3 The Dalradian of the Portsoy area

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Purpose

To examine amphibolite facies Argyll Group metasediments and (meta)igneous rocks in the area around Portsoy. The effects of intense deformation, metamorphism and migmatisation are particularly well displayed. A diverse selection of rocks and minerals can be observed, including the Portsoy 'marble' (serpentinite), which was ordered specially by Louis XIV for use in the Palace of Versailles.

Access

Portsoy is a picturesque village with a 17th century harbour situated on the Banffshire coast some 70 km NNW of Aberdeen and 95 km east of Inverness. When entering Portsoy on the main road (A98), turn north into South High Street and park in The Square (Figure 1), from which localities 1–13 can be reached on foot; 14 and 15 probably require a vehicle. Most exposures are easily accessible on the shore, although localities 1 and 2 require descent (then ascent) of moderately steep grassy slopes – beware of ticks in spring and summer! Although most localities can be visited at high tide, lower tides provide cleaner exposures and are required to access localities 14 and 15 if avoiding the working quarry. The area is covered by OS 1:50 000 Landranger sheet 29 (Banff & Huntly) and 1:25 000 Explorer sheet 425 (Huntly & Cullen) and BGS 1:50 000 Sheet 96W (Portsoy). Walking distance is 7–8 km excluding localtites 14 and 15. The excursion requires a full day.

Introduction

A wide range of deformed and metamorphosed Argyll Group metasediments and igneous rocks are well exposed along the coast in and around Portsoy. The rocks preserve a complex history of deformation, intrusion and metamorphism, much of which was broadly synchronous. The section extends from the Arnbath Psammite Formation (probably Islay Subgroup) at the western end, to the Boyne Limestone Formation (Tayvallich Subgroup) at the eastern end, and is broadly coincident with the zone of intense D2 strain associated with the Portsoy Shear Zone. The shear zone forms the western boundary of the Buchan block and is an expression of the regionally-significant Portsoy-Duchray Hill 'Lineament', a large- scale, long-lived crustal structure associated with the intrusion of mafic and ultramafic magmas (Ashcroft *et al*., 1984; Dempster *et al*., 1995; Fettes *et al*., 1986).

At the base (western end) of the section the Arnbath Psammite comprises metamorphosed psammites and migmatitic semipelites and contains a boulder bed correlated with the Port Askaig Tillite (Spencer and Pitcher, 1968). It is overlain by quartzites and metapsammites of the Durn Hill Quartzite Formation and by metamorphosed pelites and semipelites of the Castle Point Pelite Formation. These are in turn overlain by metamorphosed limestones, calcsilicates, pelites, semipelites, psammites and quartzites of the Portsoy Limestone Formation. These metasediments have been intruded by mafic to ultramafic magmas of the Portsoy Igneous Complex, dated at *ca*. 470 Ma (Carty, 2001), which are themselves metamorphosed. Intense deformation within the Portsoy Shear Zone has disrupted the stratigraphic succession immediately west of Portsoy and resulted in the interleaving of the metasediments and metaigneous rocks into a 'tectonic melange' (Read, 1960). The ultramafic rocks were completely serpentinised to produce the Portsoy 'marble'.

East of Portsoy lies the Cowhythe Psammite Formation (probably Crinan Subgroup), comprising migmatised sillimanite-bearing metasedimentary rocks and pods of serpentinite. At the eastern end of the section, the junction between the Cowhythe Psammite Formation and the Boyne Limestone Formation was originally described by Read (1923) as a major thrust (the 'Boyne Line'), although later workers have downgraded its significance (Elles, 1931; Sutton and Watson, 1956; Ashworth 1975). However, it does mark the easterly limit of D2 deformation on the western limb of the Turriff syncline (Treagus & Roberts, 1981). The Boyne Limestone Formation includes coarse metalimestone, serpentinised amphibolites and calcareous and metapelitic schists, the latter of which may contain sillimanite.

