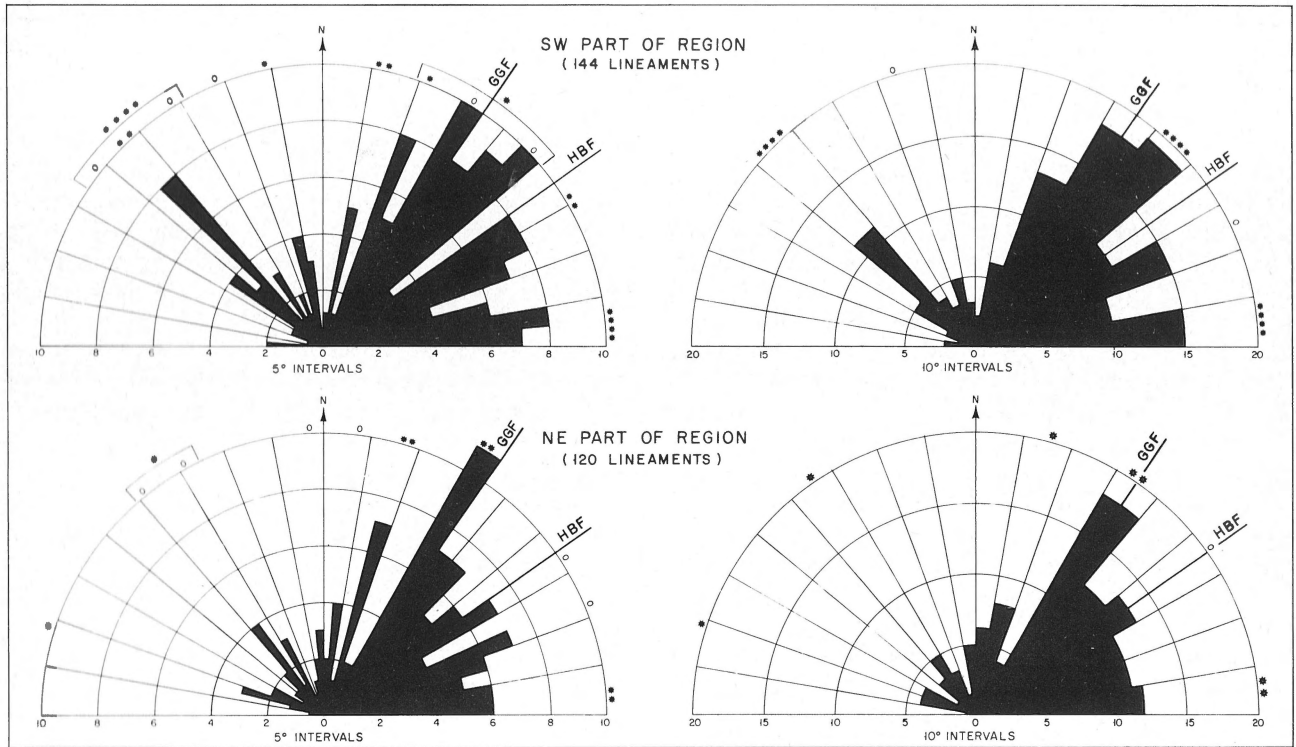


Fig. 3
Rose diagrams of frequency of Landsat Lineaments in Southern Highlands of Scotland.
Major bounding faults and peak significances as in Fig. 1.

apparent. For most of these faults, only small (less than 5 km), sinistral displacements can be demonstrated and perhaps only the Strathconan Fault (not shown) and the Strathglass Fault (035° strike) (incompletely plotted) can be considered major faults. In the northeastern part of the zone, in the region around Inverness, NE-SW faults cut Middle Devonian sediments. Therefore, the wrench-fault regime has clearly affected the rocks lying to the north of the Great Glen; furthermore, it may be noted that the Helmsdale Fault situated about 25 km northwest of the Great Glen, is part of this regime.

In the southwest part of the zone, NW-SE and N-S faults are quite common, although never of large displacement. On Mull and the adjacent mainland, faults with these orientations cut Tertiary lavas and are probably of the same age as similarly oriented faults on the other side of the Great Glen.

Ages of faulting

Reference has been made to reasonably conclusive evidence for the complex history of the Great Glen Fault and the Highland Boundary Fault. As regards the other faults, the general lack of stratigraphic control makes it impossible to demonstrate rejuvenation along individual faults within the block. What is clear is that the Laggan, Erich-Laidon, Tyn-drum and Loch Tay faults all cut Lower Devonian granites. However, the major Killin Fault and some of the minor

NE-SW faults are cut by Lower Devonian intrusives (Smith, 1961) and some granites have been intruded along fault lines. A few NW-SE faults can be shown to be earlier than these intrusives. Therefore, it is likely that the pattern of faulting was established before the main granites.

