Field guide for the geological mapping course at Inchnadamph, Assynt (NW Scotland)

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Simplified geological map of the NW Scottish Highlands and the Moine Thrust Belt (Fossen, 2010)
1. The Moine Thrust Belt

The northwestern margin of the Caledonian Orogen (430 – 400 Ma) in Scotland is defined by the Moine Thrust Belt, a major, gently SE-dipping décollement. The foreland (footwall) of the thrust belt consists of 2.7 to 3.1 Ga Lewisian gneisses, unconformably overlain by Torridonian sandstone, in turn covered unconformably by the Cambro-Ordovician passive continental margin sequence of Laurentia. From bottom to top, this sequence is composed of sandstone (“Pipe Rock”), dolomitic siltstone, shale and sandstone (Fucoid Beds), quartzite and dolomitic sandstone (Salterella Grit), and various carbonate formations (Durness Group). The hinterland (hanging wall) of the thrust belt consists of rather monotonous Moine schists.

The thrust belt is made up of shallowly (3°) dipping master thrusts, i.e., roof and sole thrusts, and numerous imbricate thrust slices between the master thrusts. The imbricate thrusts developed preferably in Cambrian-Ordovician sedimentary rocks, notably the Fucoid Beds.

Total displacement on the thrust belt amounts to about 100 kilometres. Fault rocks consist of brittle faults and mylonite, which formed under greenschist-facies metamorphic conditions.

Until the beginning of the last century, the Moine Thrust Belt was subject of the famous geological controversy, the so-called “Highland Controversy”. Then it was unclear, how Moinian rocks could overly red sandstones of the Torridonian and, at the same time, form the substrate of the Old Red sandstone; both sandstone units were believed to be the same then. Similarly, in the Assynt region geologists observed that Lewisian gneisses obviously formed the substrate of the Torridonian sandstone west of what is now known as the sole thrust, whereas east of this thrust, the same gneisses cover Torridonian sandstone. It was Peach and Horne, two mapping geologists of the British Geological Survey, who solved this paradox by detailed mapping with their discovery that rocks in the Assynt region form an imbricate thrust belt (Peach at al. 1907). Recognition that rocks could be transported over large distances on shallowly dipping thrust surfaces was contemporaneous with the identification of allochthonous nappes in the European Alps. This was a major breakthrough in geological science, notably with respect to better understanding the formation of mountain belts.

Our mapping course will be conducted in the heart of the Moine Thrust Belt. We will map segments of the sole thrust, Glencoul Thrust and the imbricated Cambro-Ordovician sedimentary sequences near Inchnadamph. During their field work, Peach and Horne resided in the Inchnadamph Hotel, located near the Inchnadamph Lodge, which became The Field Centre of Assynt in recent years and which hosts many university groups of geology students each year.
“Albert Heim’s concept of the relationships between a NW Highlands basement and an Alpine superstructure in a typical Mountain Chain (redrawn from Heim’s 1912 black and white sketch). In this diagram Heim is suggesting that the Lewisian basement and its upthrust slices are equivalent to the Variscan basement and the crystalline massifs of the Alps, and like the Alpine basement with its overlying superstructure of overfolded and thrust nappes of Permian, Mesozoic and Cenozoic sediments, the Lewisian basement would have been covered originally by a 30 km superstructure of overfolded and thrust Moinian/Torridonian, Dalradian (?) and Cambro-Ordovician sediments” (Barber, 2013).
Glencoul Thrust of the Moine Thrust belt.

Profile through the Glencoul Thrust at Loch Glencoul (Butler, 2004).

Stratigraphy of Cambrian-Ordovician sedimentary rocks.
2. Stratigraphy of the Assynt area (British Geological Survey, 2007)

**CAMBRO-ORDOVICIAN ROCKS**

*Scale 1:5,000*

- **SAILMHOIR FORMATION** (Smh)
  - Dolostone, dark to mid grey, mottled. White chert nodules and layers developed near base. Pale grey dolostone interbeds at base. Top not seen in Assynt district (true thickness not represented here)

- **EILEAN DUBH FORMATION** (EID) (c. 120 m)
  - Dolostone, pale grey to buff and brown, commonly laminated and flaggy. Minor chert bands and nodules towards base and top. Rare stromatolites and local cross-lamination. Dark grey dolostone near base. Thickness shown here based on Durness section, because of complex imbrication in Assynt

