Loch Lomondside - an excursion

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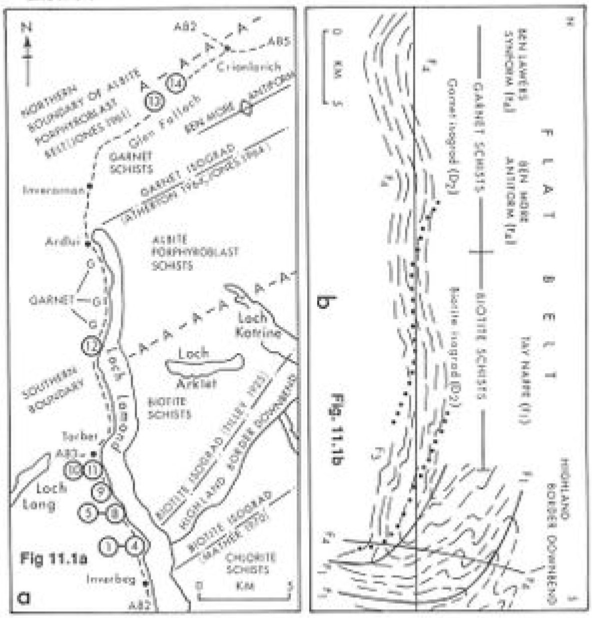

Figure 11.1. Locations (a), metamorphic isograds and cross-section (to east of Loch Lomond–(b) illustrating the main geological features.

Episode	Grampion			Athollian - - - ?		
Age (Ma)	Before 590 Ma			c. 490	c.450	
Phase	Syn-D_1	Post-D_1	Syn-D_2	Syn-D_3	Syn-D_4	Post-D_4
Quartz	—	—	—	—		—
Muscovite	—	—	—	—		—
Chlorite	—	—	—	—		—
Albite	—			—		—
Garnet		– –	—	—		
Biotite				—		—
Epidote				—		
Tourmaline	—			—		

Figure 11.2. Summary of phases of metamorphic mineral growth in relation to major episodes.

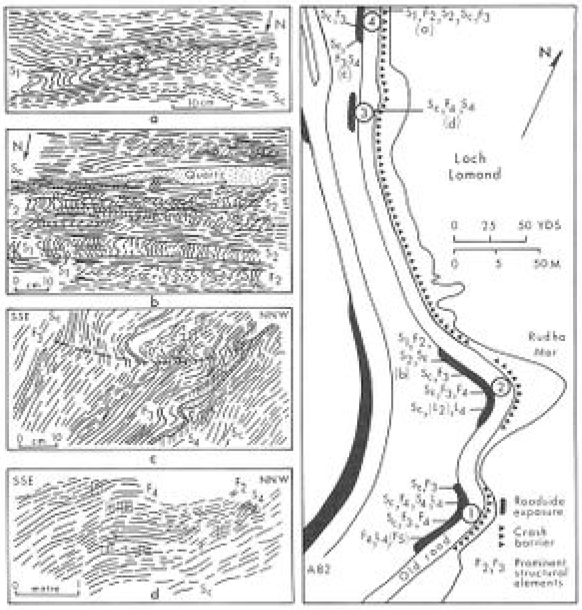

Figure 11.3. Map of Rudha Mor and examples of structural features.

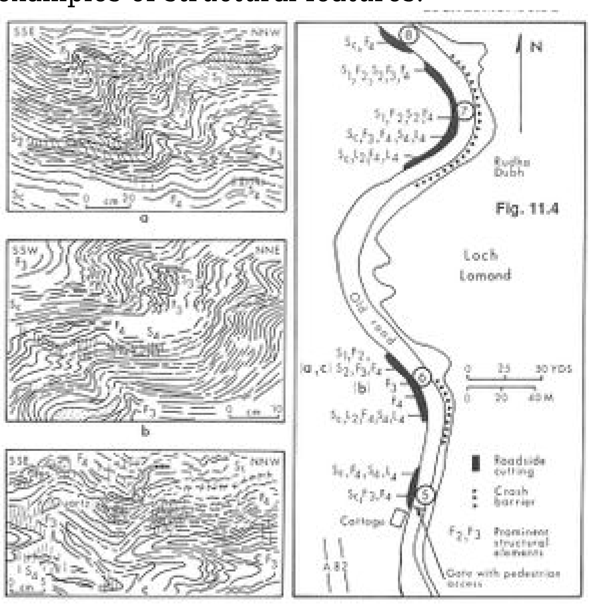

Figure 11.4. Map of Rudha Dubh and examples of structural features.