Itinerary

Locality 1. Arnbath Psammite Formation & 'Older' intrusive rocks [NJ 5787 6659]

If on foot, walk up Cullen Street then turn second right into Marine Terrace and join the cliff-top path that leads westwards to a car park on the cliff top above the open-air swimming pool ([NJ 5826 6636]; Figure 1) If using a vehicle, drive westwards from The Square along Cullen Street and right into Park Road. Follow the road round right, then right again to the same car park. From the corner of the road just west of the car park, follow the cliff top westward along the edge of the fields for around 500 metres and descend (somewhere around [NJ 5782 6649]) the grassy slopes to a small bay.

Looking seaward, from left to right (west to east) the rocks comprise: The Arnbath Psammite Formation, a sequence of migmatised semipelite and psammite with calcareous layers; medium-grained metabasic rocks ('Older Basics') containing sheets and pods of deformed granite ('Portsoy Granite' of the 'Older Granite' suite); a complex unit of metamorphosed limestones, pelites and psammites in which pods of tillite have been reported (Moig, 1986); and, buff-coloured, strongly lineated ('mullioned') quartzite (Durn Hill Quartzite Formation; Islay Subgroup). The rocks are in places intensely deformed (mylonitised), but appear to be right way up, younging to the east. Inland exposures of the 'Portsoy Granite' have been dated at *ca.* 600 Ma (Barreiro, 1998). The Arnbath Psammite Formation is currently regarded (and mapped by the BGS) as part of the Dalradian (Islay Subgroup; Stephenson *et al*. 2013), but others have suggested it could be an allochthonous slice of older basement (Moig, 1986).

Locality 2. Garnet–staurolite schist [NJ 5814 6650]

Climb back up the slope to the cliff top and head back most of the way towards the car park and to the eastern side of a grassy promontory (around 400 m from locality 1). Descend the grassy slope to the western side of the rocky headland (Castle Point) to exposures on the steep hillside. The rocks here are muscovite-rich metapelites belonging to the Castle Point Pelite Formation (Easdale Subgroup). They contain conspicuous porphyroblasts of staurolite and garnet and are characterised by a prominent crenulation cleavage. The main mineral assemblage developed here (garnet–staurolite–muscovite–biotite–quartz + minor/accessory minerals) is typical of the Barrovian facies series.

Locality 3. Chiastolite schist [NJ 5842 6638]

Return to the cliff top and back to the road, passing the car park and descending the steep winding road to the swimming pool (you can drive a car down if you prefer). The first prominent crag immediately on the south side of the road is of dark metapelite containing abundant pale prismatic 'porphyroblasts' up to 4 cm in length. This rock also crops out in low wave-washed exposures along strike (NE) close to the high water mark [NJ 5844 6640].

Close examination shows that the majority of the 'porphyroblasts' are aggregates dominated by muscovite (i.e. they are pseudomorphs), although some have cores preserving fresh andalusite. The porphyroblasts/pseudomorphs are oriented within, and wrapped by, the strong S2 foliation. Most are aligned parallel to a steeply plunging L2 lineation although others are at a high angle to L2. On subhorizontal surfaces (e.g. the wave washed exposures close to the high water mark) relict chiastolite crosses are clearly preserved (Figure 2). Some of the porphyroblasts/pseudomorphs contain pale kyanite. Garnet and staurolite also occur in this rock, as does sillimanite which is visible only in thin section.

The timing and sequence of Al_2SiO_5 growth in this rock is contentious. Some workers (Beddoe- Stephens, 1990; Carty, 2001; Carty *et al.*, 2012) consider the sequence to be andalusite to sillimanite to kyanite, whereas others interpret the sequence as andalusite to kyanite to sillimanite (Viete *et al*., 2010). The order of growth of these minerals has important implications for the pressure–temperature– deformation–time path followed by the rocks and consequently for models attempting to explain the tectonothermal evolution of the NE Dalradian.