Another point is that NW-SE trending faults are especially common in the southwest part of the block. This may imply that they are associated with extension in Tertiary times, and it is noted that the NW-SE faults, in one place at least, are younger than the NE-SW faults.

Conclusions from mapping of faults

Although complex, the fault pattern may locally be resolved into the following principal sets of faults (Fig. 1).

- (1) *The NNE-SSW to NE-SW trending wrench faults*, which were initiated in Lower Devonian times and most likely persisted until the late Carboniferous. Strike-slip displacement may have been renewed along the Great Glen Fault in the Mesozoic and Tertiary.
- (2) *The ENE-WSW trending faults*, including the Highland Boundary Fault which acted as a reverse fault in Mid-Devonian times and perhaps as a wrench fault in Carboniferous times.
- (3) *The NW-SE trending (usually minor) faults*, several of which show vertical throw. There is little evidence of horizontal displacements on these faults. Evidence that some of

these faults cut Mesozoic/Tertiary rocks indicate that the set, if not entirely of Tertiary age, was certainly active then. Widespread extensional fracturing in a NW-SE direction, with dyke intrusion, prevailed over the southwestern part of the block in Tertiary times.

(4) *The N-S to NNW-SSE trending faults*, some of which are of Tertiary age.

(5) *The E-W trending faults*, which are scarce. Their age is unknown, beyond the fact that they cut Devonian rocks.

Since the age and nature of many of the faults is uncertain, it is obvious that any kinematic interpretation of the fault pattern must be speculative. Smith (1961), well aware of these problems, suggested that the pattern represents a conjugate system of first- and second-order shears. Another hypothesis may be added here, namely that the pattern corresponds to a system of Riedel shears, i.e. R shears, R' or conjugate Riedels and P shears (Fig. 2a), along the lines set out by Tchalenko & Ambraseys (1970) for a fracture zone in Iran. Applying such a model to the faults of the Southern Highlands, the major sinistral faults (Loch Tay Fault, etc.) would be *R shears* making an angle of $15^\circ - 20^\circ$ with the *main fault* (the Great Glen Fault – Fig. 2b). The identification of P and R' shears is more controversial. The only possible P fractures are two faults located south of the Great Glen⁶). At least some of the NW trending minor faults may be R' fractures, although it would appear that they make a larger angle with the “main fault” than is normal for conjugate Riedels. The implications of this hypothesis are:

- (1) the Great Glen Fault is a major sinistral tear fault;
- (2) the whole block is a shear zone (c. 80 km across) related to the Great Glen Fault, which must be some 1500 km in length, i.e. as long as is suggested by the maximum estimates mentioned in this paper.

LANDSAT LINEAMENTS

Landsat lineament map

Enclosure 2 is a map of lineaments (in the sense of O'Leary *et al.*, 1976) observed on Landsat imagery from the area covered by Enclosure 1. For a discussion of what sort of features define a lineament on satellite imagery, see Frost – this volume. A minimum length of 5 km was taken for the lineaments, and some distinct arcuate and circular features were also included. The scenes used have identification numbers: 81035-10552 (27/Aug/72, spectral bands 5 & 6), 81231-10451 (11/Mar/73, bands 5 & 7),

81231-10453 (11/Mar/73, band 6 & false colour composite), 81233-10564 (13/Mar/73, bands 5 & 7), 81233-10570 (13/Mar/73, bands 5 & 7), 81701-10485 (24/Jun/74, bands 5 & 7) and 82122-10495 (24/May/75, bands 5 & 7); 1 : 500 000-scale images were used – the same scale as the final map. Apart from two small cloud-covered areas in the north of the region, the quality of the coverage was extremely good. After an initial drafting of the map, a comparison was made with 1 : 250 000 Ordnance Survey geographical maps, and any apparently wholly man-made linear features were removed.

It is beyond the scope of this paper to discuss each lineament in turn in terms of its geological, and particularly tectonic, significance; however, some general points can be made as set out below.

(1) The main features of the fault pattern are clearly brought out in the lineament map – this is perhaps not surprising but it should be emphasised that the lineament map was constructed largely without reference to any fault map.

(2) Many of the minor features of the fault map are also seen, though equally many are not reflected on the photographs.

(3) In a number of cases the lineaments extend for a greater distance than mapped faults (e.g. Loch Tay, Killin and Tyn-drum faults), though sometimes the converse is true (e.g. Erich-Laidon and Laggan faults).

(4) Sometimes lineaments join up short sections of mapped faults to make one continuous feature (e.g. lineament running SE of Balmoral – c. 057°N , 003°W).

(5) Lineaments are invariably straighter than the corresponding faults on Enclosure 1 (e.g. the fault running across Loch Etive), or are more clearly seen to be made up of a series of straight or slightly curvilinear segments. Such segments are often joined at points where other lineaments cross or join at a high angle (e.g. in the area of the Loch Tay Fault at about 057°N).