Contents

Key details

Author	D.R. Bowes
Themes	Polyphase deformation and polymetamorphism in the Caledonides; Barrovian-type metamorphism; Grampian and Athollian episodes.
Features	Dalradian Supergroup, folds, lineations, metamorphic mineral growth, schistosities, schists (chlorite, biotite, garnet, albite porphyroblast).
Maps	O.S. 1: 50 000 Sheet 56 Loch Lomond & Invararay 1: 63 360 Sheet 53 Loch Lomond B.G.S. 1: 50 000 Sheet 038 W Ben Lomond
Terrain	Roadside exposures.
Distance and Time	About 21 miles (34 km) one way. With many localities facing east, morning light is advantageous. Because of the clearly displayed relationships of the structural elements at Rudha Mor and Rudha Dubh, a northerly traverse is recommended. The major features can be examined in 4–5 hours. If only 1.5–2 hours are available, the Rudha Dubh Localities, (5 to 8), provide the greatest range of features and relationships. For those en route with only a very brief time to spare, Localities 9, 10 and 11 give a brief glimpse of many of the features.
Access	A82 on the western side of Loch Lomond. At most times the road is very busy, with many heavy trucks and buses as well as much tourist traffic, so care is essential. South of Tarbet the road is a clearway with roadside parking prohibited. North of the loch, through Glen Falloch to Crianlarich, much of the road is a succession of broad, sweeping curves with vehicle speeds generally high and roadside parking can cause potentially dangerous bottlenecks. Many of the recommended localities are on parts of the old road or adjacent to lay-bys and car parks. While new road cuttings may look excellent for study, many have numerous vertical drill markings and lack three-dimensional exposure such as that available on the old road. Here also, absence of passing traffic permits examination of representative outcrops without the potential danger of members of the party inadvertently straying on to an exceptionally busy road. It should be noted that because of much road improvement, published maps do not consistently show road location precisely. There are toilets open throughout the year at car parks in Luss and Crianlarich. Those at the car park opposite the Loch Sloy hydro-electric power station are open during the tourist season only. Although occasional long-distance buses stop at Tarbet, this excursion is not easily accomplished using public transport.

Road log

Distances from Inverbeg [NS 345 978] travelling north and in brackets from Crianlarich [NN 384 253] travelling south. 0.0 miles, 0.0 km (21.2, 34.1): Inverbeg.

1.0 miles, 1.6 km (20.2, 32.5): lay-by on western side of road–entrance from south only.

1.1 miles, 1.8 km (20.1, 32.3): old road leading to Rudha Mor Localities 1 to 4 (Figure 11.3) abuts against embankment of new road–no vehicular access.

1.3 miles, 2.1 km (19.9, 32.0): large cutting begins -dangerous bend ahead.

1.6 miles, 2.6 km (19.6, 31.6): large cutting ends.

1.7 miles, 2.7 km (19.5, 31.4): lay-by on eastern side of road–entrance from north only (cars and minibuses can enter or exit with a U-turn, but not coaches); nearest stopping place for Rudha Mor Localities 1 to 4 (Figure 11.3).

2.4 miles, 3.9 km (18.8, 30.2): lay-by on western side of road–entrance from north not prohibited.

2.5 miles, 4.0 km (18.7, 30.1): on eastern side of road, small access road for Rubha Dubh Localities 5 to 8–not suitable for coaches which should park in lay-bys to south or north. 3.1 miles, 5.0 km (18.1, 29.1): small paved area on western side of road suitable for one car or minibus only (Locality 9).

3.2 miles, 5.1 km (18.0, 29.0): lay-by on eastern side of road–entrance from south not prohibited; for Rubha Dubh Localities 5 to 8 walk 200 m south on road verge to where there is direct access (without fences) down a bank to the old road 300 m north of (Figure 11.4).

3.9–4.0 miles, 6.3–6.4 km (17.2–17.3, 27.7–27.8): large lay-by on western side of road; AA telephone at southern end; Localities 10, 11, 4.9 miles, 7.9 km (16.3, 26.2): Tarbet; turn right at A82–A83 junction.