Locality 4. The 'Portsoy Limestone' [NJ 5841 6644]

The rocks exposed within the swimming pool and on the headland to the north consist of an alternating sequence of metalimestones and siliceous material ('Portsoy Limestone'). Excellent examples of F2 folds are developed. The folds are tight to isoclinal and vary in intensity, sometimes occurring as isolated fold hinges. F2 fold axes plunge steeply down dip, sub-parallel to a mineral stretching lineation. The S2 foliation is axial planar to these folds. In the crags beyond the western wall of the swimming pool, later F3 folds can be seen to deform the S2 foliation.

Locality 5. Greenschist facies shear zones [NJ 5851 6638]

Join the poorly defined path eastwards along the shoreline. A few metres north of the path, close to the high water mark, large blocks and lenses of weakly deformed metagabbro are wrapped by an intense anastomosing shear fabric developed within fine-grained metagabbro. The large blocks preserve amphibolite facies assemblages dominated by hornblende and plagioclase whereas the intensely deformed material is rich in chlorite and quartz and records lower-grade (greenschist facies) conditions. As most of the shear zones in the section preserve amphibolite facies assemblages (see localities 8 & 9), these features suggest later shearing during retrogression (Carty, 2001).

Locality 6. Portsoy 'marble' [NJ 5854 6636]

Continue on the path a few tens of metres to the western edge of the prominent pale green-grey exposures of Portsoy 'marble'. The rock is actually serpentinite (a metamorphosed and hydrated ultramafic rock), varying in colour from nearly black through dark green to light green and containing thin bands and veins of red jasper and white quartz (Gillen, 1987). Exposures close to the high water mark contain dark red aggregates of iddingsite pseudomorphing primary olivine. Steeply-inclined veins within the main body of the serpentinite contain abundant talc. Exposures close to the low water mark show that the sepentinite is in places highly folded.

If the tide is high, proceed eastwards by climbing up the steep grassy slope to the path, then down to the shore again after about 50 m. At the eastern margin of the body [NJ 5860 6634], the serpentinite is in contact with a folded sequence of calc-silicates, metapsammites and metapelites. The contact is highly deformed and complex, with numerous veins and interleaving of the various rocks types. Rounded wave washed exposures of dark-coloured metapelite below the high water mark contain small euhedral porphyroblasts of andalusite, up to 1 mm in length, that appear to be randomly oriented. Coexisting kyanite and andalusite are reported in metapelites from here (Gillen, 1987).

Locality 7. 'Mullioned' quartzite [NJ 5865 6632]

Walk across the bay a short distance to impressive exposures of quartzite, which is buff-coloured when weathered but white on fresh faces. The quartzite contains a steep lineation and forms distinctive rods or 'mullions' (Figure 3). In cross section the 'mullions' are slightly elliptical and up to about 30 cm in diameter. The western part of the quartzite is conglomeratic and the pebbles have been strongly stretched (Treagus and Roberts, 1981). A short distance to east of the metaquartzite occurs a pure, white calcite marble containing sulphide veins and horizons rich in tremolite.

Locality 8. Anorthosite [NJ 5867 6628]

Jutting out from the base of the grassy slope in the bay to the east of the prominent exposures of quartzite is an exposure of pale-grey to cream coarse-grained metamorphosed anorthosite. It is composed primarily of plagioclase (labradorite) with accessory amphibole and chlorite and is cut by minor shear zones. Its contact relations are unexposed but are presumably tectonic.

Ascend the steep grassy slope to the cliff-top path. If driving, walk westwards back to the car park and return the way you came, parking in The Square or at the old harbour near the Portsoy Marble Shop. If on foot, walk eastwards and follow the path north round the steep grassy slope, from which there are excellent views of the 'mullioned' quartzite and serpentinite body (Figure 4). Just around the corner, opposite the end of Barbank Street, descend a steep grassy path leading to the back of the Portsoy Marble Shop. At the end of the path turn left (west) to the broken railings and the disused hospital tip.

