Field Excursion to the Old Red Sandstone coast west of Fraserburgh, Pennan to New Aberdour

The fine coastline between Troup Head and Dundarg has impressive cliffs made of Old Red Sandstone, here we offer some thoughts on the processes that shaped these rocks, for folk who wonder about such things and may like to go there.

Highland Geology Limited

Dr John Nicholson

Following his Ph.D on East Greenland Old Red Sandstone, at Cambridge University in 1971, John worked for the West Australian Geological Survey then joined BP in Australia and subsequently worked for them and then for Britoil in the UK. In 1984 he co-founded and managed the Midland Valley Exploration consultancy based in Glasgow, specialising in structural geology and software development. After 11 years with MVE, in 1996 he established Highland Geology Limited, now in its 25th year.

John has been a member of and led numerous teams which have been successful in drilling exploration and development wells. He has worked in many of the world's prospective basins including Northwest Shelf of Australia, onshore Australia and Papua New Guinea; the Gulf Coast of the USA; the UK and Norwegian Northern, Central, Southern, Danish and Dutch North Sea; the English Channel and Southwestern Approaches basins, offshore Ireland; the UK Midlands and Dorset; in the Andes in Argentina, Bolivia and Colombia; in Russia; and in nearly all of the offshore and onshore basins of India. India has been a particular focus: he was contracted as Senior Asset Manager for an operator which drilled a major gas well in Tripura, also for them he re-mapped the complex Kharsang Field for a successful programme of oil development wells.

His interest in the onshore and offshore UK geology and petroleum potential goes back to 1978, heading-up BP's onshore team in Eakring, and since then he's followed and contributed to the Industry exploration effort onshore UK. He continues to provide insight for persons and companies interested in UK's energy policy and potential, into Northern England's considerable remaining potential for hydrocarbons.

Huge northeast-trending wrench faults dominate the structure and history of Inner Moray Firth, and thinking about their nature and processes of deformation adds a dimension to visiting this splendid Old Red Sandstone coastline. Here we are looking east over the Old Red's boundary, its a massive fault which we think is part of the Banff Fault system. The blue line in the inset marks its location, basement Dalradian rocks form the coast between Dundarg and Fraserburgh. This fault may actually be the most important of the Banff faults, the driver for the rest of them, though people writing about the southernmost offshore faulting haven't drawn it that way.

We see the huge contrast here between excellent cliff exposures (don't expect cliff top paths!), and very sparse outcrop inland.

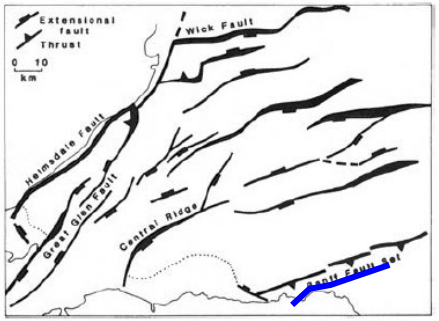
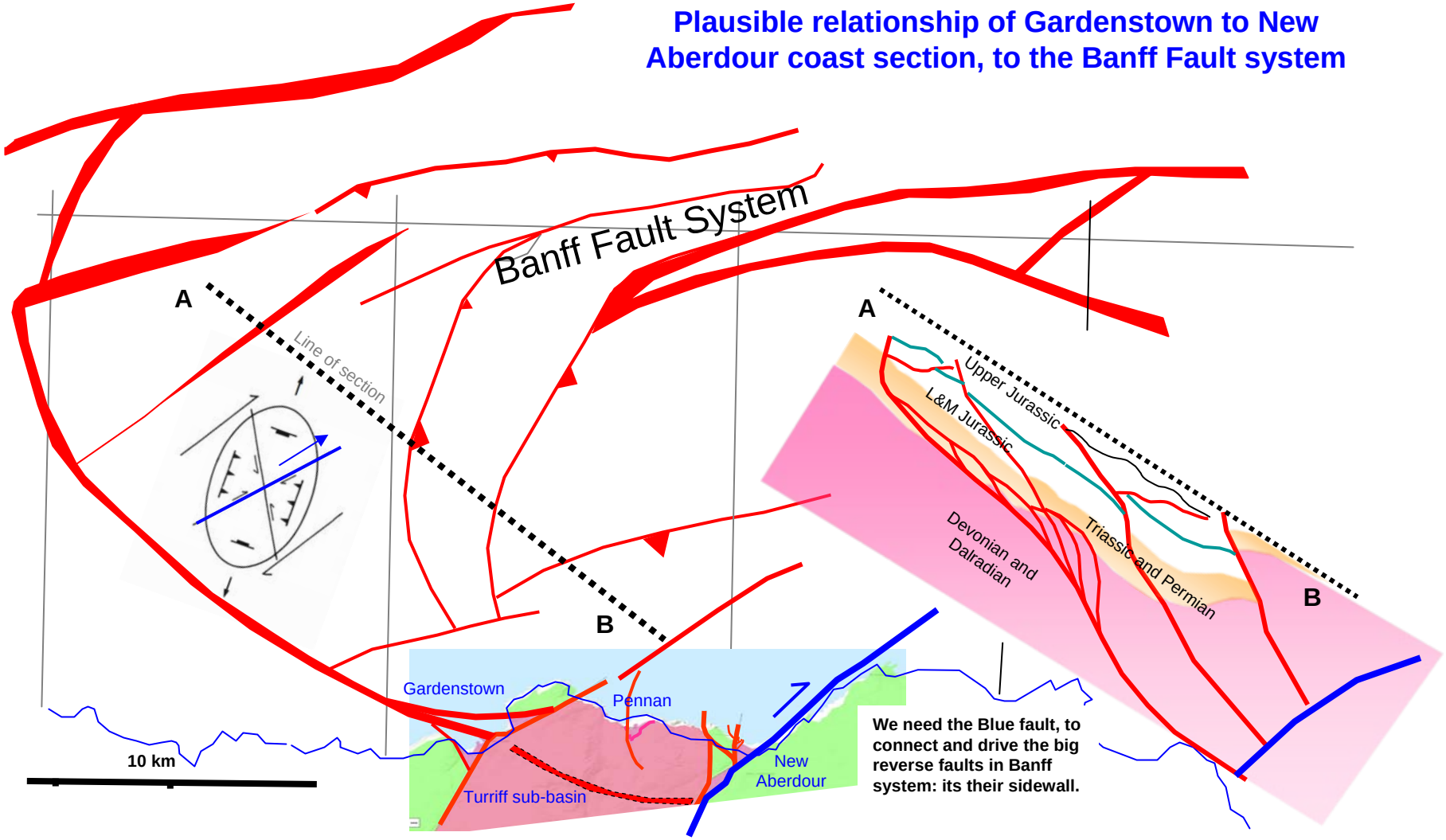