8.9 miles, 14.3 km (12.4, 20.0): viewpoint, picnic area, large car park on eastern side of road [NN 322 098] with Loch Sloy hydro-electric power station on western side (Locality 12).

14.8 miles, 23.8 km (6.4, 10.3): Inverarnan (setting off point for Garabal Hill intrusion).

16.8 miles, 27.0 km (4.4, 7.1): entrance to picnic area on eastern side of road–cars only (2 m headroom) (Locality 13).

18.3 miles, 29.4 km (2.9, 4.7): road bridge over railway. 18.4–18.9 miles, 29.6–30.4 km (2.3–2.8, 3.7–4.5): road cuttings on western side; off road parking on eastern side possible for cars on remnant of old road at 18.5 miles, 29.8 km (2.7, 4.3) (Locality 14).

21.2 miles, 34.1 km (0.0, 0.0): Crianlarich; toilets on northern side of railway bridge and 50 m from A82 (Glen Coe, Ballachulish, Fort William) (A85 Oban)–A85 (Perth) (A84 Stirling) junction.

Geological context

The rocks seen on this excursion are mainly quartz–mica schists and mica schists of the Leny–Ben Ledi Grits Formation of the Southern Highland Group of the late Proterozoioc Dalradian Supergroup. They are on the inverted lower limb of the Tay Nappe within a structural domain known as the "flat belt" because of the generally flat-lying disposition of the lithological units (Se), the dominant (composite) schistosity (Sc) and many blind veins of quartz that are generally concordant with the schistosity (Figure 11.1)b. Structures formed in five deformational phases (D_{1-5}) are seen: these reflect the tectonic evolution of the region over more than 150 million years from about the Precambrian–Cambrian boundary until Silurian times. However the most prominent structures are (1) a composite fabric (S_c) incorporating the Dalradian sedimentary layers and two essentially concordant penetrative schistosities (S_1 and S_2 formed during D_1 and D_2) that represent phases of the Grampian episode (pre-590 million years) (Figure 11.3)a, b and (2) upright, open folds (F_4) (Figure 11.3)d having subhorizontal axes with a NE–SW ("Caledonian") trend associated with a period of major uplift in late Ordovician times (c. 450 million years).

From south to north there is a change in metamorphic grade from chlorite through biotite to garnet (Figure 11.1). However many of the minerals have grown at more than one stage (Figure 11.2) so that what has been considered to be a relatively simple pattern of metamorphic isograds is complex because of (1) the superimposition of two major episodes of prograde mineral growth up to garnet grade, (2) the overprinting of albite porphyroblasts (post-D_4) over Barrovian-type isograds, metamorphic zones and mineral assemblages and (3) the extensive effects of retrograde metamorphism during which much chlorite was formed at the expense of biotite and garnet. The peak of the earlier episode of prograde metamorphism was during D_2 (in the Grampian episode that generally corresponded in time to the Cadomian (or Middle Pan-African) orogeny of NW Europe). The regional distribution of isograds in the district (and in SW Scotland generally) is largely the result of this episode, but there is no unanimity about their precise locations (Figure 11.1)a. The peak of the later episode that also reached garnet grade was during D_3: this is related to a corresponding (D_3) metamorphic peak during early Ordovician times associated with the development of Barrovian zones in their type area in NE Scotland (in the Athollian episode). There is a general correspondence of events in the Irish Caledonides in Connemara where D_2 dynamothermal metamorphism is overprinted during early Ordovician times by metamorphism associated with D_3 tectonic and igneous activity.

The albite porphyroblast and related mineral growth was post-D_4. Its regional expression southwestwards through Kintyre to Antrim, controlled by major F_4 structures (including the Cowal antiform), and its characteristics of a post-tectonic thermal overprint could be related to large masses of basic magma at depth whose higher level expressions are the early Silurian explosion-breccia–appinite–diorite masses that are common in the Loch Lomond district (e.g. Arrochar, Garabal Hill). The control of F_5 and S_5 on the emplacement of some of these masses means that the upper time limit on the D_{1-5} features is c. 425 million years.