Locality 9. Sheared metagabbro at the old hospital tip [NJ 5877 6637]

On either side of the broken railings are exposures of what appear to be two generations of metagabbro. Fine-grained metagabbro is in places cross-cut by coarse-grained to pegmatitic metagabbro, although both types are deformed within anastomosing D2 shear zones suggesting syn- kinematic (syn-D2) intrusion. The ductile shear deformation is strongly heterogeneous. Individual shear zones range from a few millimetres to several metres across, within which there is an intense grain-size reduction (Figure 5). The S2 foliation is steeply dipping and contains a steeply plunging mineral lineation. The metagabbros (deformed and relatively undeformed) preserve amphibolite facies assemblages dominated by hornblende and plagioclase, although primary (igneous) clinopyroxene is common in the cores of hornblende or hornblende aggregates in less deformed metagabbro. Shear sense indicators are commonly ambiguous although the presence of symmetrical conjugate shear zones with opposite senses of displacement suggest deformation was dominated by coaxial shortening perpendicular to S2 (Carty, 2001).

Locality 10. Sheared metagabbro and calc-silicate zenoliths [NJ 5884 6639]

Follow the small path round the back of the Marble Shop to the gable end of a derelict building.

Metagabbros immediately below the southwest of the building preserve excellent examples of the D2 shear zones that extend along strike from locality 9. Top to the NW shear sense indicators are particularly well developed in discrete shear zones that dip 40–60° towards the SE.

Walk NNE onto the rocky peninsula of Doonie Point. Xenoliths of metasediment within a generally weakly-deformed fine-grained metagabbro are mostly diopside-rich calc-silicate. Patches and veins of almost pure hornblende are common in the metagabbros in close proximity to the calc-silicate xenoliths (e.g. on the elevated exposure at [NJ 5889 6646]), many of which contain large euhedral sphene.

Locality 11. Xenoliths in metagabbro and refolded folds [NJ 5920 6643]

Walk around the old harbour and up Shore Street onto the headland east of the new harbour.

The metagabbros contain numerous metasedimentary xenoliths, mainly calc-silicate and marble, and are cut by a number of granitic pegmatite sheets. Some elongate xenoliths are intensely deformed and there are nice examples of refolded folds (F3 refolding F2) in both the xenoliths and metagabbro. The pegmatites, which are up to a few metres in thickness, range from undeformed to highly deformed, suggesting they intruded syn- to post-D2. An undeformed pegmatite that cross-cuts the S2 fabric has been dated by Carty *et al.* (2012) at 474 +5/–3 Ma, considered by these authors to constrain the minimum age of D2 deformation.

Locality 12. Cowhythe Psammite Formation migmatites [NJ 5954 6629]

Walk around Links Bay to its eastern side, where the folded contact between calc-silicate and metasemipelitic rocks of the Cowhythe Psammite Formation is exposed in barnacle-covered rocks. Follow the path NNE along the shore. A short distance seawards of the path are clean exposures of migmatitic semipelitic. Quartzofeldspathic veins (stromatic leucosomes) in the migmatite are oriented parallel to a strong S2 foliation defined by biotite that is folded into open to tight F3 folds (Figure 6), suggesting the peak of metamorphism was pre- to syn-D2. The dark portions of the stromatic migmatites (melanosome) contain abundant biotite, quartz and feldspar with variable quantities of fibrolitic sillimanite; some layers contain garnet. The lack of obvious ferromagnesian minerals within the leucosome suggests they were generated by partial melting reactions consuming muscovite. Coarse plates of randomly-oriented muscovite are ubiquitous and probably record reaction with crystallising melt during cooling.

The Cowhythe Psammite Formation is generally regarded as belonging to the Crinan Subgroup (Stephenson *et al.* 2013), although it has also been proposed to be an allochthonous slice of basement gneiss (Ramsay & Sturt, 1979; G. J. H. Oliver unpublished data cited in Viete *et al.*, 2010).

Locality 13. Tourmaline pegmatites [NJ 5969 6642]

Some 150 m further north, at the western entrance to a small bay, several pegmatites intrude the migmatites. These are generally aligned subparallel to the foliation but are weakly deformed or undeformed. Large euhedral grains of tourmaline are abundant. Chilled margins are absent and some contacts are diffuse suggesting the pegmatites were emplaced close to the metamorphic peak.

