6 The Dalradian of Fraserburgh

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Purpose

To examine the sedimentary, structural and metamorphic features of upper amphibolite facies metasedimentary rocks of the Southern Highland Group and Tayvallich Subgroup and associated igneous rocks, including evidence for the onset of partial melting in metapelitic rocks.

Access

The exposures lie along the shore around the town of Fraserburgh (Figure 1), known locally as 'The Broch', which was at the time of writing the largest shellfish port in Europe. In the town, turn north off the main Banff road (A98) onto Broadsea Road and follow the road round left into Main Street and find a parking place after 100 m or so (Main Street runs parallel to the southwestern edge of Broadsea Shore; locality 5). The total walking distance is around 2 km and the excursion requires half a day (4–5 hours). Localities 1, 5 and 8 require reasonably low water. Many of the salient features are particularly well displayed at locality 7 (Kinnaird Head) in clean exposures above the high water mark. The area is covered by OS 1:50 000 Landranger sheet 30 (Fraserburgh), OS 1:25 000 Explorer sheet 427 (Peterhead and Fraserburgh), and BGS 1:50 000 sheet 97 (Fraserburgh).

Introduction

This excursion straddles the boundary between the Southern Highland Group (Macduff Formation) and the uppermost subdivision (Tayvallich Subgroup) of the Argyll Group, locally termed the Strichen Formation. This boundary is conventionally placed at the upper (westerly) limit of conspicuously calcareous metasediments (Fettes & Harte in Harris & Pitcher, 1975), although there is no abrupt facies change. The metasediments (Macduff Formation) stratigraphically and structurally above this boundary are metamorphosed distal siliciclastic turbidites. Below this boundary the sedimentary protoliths are typical of the Tayvallich Subgroup in consisting largely of resedimented material with a significant calcareous component and in their association with volcanogenic material. They are comparable with the Tayvallich Subgroup in its type area, where calcareous sediments alternate with purely terrigenous material. Calcareous turbiditic grits in the upper part of the Tayvallich Subgroup are thinner and finer grained than at the equivalent stratigraphic level, near Whitehills, to the west of the Turriff Syncline and, although the base is not exposed (it is somewhere in Fraserburgh Bay to the east), the estimated thickness of the Subgroup here – some 500 m after deformation – is probably less than half as thick.

Two prominent phases of deformation have affected the rocks, one earlier and one later than, or synchronous with, the metamorphic peak and growth of porphyroblast minerals. These are referred to here as D1 and D3, following Fettes (1970). F1 folds are ubiquitous whereas F3 folds are more localised. The main metamorphic recrystallisation overprints the S1 cleavage producing rather obdurate, granofelsic rocks where unaffected by later S3 deformation. The two fold phases are more or less homoaxial, the axes of both sets plunging gently northwards. Both sets have an overall westerly vergence and the regional dip of the succession is to the west (Figure 1).

The rocks preserve upper amphibolite facies mineral assemblages and record metamorphism under high-temperature, low-pressure conditions (i.e. an elevated thermal gradient). Metapelitic rocks contain fibrolitic sillimanite and pophyroblasts of cordierite, andalusite, corundum and/or prismatic sillimanite. Most lack primary muscovite (sillimanite + K-feldspar zone) and, around Kinnaird Head and further east, preserve evidence for incipient *in situ* partial melting. Syn-metamorphic pink granite sheets occurring throughout the section may record transfer of melt derived from deeper

crustal levels exposed to the east (Excursion 7), possibly to feed larger bodies of syn-metamorphic granite (Johnson *et al.*, 2001).

Itinerary

Locality 1. Maw's Haven [NJ 9844 6733]

Walk northwest to the end of Main Street where the metalled road becomes a track. Walk westwards along the track for 220 m and take the right fork (the old track) and follow it a further 280 m to the square hut. Descend to the shore and out to a prominent crag (Maw's Haven) alongside which runs a slippery concrete waste outfall.

The crag is of metamorphosed gritty psammite and granular conglomerate. The beds are amalgamated (i.e. no metapelitic intercalations) and display numerous examples of graded bedding, mudflakes, convolute bedding and occasional slump folds. The orientation of these features shows that the beds are locally inverted due to folding. This coarse unit displays many of the same features as putative channel-fills seen further west at Macduff and Gamrie Bay on the western limb of the Turriff syncline, although the example here is not so clearly demarcated at its base. It stratigraphically overlies, but is structurally beneath, a thinner-bedded sequence of metagreywackes and metapelites.