While the Loch Lomond district is within the Caledonides, the term "Caledonian" has no precise meaning in relation to the evolution of rocks whose structural imprint spans from the Precambrian - Cambrian boundary to early Silurian times: the NE–SW "Caledonian trend" is shown both by D_1 and D_4 structures that are separated by c. 150 million years. Hence while a sequential development from D_1 to D_5 can be demonstrated from refolding and cross-cutting relationships in the Loch Lomond district, and in adjacent regions, not only must these deformational phases be considered in cognate groups based on an integration of structural and geochronological data (D_1, D_2 -Grampian; D_3–Athollian; D_4–regional uplift, possibly late in the Athollian episode; D_5–continued uplift to development of transcurrent faults of the Loch Tay set), but also as a partial record of geological evolution: evidence for the existence of other phases that had only limited structural or metamorphic expressions may have been masked by superimposed, more strongly expressed features, or may be identifiable only by isotopic data. In addition the metamorphic zones–isograds developed before 590 Ma (in the Grampian episode) as the result of Barrovian-type metamorphism need to be separated from the metamorphic zones–isograds formed 100 million years later (in the Athollian episode at the time of development of the type Barrovian metamorphic zones). This applies not only in the Loch Lomond district but in reconstructions of "Barrovian zones" throughout the Scottish Caledonides to ensure that metamorphic isograds whose formation was separated by c. 100 million years are not joined to give patterns without geological significance.

At the level now exposed D_1 and D_2 resulted in the structural and metamorphic modification of cover rocks (Dalradian Supergroup) during the Grampian orogeny. However at the time of D_3 deformation the rocks of the Loch Lomond and adjacent regions must have been crystalline basement to an as yet unrecognized early Palaeozoic cover assemblage that was involved in crustal thickening during early Ordovician tectonism. Which stage(s) of deformation in cover rocks during the Athollian episode relates to D_3 deformation in the basement schists is not known. However at the initiation of that phase the total effect of D_1, D_2, and any as yet unrecognized later deformational phases of the Grampian episode (or any tectonism between the Grampian and Athollian episodes), left both schistosity and lithological layering essentially flat-lying. This was a favourable attitude to facilitate the essentially horizontal tectonism, deduced from D_3 structural features, that resulted in SSE (to S)-

directed movements during the Athollian episode.

Structural elements

The most prominent structural element (S_c) consists of S_1 + S_2 (+ S_0). Variations in its attitude result largely from folding during D_4: F_4 deforming Sc on the long limbs of F_3 can be seen at almost every exposure (cf. (Figure 11.1)b. To a lesser extent, and generally in localized zones, hinges of F_3 folds are seen to deform Sc. The expression of D5 structures is very limited. Field photographs and photomicrographs of D_1, D_2, D_3 and D_4 structures are given in Bowes (1979). They and the structures in (Figure 11.3) and (Figure 11.4) correspond to features present throughout the many hundreds of square kilometres of the flat belt. However the number of F_3 fold hinges at Rudha Mor (Localities 1–4) and Rudha Dubh (Localities 5–8) is far in excess of that normally seen.

(i) Structural elements of the first deformational phase: Evidence for a large D_1 recumbent fold (Tay Nappe) is given by a regional inversion of the stratigraphical sequence. Mesoscopic F_1 folds are not seen but there was growth of quartz, muscovite and chlorite in S_1 and the development of blind quartz veins as the result of metamorphic segregation. The progressive development and modification of D structures are particularly well expressed near Rosneath (Excursion 13) and axial traces of large F_1 structures, with near-vertical axial planes because of superimposed D_4 deformation, pass through Luss (to the south) and north of Aberfoyle (Excursion 10) (Figure 11.1)b.

(ii) Structural elements of the second deformational phase: Locally, and particularly in the more psan-unitic units, there are much dissected intrafolial folds that deform S_1 and S_0 (Figure 11.3)a, b; (Figure 11.4)a. Some are tight but most are isoclinal. Commonly fold noses are much thicker than fold limbs and many occur as isolated fold hinges. There is a prominent axial planar schistosity (S_2) but on fold limbs, that greatly predominate over fold hinges, the schistosity is composite (Sc - S_1 + S_2) with evidence of transposition. Within, or at a very low angle to S_c, are abundant quartz masses with lensoid sections having the appearance of boudinaged quartz veins. Development as the result of syntectonic metamorphic segregation during D_1 with subsequent tectonic modification during D_2 is consistent with at least most of the textural observations. The dominant metamorphic zonation (chlorite in the south, biotite, garnet in the north) formed as a response to D and D_2 crustal thickening with the peak during D_2 and the isograds generally flat-lying (Figure 11.1).