If time permits, continue along the path to [NJ 6004 6667] where a large lens of serpentinite occurs within the migmatites. A thick (~3 m) pegmatite sheet rich in muscovite and tourmaline intrudes the gneisses around 150 m or so further NNE.

Return to the car and the A98 and drive east. Around 250 m after the sharp bend south, just as you are leaving Portsoy, take the left turn onto the B9139 (not signposted). Continue on this narrow road, crossing the Burn of Boyne, and turn left at the junction. Continue for around 200 m then turn left (north) and park near the end of the track that leads to Boyne Bay Quarry (Figure 1). Being mindful of quarry vehicles, walk down the track towards the quarry (alternatively follow the western edge of the field immediately east of the quarry track). Close to the quarry entrance, where it turns sharp left over the bridge, follow the muddy track to the right and descend to Boyne Bay. At its northwestern edge, hop over the Boyne Burn then climb the steep path over the low point on the grassy headland and down into the bay known as Old Hythe. (Note: access to localities 14 and 15 from here require a fairly low tide).

Locality 14. Boyne Limestone Formation [NJ 6153 6618]

In the southern part of the bay are exposed an interbedded sequence of marbles and metapelites that exhibit spectacular F3 folds, many of which are apparently refolded F1 folds. Sheath folds are particularly common. Metapelitic layers contains fibrolite and small, coarse-grained quartzofeldspathic segregations (Figure 7), which may provide evidence for incipient partial melting.

Locality 15. Boyne Limestone Formation–Cowhythe Psammite Formation contact [NJ 6146 6627]

On the northern side of the bay the faulted contact between the Boyne Limestone Formation and Cowhythe Psammite Formation is well exposed. The contact trends NNE and is sharp. Mylonitic fabrics are developed in the Cowhythe Psammite Formation, and the contact has been interpreted as a major thrust by Read (1923). Sutton and Watson (1956) and Ashworth (1975) questioned the status of this structure and argued that it is a late-stage fault, not a thrust as Read (1923) had suggested. This location is considered significant in marking the uppermost (easterly) extent of D2 deformation to the west of the Turriff syncline (Treagus & Roberts, 1981).

If time and tide permit, continue round the headland to Cowhythe Head to extensive exposures of the Cowhythe Psammite Formation. Here it is intensely deformed by F3 folds and contains elongated and thinned slices of metapsammite. Sillimanite and cordierite are reported from here (Gillen, 1987).

(Appendix 1 extra images) Extra images

(Appendix 2 extra images) Extra images

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Figures

(Figure 1) Location map of the coastal section between Portsoy and Boyne Bay. Structural data from Gillen (1987). Contains Ordnance Survey data © Crown Copyright and database right 2013 and British Geological Survey materials ©NERC 2013.

(Figure 2) Looking down the steep L2 lineation on a sub-horizontal surface of the metapelite (locality 3). Basal sections of andalusite (mainly pseudomorphs) commonly containing relict chiastolite crosses.

(Figure 3) Steeply inclined rods or 'mullions' in quartzite (locality 7).The rucksack is around 30 cm wide.

(Figure 4) View towards the west from the steep path south of locality 9. The 'mullioned' quartzite (locality 7) forms prominent crags in the bottom left. The pale green-grey promontory in the centre is serpentinite (Portsoy 'marble' – locality 6); the dark grey promontory on the far right is metalimestone, behind which is the chiastolite schist (locality 3). Metagabbroic rocks occur between the serpentinite and metalimestone (e.g. at locality 5) and to the left (east) of the quartzite.