Locality 2. [NJ 9869 6737]

Walk ENE along the beach towards the next obvious promontory (Meikle Bawdley). Low exposures close to the high water mark comprise a varied sequence of metapelites and metapsammites. Beds of metapsammite vary from about 0.1 to 1.0 m thick, the thicker beds generally being rather better sorted. Graded bedding is present in most horizons, as are other features indicative of deposition from turbidity currents, including small-scale load and flame structures. Partial or complete Bouma sequences are preserved, in which current directions determined from their cross-laminated 'c' divisions are on average from the NW, but are widely scattered.

These metaturbidites sit near the base of the Southern Highland Group. Compared with equivalent rocks at Bear's Head, Whitehills, the sedimentary protoliths here were generally finer-grained and probably represent a more distal position in the fan. Primary sedimentary features reveal changes in way-up due to the presence of recumbent west-verging D1 folds. In regularly layered parts of the succession, these folds have a tight chevron style clearly seen from the track above the shore.

Metapelitic horizons contain conspicuous porphyroblasts of randomly oriented pale prismatic andalusite, dark ovoid cordierite and corundum, the latter occurring in silica-deficient layers as yellowish stubby grains that stand proud of the matrix due to their extreme hardness. Muscovite-bearing granitic pegmatites occur as irregular sheets up to 20 cm in thickness that are generally oriented subparallel to bedding. These sheets become more abundant to the east.

Locality 3. Meikle Bawdley [NJ 9876 6747]

Outcrops around the promontory are formed by metapsammitic beds around the closure of a large westwards-verging recumbent anticline, the hinge of which runs along another concrete waste outfall. Beds dipping more steeply to the east are inverted. A search around reveals mudflakes and good examples of structures indicating loading. Contact strain in metapelites around fold closures can give the impression of a folded cleavage, leading to the interpretation of a D3 age for these folds. However, the metapelites here are very poorly fissile, suggesting that their only cleavage is the overprinted S1 and that S3 is absent. This feature, and the consistent relationship of way-up to these folds (steeper limbs are inverted), suggests that they are D1 structures.

Locality 4. [NJ 9880 6744]

Continuing eastwards a considerable amount of pale green calcareous material appears (Figure 2), with calcareous sandstones and grits with intercalated siltstones constituting up to 80% of the section. The calc-silicate rocks contain abundant granoblastic diopside and most show a pronounced lamination parallel or subparallel to bedding. These units

are correlated with the thicker and often coarser calcareous grits and 'flags' west of Whitehills some 35 km to the west, both being assigned to the top of the Tayvallich Subgroup (uppermost Argyll Group). All the rocks between this point and Fraserburgh Bay are correlated with the Tayvallich Subgroup (locally the Strichen Formation). The BGS have the boundary mapped between localities 1 and 2 (Figure 1).

Despite the change in character of the rocks, the environment of deposition appears to be similar to that of the adjacent Southern Highland Group rocks. Many of the thinner calcareous beds show similar sedimentary characteristics to the sandy metaturbidites in the Southern Highland Group at Macduff and Gamrie Bay, with base cut-out Bouma sequences. A nice example of a westward-verging recumbent F1 fold can be seen some 20 m northeast from this locality.

Locality 5. Broadsea Shore [NJ 9926 6740]

Close to the western side of Broadsea Shore is a crag into which is intruded a shallow-dipping sheet of pink, muscovite-bearing leucogranite, probably of Ordovician age. The granite is associated with a number of pegmatitic layers that are also shallow dipping but generally discordant to bedding in the host metasediments. The pegmatites are composite suggesting intrusion of multiple magma batches along the same weakness. Contacts are sharp but there is no recognisable thermal (contact metamorphic) effects in the metasediments, suggesting the leucogranite and pegmatites were intruded close to the peak of metamorphism.