A lineation expressed as a fine colour banding formed by the alignment of micas and other mineral aggregates is present within Sc. The micas that are muscovite and chlorite in the lower grades and biotite (in places with muscovite) in the higher grades are generally < 1 mm across and a few mm long. The expression of the lineation is very patchy being best shown in pelitic units. It is deformed by folds and on their generally flatly-disposed long limbs it trends NW–SE to NNW–SSE with variations in attitude related to the effects of open F_4 folds. This lineation appears to be equivalent to the "stretching lineation" that is so widely expressed in the SW Highlands. Whether it is solely related to D_2 has not been determined but it is expressed in S_c pre-dates D_3 and is referred to here as L_2. Whether D_2 is itself polyphase is not known, but it is one explanation of variations in attitude of F_2 fold hinges.

(iii) Structural elements of the third deformational phase: Folds (F_3) deforming S_2 and F_2 (Figure 11.3)c; (Figure 4)a, b are commonly asymmetrical with generally gently to moderately inclined axial planes and axes that plunge west or east at low angles. They are not large structures with maximum observed wave length of < 2 m. The folds consistently face SSE or south and in places there is evidence for axial planar thrusts on which the movement was also consistently towards the SSE (or south). Curvature of axial planes and thrusts due to superimposed F_4 folds is evident, but in some of the more psammitic assemblages the curvature is like that shown by ramps in thrust duplexes. However, utilization of the generally flat-lying Sc for much of the D_3 movement would account for both some of the retrogressive development of chlorite and the patchy expression of (remnants of) L_2. D_3 folding was dominantly flexural in psammitic units but flexural-flow in interbanded pelitic–psammitic assemblages with localized development of S_3 (Figure 11.4)b.

(iv) Structural elements of the fourth deformational phase: Folds (F_4) that deform the axial planes of F_3 folds and the earlier formed F_2 and Scare the most common mesoscopic structures throughout the region (Figure 11.3)d; (Figure 11.4)b, c. They correspond to the Cowal antiform, its continuation in the Highland Border downbend, the Ben More anti-form and the Ben Lawers synform (Figure 11.1) whose subhorizontal NE–SW ("Caledonian")-trending axes can be traced for many tens of kilometres. The folds are generally open and upright with a prominent axial planar cleavage (S_4) in pelitic units (Figure 11.3)c, d; (Figure 11.4)a, b, c associated with microfolds and a crenulation lineation (L_4) that is prominent on most micaceous surfaces of S. However both the profiles of F_4 folds and the attitude of axial planes vary with box-folds occurring where asymmetrical folds with SE- and NW-dipping axial planes are juxtaposed. In places, F_3 and F_4 folds affect the same layer of Sc without the F_4 fold affecting the F_3 fold hinge: the resultant structures have the appearance of box-folds. Where F_4 folds are superposed on F_3 folds interference structures occur and these play a major structural control on the emplacement of explosion-breccia -appinite–diorite complexes in the district.

(v) Structural elements of the fifth deformational phase: These are very weakly developed but are much more prominent further west. Very open, upright flexures (F_5) deform F_4 hinge zones and L_4; axes trend N–S to NNE–SSW. Strong N–S joints also occur and these also exert a structural control on the development of some of the explosionbreccia–appinite–diorite complexes.

Localities 1–4. Rudha Mor [NN 346 000] and nearby (Figure 11.3)

Park in one of the lay-bys indicated in the road log. S_1 deformed by F_2 with development of S? (and Sc) is shown in psammitic rocks in NNE-facing near-vertical faces at the northern end of Locality 2 and in subhorizontal faces at the northern end of Locality 4. Sc is the dominant planar fabric in all four exposures and its deformation by F_3 is well shown in the northern–central parts of Locality 2, the northern part of Locality 1 and the northern–central parts of Locality 4. F_4 deforming Sc dominates in Locality 3 and in much of the central and southern parts of Localities 1 and 2. In the more pelitic layers, such as at the most southerly part of Locality 1, L4 crenulation is prominent and curvature around very open N–S-trending F_5 is seen. F_2–S_2 deformed by F_3 is shown in the northern parts of Locality 2. F_3 deformed by F_4 with the development of S_4 and L_3 crenulation at a low angle to L4 crenulation can be seen in a number of places in Localities 1 and 2 and at the southern end of Locality 4.