(6) The density of lineaments is *not* noticeably less in the NE of the map, where far fewer faults can be observed.

(7) There are apparently more roughly E-W features than on the fault map.

A rapid comparison of the lineament map and published geological and aeromagnetic maps was undertaken in order to see what, if anything, gave rise to those lineaments that did not correspond with known faults. Geologically, it was found that the lineaments could be divided into the eight rough categories below, according to what happened along the major part of their observed lengths.

⁶ G. Mandl has pointed out that P shears can only occur along a major wrench fault in regions where normal stress “parallel” to the fault is very high. Unfortunately, the authors know of no evidence to demonstrate unusually large compressive stress in the rocks immediately to the south of the Great Glen Fault at the time it was active.

Those that followed:

- | | |
|--|-----|
| (A) faults, | 40% |
| (B) lithological boundaries described as unfaulted, or | 10% |
| (C) straight igneous contacts or dykes. | 5% |

Those that cut lithological boundaries:

- | | |
|---|-----|
| (D) without any disturbance, | 10% |
| (E) with obvious disturbance of some kind, or | 5% |
| (F) or with possible disturbance. | 10% |

Those that followed no known geological discontinuities and cut across no lithological boundaries:

- | | |
|---|-----|
| (G) but cut across the structural grain, or | 5% |
| (H) and did not cut the structural grain. | 15% |

It is suggested that only category (B) and a proportion of (D) and (G) are unlikely to represent fractures. Category (C) is probably largely tectonically controlled; at least some of (D) may correspond with joints or small-displacement faults; (E) & (F) could consist mainly of previously unidentified faults and, although (G) & (H) could contain many fractures, this cannot be verified without careful ground-checking.

The above conclusions are supported by comparison of the lineament map with aeromagnetic maps, when it was found that 30% of category (A) followed definite magnetic lineaments and 30% followed a zone of some kind of magnetic disturbance; the corresponding figures for categories (C), (E), (F) & (H) were 20% and 30%, respectively, but for categories (B), (D) & (G) only 10% and 30%, respectively.

Recently, successful use has been made of Landsat images in identifying previously undetected fractures (William & Carter, 1976; Hodgson *et al.*, 1976; Halbouty, 1976). It is therefore concluded that it might be most rewarding to examine the nature of the last five above categories of lineaments, and also to see if the continuation of faults can be verified where lineaments extend beyond their terminations shown in Enclosure 1.

Directional analysis of Landsat lineaments

Rose diagrams of the frequency of Landsat lineaments are shown in Fig. 3. In constructing these diagrams, only the "sharply" and "moderately well defined" lineaments were used; because of their often uncertain status, the "poorly defined" lineaments were omitted from this analysis. Comparison of the data on just the block between and including the Great Glen and Highland Boundary faults, with the data including the rest of the region revealed no significant differences; therefore, such a subdivision is not considered here. Rose diagrams were also drawn of total-length data, but they were similar to the frequency diagrams, except in tending to emphasise the peaks in the NE quadrants of Fig. 3. The statistical method for determining peak significances is that outlined by Frost (this volume). Unfortunately, between 020° and 090°, the peaks are so close together that the significance percentages must be regarded as minimum values only.

The most striking aspect of Fig. 3 is that the most promi-

nent directions agree extremely well with those in Fig. 1, confirming the visual impression from the two maps. The main differences appear to be the increased importance of the 080/090-260/270 direction and decreased intensity of features trending 135/145-315/325 and (in the SW section only) 160/170-340/350. Several factors which differ between the two sections in Fig. 1 can also be observed in Fig. 3, i.e. the apparent shift of the NW-SE peak from 130/140-310/320 (SW section) to 140/150-320/330 (NE section), and the presence of an 010/020-190/200 peak and the absence of 160/170-340/350 and 105/120-285/300 peaks in the NE with respect to the SW. The last-mentioned peak appears to be statistically significant in Fig. 3, though not in Fig. 1, and may thus represent an additional principal fracture direction.

Conclusions from lineament study

It has been demonstrated in the previous two sections that lineaments observed on Landsat imagery correspond well with mapped faults, particularly with respect to their directional pattern (compare Figs. 1 and 3). Furthermore, it seems likely that some previously undescribed fractures and extensions of known faults have been observed in the lineament study; this is supported by comparison of Enclosure 2 with published geological and aeromagnetic maps.

The high density of lineaments in the NE section of the region studied, which is predominantly drift-covered or consists of very uniform Moinian lithology, may be an illustration of the ability of satellite imagery to "spot" fractures under such difficult circumstances.

E-W lineaments are abundant, especially in the NE when compared with the faults. These could well be related to the E-W faulting and folding, dominant in the eastern Moray Firth and the region west of the Forties area (Kent, 1975).

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