Metasediments to the west of these intrusions dip at low to moderate angles towards the west and are dominated by metaturbidites, the metapelitic tops of which contain porphyroblasts of cordierite (Figure 3) and andalusite + cordierite, indicating that the metasediments here are the right way up. Between the leucogranite and pegmatite sheets, close to the southern end of the outcrop, a metapelitic layer contains large porphyroblasts of andalusite and corundum (Figure 4). Both porphyroblast minerals are mantled by large flakes of retrograde muscovite. Also present are thin layers containing highly prismatic aggregates of muscovite that commonly occur as radiating clusters (Figure 5), which are probably pseudomorphs after sillimanite.

Corundum is fairly common as porphyroblasts throughout this section. Its development requires silica-deficient metapelitic compositions and it forms by the breakdown of muscovite (to corundum, K-feldspar and H_2O) in the absence of quartz. The temperature at which this reaction occurs (and that which formed some of the andalusite and/or sillimanite by breakdown of muscovite and quartz) will have been lowered in the presence of CO_2-rich fluids produced from nearby calc-silicate rocks.

Locality 6. [NJ 9930 6732]

Near the high water mark a short distance southeast of the intrusions are pinched, cuspate outcrops that resemble highly non-cylindrical folds. From exposures a little further down the foreshore it can be seen that this structure is a consequence of boudinage of the overlying quartzitic metapsammite, the boudins having a northerly elongation. This style of deformation is a consequence of the competent, quartz-rich nature of the metapsammite compared to the less competent metapelites. Wave-washed metapelitic layers on the east side of the pinched outcrop contain radiating clusters of sillimanite and stubby andalusite.

Locality 7. Kinnaird Head [NJ 9984 6761]

Either continue along the shore on foot or return to the A98 and turn left then left again into Denmark Street and follow the road round (left then right) to the lighthouse museum. Park in the small gravelled parking bay atop the shore opposite the lighthouse museum car park. Follow the path eastwards and descend to the rocky shore (Kinnaird Head) close to the foghorn. Take care as the rocks here are slippery when wet and there is often a lot of rubbish about, including broken glass and worse. Many of the most important field relationships can be observed within a small area around this locality. The rocks are dominated by green (diopside-rich) calc-silicates and purplish-brown (biotite-

and cordierite-rich) metapelites and semipelites that are interbedded on a scale of a few centimetres or tens of centimetres. Several westward-verging F3 folds are clearly defined by preferential weathering of the softer laminated

calc-silicates.

A few metres east of the foghorn, above sloping exposures in a small cleft (at the grid reference provided), is a fine example of an F1 fold refolded by F3 (Figure 6). Both S1 and S3 are clearly picked out in the calc-silicate layers by seams of ferromagnesian minerals that weather proud of the matrix. A more diffuse bedding-parallel lamination is folded by F1 and is presumably of sedimentary origin.

Metapelitic horizons in this area contain andalusite, cordierite, biotite, quartz, plagioclase, K-feldspar and sillimanite (minor/accessory tourmaline, pyrite, apatite and zircon are seen in thin section). Large flakes of muscovite are retrograde. Thin (< 1 mm) quartzofeldspathic veins are ubiquitous in metapelitic horizons (Figure 7). Most are interpreted as leucosomes and provide evidence for *in situ* partial melting of metapelitic rocks at temperatures at or close to the H2O-saturated solidus (i.e. the rocks are migmatites). These veins are not present in metapelitic rocks at Broadsea Shore, constraining the onset of partial melting (the 'migmatite-in') isograd to somewhere on the western side of Kinnaird Head, not in Fraserburgh Bay as previously proposed (Johnson, 1999; Johnson *et al*., 2001).

About 20 m north to northwest of the refolded fold are several irregular veins of fine-grained garnetiferous aplite (quartz + microcline + plagioclase + garnet + tourmaline) and coarse-grained granitic pegmatite (quartz + perthite + plagioclase + muscovite + biotite). The tourmaline occurs as dusty grey patches. The garnets form tiny euhedral dodecahedra and are rich in manganese (spessartine). These intrusions seem unaffected by either phase of folding, suggesting they are of a similar age to granite sheets at localities 2 and 5. Close examination of the contact between the aplites and metapelites shows that the former are interconnected with the small leucosome veins in the latter, suggesting the aplites are the products of local generation and segregation of melt. The pegmatites, which were clearly derived from the aplites, suggest these melts were H_2O-rich.