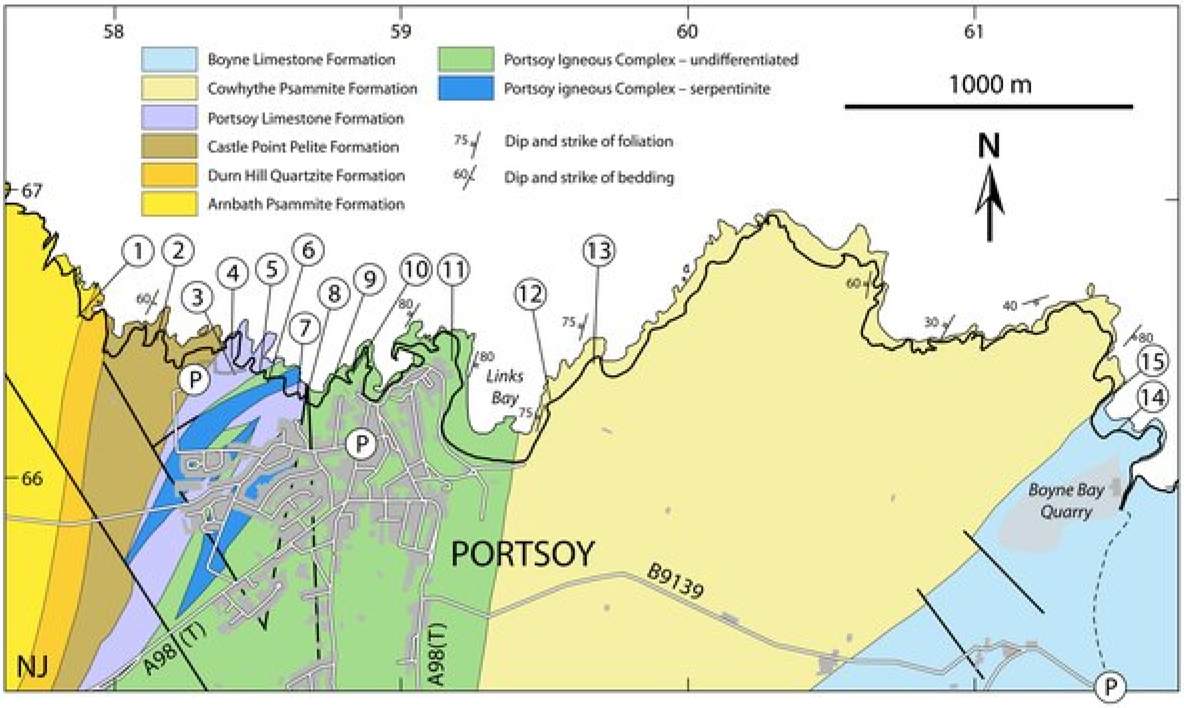
(Figure 5) Looking southwest towards steeply inclined S2 amphibolite facies shear zones in metagabbro (locality 9). In the bottom right the metagabbro is relatively undeformed and much coarser grained.

(Figure 6) Folded stromatic leucosomes in semipelitic migmatite of the Cowhythe Psammite Formation (locality 12). Leucosomes are aligned parallel to S2 which is folded by F3.

(Figure 7) Folded marble with interbedded metapelite in Old Hythe (locality 14). Refolded tight to isocli nal F1 folds are abundant. The metapelitic layers show evidence for partial melting.

(Appendix 1 extra images) **Top left** – Looking north at locality 1. Rocks on the far left are migmatised semipelites and psammites of the Arnbath Psammite Formation. On the far right (including the peninsula in the distance) are quartzites of the Durn Hill Quartzite Formation. The darker rocks between are medium-grained metabasic rocks ('Older Basics') containing sheets of granite and a complex unit of metamorphosed limestones, pelites, psammites containing pods of tillite. **Top right** – Looking south at a subvertical face of the dark chiastolite schist (locality 3). Most of the pale grains are pseudomorphs after andalusite and are strongly aligned within the steep L2 lineation. **Middle left** – Pseudomorphs of red iddingsite replacing euhedral–subhedral olivine in serpentinite (locality 6). The pale material contains abundant talc. **Middle right** – Small porphyroblasts of andalusite in metapelitic rocks a couple of metres from the eastern margin of the serpentinite. These appear to be randomly oriented. **Bottom left** – Coarse-grained (top) and fine-grained metagabbro (locality 9). A vein of the former cross-cuts the latter but is itself folded. **Bottom right** – Sheared metagabbro (locality 9). The steep nature of the shear zones and the extreme grain-size reduction is apparent.