Localities 5–8. Rudha Dubh [NN 345 017] and nearby (Figure 11.4)

Park in one of the lay-bys indicated in the road log, or for cars and minibuses only, park on the access road 50 m from the A82 or south of the second white house ("Cottage" on (Figure 11.4)) from the turn off.

In the central–northern part of Locality 6 and the central and northern parts of Locality 7, S_1 is deformed by F_2 folds, most of which are much dissected with S_2 developed. L_2 is best shown on the

SE-facing micaceous schistosity surfaces in the southern part of Locality 7: it is at millimetre scale and its general NW–SE trend is nearly perpendicular to F_4 fold hinges and L_4 crenulation. L_2 is also shown in the southern part of Locality 6, again at a high angle to the very prominent L_4. F_3 folds little affected by later deformation are shown in the central part of Locality 6. F_4 folds, S_4 crenulation cleavage and L_4 crenulation are very prominent in the southern part of Locality 6 where L_3 and L_4 show only a small angular difference. There are also L4 crenulations corresponding to the F_4 folds having SE- and NW-dipping axial planes. F_4 folds are also strongly expressed at the northern end of Locality 5 and at Locality 8. F_3 and F_4 folds commonly occur in juxtaposition, with F_3 axial planes strongly folded and complex patterns displayed, particularly where thin units with marked competence contrasts are adjacent, as in the northern part of Locality 6. In the southern–central parts of Locality 7 some faces are dominated by F_3 deforming Sc and others by F_4 deforming S_c.

Locality 8

S_c and blind quartz veins are deformed by open, upright F_4 folds with the development of S_4 and L_4. Adjacent to the parking place F_3 folds with subhorizontal axial planes are seen and their axial planes are curved around F_4.

Localities 10, 11

Two large vertical faces with little three dimensional exposure are composed mainly of massive psammitic units that define open F_4 folds. In the more northerly Locality 11 some inter-banded pelitic units show L_2 on Sc, tighter F_4 folds than in psammitic units, as well as S_4 and L_4. There are a few poorly expressed F_2 folds near the northern end of this exposure. In the more southerly Locality (10) there are F_3 folds with flat-lying axial planes near the southern end (near the AA box) as well as upright F_4 folds.

Locality 12

Near-vertical faces at the southeastern corner of the car park show F_4 folds deforming S_c in semipelitic and psammitic quartz–biotite schists. There are also small F_3 folds, S_1 and S_2 intersecting at a very low angle and, in schistosity surfaces near the landing stage, NW–SE-oriented biotite flakes (at mm size) define L_2. The F_4 folds are much tighter than generally seen, are commonly asymmetrical with the shorter steep limb inclined towards the northwest and have axial planes that dip towards the southeast. On subhorizontal surfaces curvature of F_4 hinges indicates D_5 folding.

Locality 13

Exposures in the vicinity of the picnic area, including a small side stream to the south, show albite porphyroblasts that have overgrown steeply-disposed NE–SW-striking S_4 in garnet -mica schists (in places with much chlorite due to retrogression). Upright F_4 folds and L_4 crenulation deforming Sc are the most prominent structures, but in places they deform F_3 folds with subhorizontal (to gently inclined) axial planes, that in turn deform the schistosity in which garnet (almandine) porphyroblasts have grown.

Locality 14

In most of the road cuttings S_c and near-concordant blind quartz veins, are seen to be deformed by F_4 folds in psammitic, s emipeli tic and pelitic micaceous schists in which D_2 garnet (almandine) and post- D_4 albite (many with cores of Ab100–99.5) occur as porphyroblasts in suitable lithologies. Chlorite is common in S c as the result of retrogression. F_4 fold profiles vary and on the steep limbs of some F_4 folds the prominent NE–SW-trending subhorizontal crenulation is associated with F_4 axial planes and S_4 that are subhorizontal rather than steeply inclined as is generally the case. Where Sc is not steeply inclined, F_3 asymmetrical folds have E–W trending axes and curved (by F_4) subhorizontal to gently inclined axial planes. Their distribution is patchy while the occurrence of F_2 is rare.

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