Assemblages in the calc-silicate layers are diverse, reflecting compositional variations of both the rocks and the fluids with which they interacted. Most are rich in diopside, calcite and quartz with biotite, hornblende, grossular garnet, scapolite, chlorite, plagioclase, epidote and (clino)zoisite. Skarn-like assemblages are developed in calc-silicate layers close to pegmatites. A good example occurs 13 m ENE from the refolded fold at the junction between a pale calc-silicate layer (around 10 cm thick) and a coarse pegmatite. The calc-silicate layer contains large (several mm across) equant to prismatic pale pink to brown porphyroblasts set in a fine-grained white matrix. The darker brown prismatic porphyroblasts are vesuvianite and the paler, more abundant equant porphyroblasts are grossular garnet. The matrix is mainly wollastonite (seen only in thin section). With increasing distance from the pegmatite, vesuvianite and then grossular disappear, and wollastonite gives way to calcite. Such features suggest flushing of the calc-silicate by aqueous fluids derived from de-watering of the pegmatite as it crystallized, with the fluid phase increasingly diluted with CO_2 with increasing distance from the intrusion (Johnson *et al*., 2000).

The mineral assemblages in the metapelitic and calc-silicate rocks combined with the evidence for partial melting suggests peak metamorphic conditions of around 3 kbar and 650 °C.

Locality 8. 'Wine Tower' [NJ 9996 6749]

Rejoin the path above the shore and head east to the 'Wine Tower' (probably 15th century and Fraserburgh's oldest building). A large crag in the middle of the bay below is formed of rather homogeneous, crudely foliated biotite-actinolite schist exposed beneath metapsammite. The rock shows an indistinct layering and is parted by a calc-silicate band. The weathered surfaces reveal small ellipsoidal mafic clots consisting of biotite and actinolite. The texture of the rock is reminiscent of some metamorphosed basic tuffs seen at a similar stratigraphic level elsewhere in the Dalradian.

On the NW side of the bay a granite sheet low down in the cliff is broadly concordant with the metasedimentary rocks it intrudes (Figure 8). Another large pegmatite occurs higher up in the same cliff, and is again associated with skarn-like layers of calc-silicate containing garnet and vesuvianite.

Locality 9. Lackie Head [NK 0007 6744]

Trying not to inhale too deeply, walk round to the opposite side of the bay and onto Lackie Head. Outcrops here consist of banded calcareous and semi-pelitic schists with occasional sandy limestone bands. Examination of wave-washed outcrops reveals that these were originally graded units with calcareous bases and silty tops, though metamorphic recrystallisation has completely obscured the original grain-size variation.

These rocks are affected by numerous, near-isoclinal westward-verging F1 folds. The development of an axial-planar spaced cleavage in the calc-silicates has largely obliterated the original sedimentary features, but near F1 closures an original bedding-parallel lamination can be seen. All these structures are refolded by F3 folds. Calc-silicate layers in the hinge regions of F3 closures show transposition of the S1 cleavage into S3.

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Appendix – additional field photos

(Additional field photographs 1) **Top left** – Looking north to the crag at locality 1. These coarse metasediments probably represent a channel-fill but are now inverted. The waste concrete outfall is around 1.5 m wide. **Top right** – Apparently randomly oriented prismatic porphyro- blasts of andalusite in metapelite (locality 2). **Middle left** – Recumbent west-facing F1 fold around 20 m northeast of locality 4. **Middle right** – Typical right-way-up metamorphosed graded bed with metapsammitic base and metapelitic top, the latter containing abundant porphyroblasts of cordierite (locality 5). **Bottom left** – Composite granitic pegmatites discordant to bedding in the host metasediments (locality 5). **Bottom right** – Metapelite containing randomly oriented acicular aggregates of muscovite replacing sillimanite (locality 6). Smaller stubby porphyroblasts are andalusite.