(Appendix 2 extra images) **Top left** – Close-up of anastomosing shear zones within metagabbro (locality 9). **Top right** – Irregular veins and patches of hornblendite within the metagabbros commonly contain large euhedral crystal of sphene (locality 10). **Middle left** – Looking north at a refolded fold (F1 nose at top, F3 nose on right) in metagabbro on the headland east of the new harbour (locality11). **Middle right** – Pink granite pegmatite at locality 11. This sheet is deformed by S2 but other examples are undeformed. **Bottom left** – Typical folded stromatic migmatite (F3 refolding S2) of the Cowhythe Psammite Formation (locality 12). **Bottom right** – Looking northeast at the sharp contact between migmatites of the Cowhythe Psammite Formation (left) and metacarbonate-rich rocks of the Boyne Limestone Formation at Old Hythe (locality 15).



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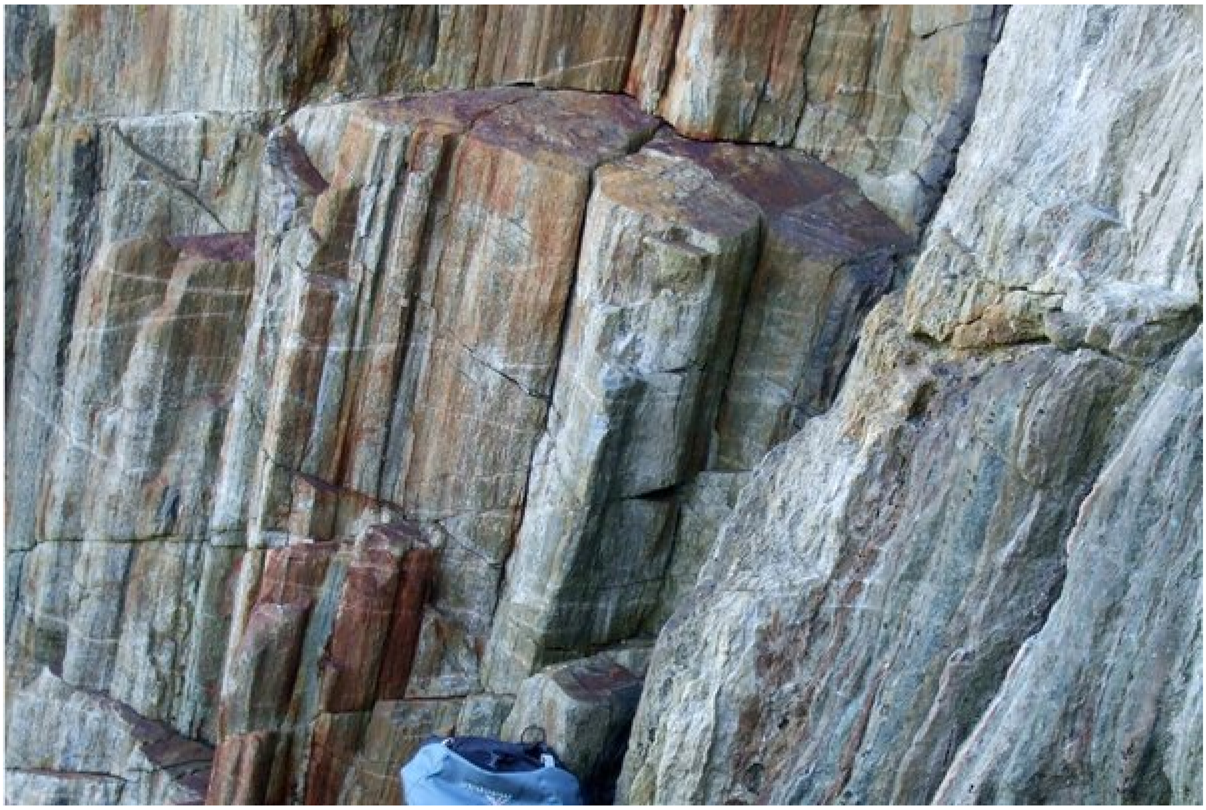

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