- **GHURUDAIDH FORMATION** (GUD) (c. 66 m)
  - Dolostone, dark grey, with burrow motting, ooidal layers and rare stromatolites. Pale grey dolostone towards top; interbeds of siliciclastic rock near base

- **ANT-SRON FORMATION** (ASR)

**DURNESS GROUP**

**ARDVECK GROUP**

- **Sailmore Member (Sqm)**
  - Quartz-arenite, white and grey, with dolomitic sandstone and mudstone. Characterised by small conical shells of Saltarella

- **Fucoid Beds Member (FuB) (10–20 m)**
  - Dolomitic siltstone and mudstone, potash-rich ferruginous and brown, with arenaceous dolostone and thin quartzite beds. Abundant Planolites burrows

- **Pipe Rock Member (PpR) (75–100 m)**
  - Quarz-arenite, white and pink to purple, with abundant bioturbation and Skolithos and locally Monocraterion burrows ('pipes') perpendicular to bedding. White towards base and pink towards top

- **Basal Quartzite Member (BaQ) (75–125 m)** (Formerly 'False-Bedded Quartzite Member'),
  - Quartz-arenite, white with cross-bedding, locally herring-bone cross-bedding. Conglomerate at base with clasts of vein-quartz, microlite and feldspar

**NEOPROTEROZOIC ROCKS**

*Scale 1:10,000*

- **Cape Wrath Sandstone Member (TCCW)**
  - Sandstone, pale red, coarse-grained, tabular and trough cross-bedded, with minor pebble-conglomerate and mudstone. Locally with soft-sediment deformation structures (Facies 3 and 4 of Williams, 2001) (minimum 300 m)

- **Pebble-conglomerate and coarse-grained sandstone, pale red, tabular and trough cross-bedded. (Facies 2 of Williams, 2001) (c. 170 m)**

- **(c. 100 m)**

**TORRIDON GROUP**

- **APPLECROSS FORMATION** (TCA) (minimum 1000 m)
  - Sandstone, red, coarse to very coarse-grained, pebbly, feldspathic to subfeldspathic. Commonly trough cross-bedded. Locally with soft-sediment structures

- **DIABAIG FORMATION** (TCD) (0–75 m)
  - Mudstone, sandstone, conglomerate and basal breccia
Lewisian Gneiss (about 3.0–2.7 Ga)
The gneiss forms the Laurentian basement and was metamorphosed to granulite facies. It consists of ultramafic to mafic and acid layers that are truncated by WNW-striking, mafic dikes of the Scourie swarm. Basic gneiss is made up of pyroxene-hornblende-feldspar rocks and felsic gneiss consists of quartz-feldspar-pyroxene rock. Lewisian Gneiss contains structures (foliations, folds, shear zones) formed during ductile deformation.

Torridonian sandstone (1000–800 Ma)
Coarse-grained, purplish-red feldspathic sandstone (arkose) showing cm- to dm-scale cross-bedding and conglomeratic intercalations. Pebbles include jasper, chert, tourmaline-quartz, porphyritic rhyolite and acid tuffs. The thickness of this sandstone unit is up to 6 km.

Quartz sandstone ‘pipe rock’ (540–390 Ma)
The sandstone is often stained purplish brown by iron and manganese oxide. Vertical "pipes" stand out in white against the stained matrix of the sandstone. The pipes are sand-filled tubes or burrows of worm-like, suspension feeding organisms (Skolithos). Thickness of this unit is about 75 to 100 m. (view shows horizontal bedding with vertical pipes)

Quartz sandstone ‘pipe rock’
Circular white spots are tops of pipes (looking down on bedding plane).
**Fucoid Beds**
The Fucoid beds consist of rusty-weathered shale and dolomitic layers. Worm tracks of *Planolites*, in previous times misinterpreted as fucoid remains (seaweed), are visible on the bedding planes. The trilobite *Olenellus* may be present in this rock unit. The thickness of the Fucoid Beds is about 15 m.

**Salterella Grit**
This unit consists of quartz sandstone and dolomite which contains small conical fossil tubes known as *Salterella*. The unit is about 9 m thick.

**Limestone of the Durness Group**
The Group is made up of limestone, dolomitic limestone and pure dolomite. Limestone of the lower part of the Durness Group is dark grey and leaden coloured (Ghrudaidh Formation), but rocks higher up the limestone succession are distinctly lighter in colour, fine-grained and may contain chert layers (Eilean Dubh Formation). Limestone surfaces are not covered by lichens. Areas underlain by limestone are grassy and contain wild flowers.