(Additional field photographs 2) Field relations on Kinnaird Head (locality 7). **Top left** — Looking southeast to the small cleft just to the east of the foghorn. The refolded fold is at head height and just to the right. **Top right** — Looking north towards flat-lying granetiferous aplites and pegmatites that intrude the metasediments. **Middle left** — Pale

wollastonite-rich calc-silicate rock containing large por phyroblasts of grossular garnet and vesuvianite that stand proud of the softer matrix on weathered faces (right). In the fresh surface (left), pale pink garnet is more abundant and paler in colour than brown vesuvianite. **Middle right** — Looking north at a typical westward-verging F3 fold. These folds are clearly picked out by softer calc-silicate layers (50 pence in calc-silicate for scale). **Bottom left** — Close-up of migmatised metapelite/metasemipelite recording evidence for incipient partial melting. **Bottom right** — Close-up of migmatised metapelite preserving evidence for incipient partial melting.

Figures

(Figure 1) Location map of the coastal region around Fraserburgh. Contains Ordnance Survey data © Crown Copyright and database right 2013 and British Geological Survey materials ©NERC 2013.

(Figure 2) Looking south at recumbent tight F1 folds in uppermost Tayvallich Subgroup rocks compris- ing finely laminated calc-silicate (pale green) interbedded with dark metasemipelite (locality 4; 50 pence for scale).

(Figure 3) Typical cordierite-rich metapelite (locality 5).

(Figure 4) Silica-deficient metapelite containing porphyroblasts of prismatic andalusite, stubby corun- dum and acicular sillimanite pseudomorphs (to the left of the coin) (locality 5).

(Figure 5) Acicular aggregates of muscovite replacing sillimanite (locality 5).

(Figure 6) Refolded fold a few metres east of the foghorn. Note the prominent development of S3 in the softer calcsilicate layers within the F3 closure (locality 7; 50 pence for scale).

(Figure 7) Contact between a garnetiferous aplite (left) and dark metapelite containing small porphyroblasts of andalusite and thin leucosome veins that interconnect with the aplite.

(Figure 8) Looking northwest at the Wine Tower and the bay below. A ~metre-thick granite sill intrudes metasediments at the base of the cliff and an irregular pegmatite occurs at its top. The crag in the bay is probably a metamorphosed tuff (locality 8).

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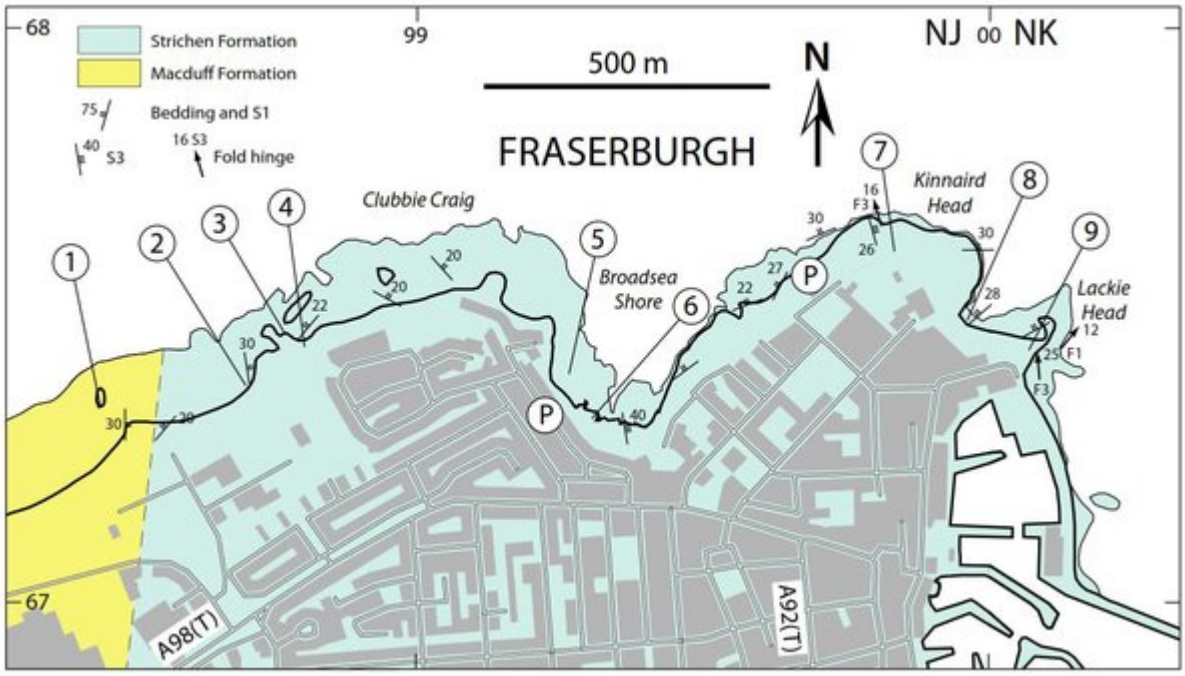

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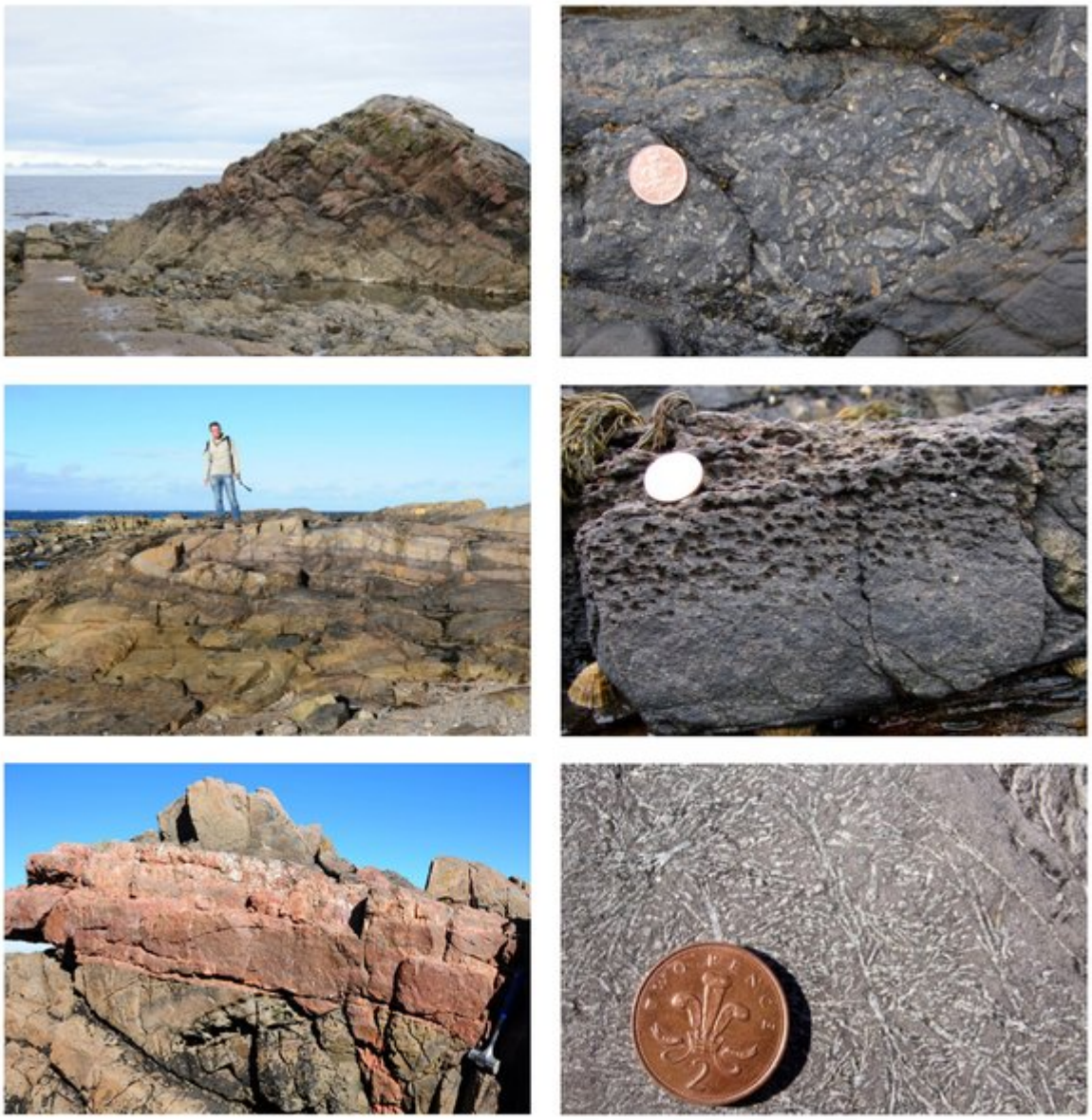

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