**Post-Cambrian intrusive rocks (430 Ma)**
These rocks form a suite of alkaline sills and dikes of Silurian age. Rock types include: peralkaline rhyolite, hornblende microdiorite and vogesite rocks. Collectively, these rocks are rich in potassium and sodium and, thus, contain abundant K-feldspar and foid minerals.
3. References


4. Appendix

Simplified geologic map of Scotland. Inset shows the major terranes of Scotland. After Leslie et al. (2008).
Regional metamorphism in Scotland modified from Fossen (2010). (a) Index minerals of metamorphic zones (Barrow zones). (b) Distribution of metamorphic zones in map view.

Pressure-Temperature Diagram showing metamorphic facies modified from Frisch et al. (2011).
Structural elements of a tectonic wedge.

Kinematic evolution of a duplex.
Geometry of frontal and lateral ramps (Fossen, 2010).

Structural elements of a normal fault.

Fold elements modified from Fossen (2010).
**Geologic Map Symbols**

**FOLIATION AND CLEAVAGE**
- Strike and dip of foliation
- Strike and dip of cleavage
- Strike of vertical foliation
- Strike of vertical cleavage
- Horizontal foliation
- Horizontal cleavage

Alternative symbols for other planar elements

**JENTS**
- Strike and dip of joint
- Strike of vertical joint
- Horizontal joint

Strike and dips of multiple systems

**BEDDING**
- Strike and dip of beds
- Horizontal beds
- Approximate strike and dip
- Strike of vertical beds
- Strike and dip of beds where top of beds can be distinguished; used only in areas of complex overturned folding

Generalized strike and dip of crumpled, plicatad, crenulated, or undulating beds

**FOLDS**
- Strike and dip of beds and plunge of slickensides
- Anticline, showing crestline and plunge
- Overturned anticline, showing trace of axial surface, dip of limbs and plunge
- Minor anticline, showing plunge
- Syncline, showing crestline and plunge
- Overturned syncline, showing trace of axial surface and dip of limbs
- Minor syncline, showing plunge

**CONTACTS**
- Contact
- Approximate contact
- Inferred contact
- Concealed contact
- Contact, showing dip
- Vertical contact

**LINEATIONS**
- Bearing and plunge of lineations
- Vertical lineation
- Horizontal lineation

Double lineation
- Strike and dip of beds and plunge of lineation
- Strike and dip of foliation and plunge of lineation

Strike and dip of beds showing horizontal lineation
- Strike and dip of foliation showing horizontal lineation

Vertical foliation, showing plunge of lineation
- Vertical beds, showing horizontal lineation
- Vertical beds, showing horizontal lineation

Generalized strike of folded beds or rotation, showing plunge of fold axes

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*The map explanation should always specify the kind of cleavage mapped*
Geologic Map Symbols

FOLDS (continued)

- Approximate axes
- Interred axes
- Concealed axes
- Doubtful axes, dotted where concealed
- Horizontal fold axes
- Dome

Fold with inclined axial plane, showing dip and bearing of plane and plunge of axis

FAULTS

- Fault, showing dip
- Approximate fault
- Vertical fault
- Inferrred fault
- Doubtful fault, dotted where concealed
- Concealed fault

Normal fault, ratchures on down side
High angle fault, movement - U (up) and D (down)
Thrust or low-angle reverse faults, T, upper plate
Thrust or reverse fault, bars on side of upper plate
Fault, showing relative movement

OIL AND GAS WELLS

- Oil well
- Well location
- Abandoned oil well
- Oil well, with show of gas
- Dry hole
- Abandoned oil well, with show of gas
- Oil and gas well
- Dry hole, with show of oil
- Abandoned oil and gas well
- Gas well
- Dry hole, with show of oil and gas
- Abandoned gas well, with show of oil
- Gas well, with show of oil
- Dry hole, with show of gas
- Abandoned gas well
- Shut in well

CROSS SECTIONS

- High angle faults
- Low angle faults
- Overthrust
- Underthrust
- Reverse fault

Fault, showing relative lateral movement A, away from observer T, toward observer
2009 GEOLOGIC TIME SCALE

**CENOZOIC**

**MESOZOIC**

**PALEOZOIC**

**PRECAMBRIAN**

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*International ages have not been fully established. These are current names as reported by the International Commission on Stratigraphy.