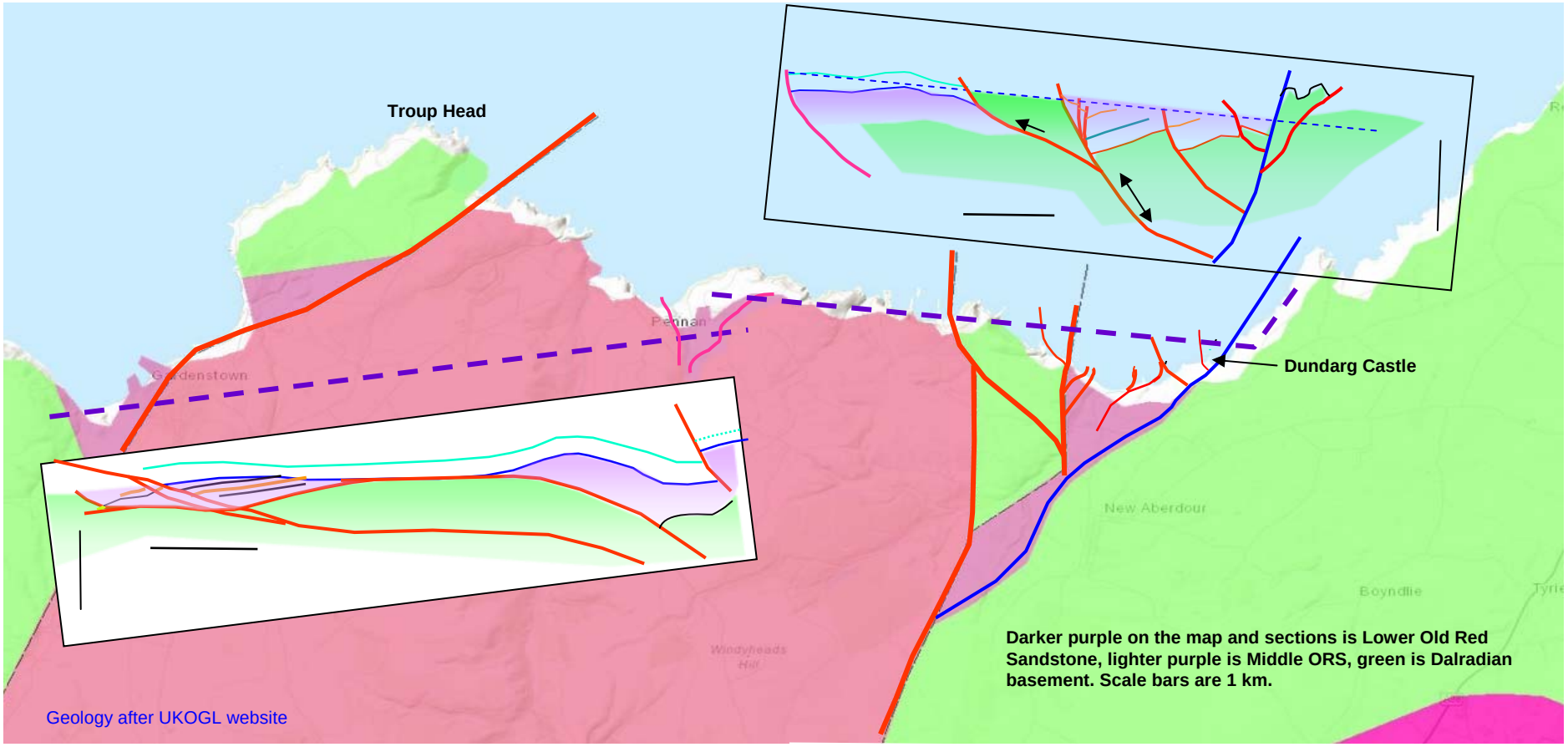
Fig. 1. Generalised map of principal structural elements of the Inner Moray Firth Basin.

Easily the most exciting – but never quoted – technical summary on the Inner Moray Firth geology is Bird, T. J., Bell, A., Gibbs, A. D. & Nicholson, J. : Aspects of strike-slip tectonics in the Inner Moray Firth Basin, offshore Scotland. Norsk Geologisk Tidsskrift, Vol. 67, pp. 353-369. Oslo 1987. ISSN 0029-196X. Its on the internet and can be downloaded free, and its in English, despite the journal being Norwegian. Not to be missed!

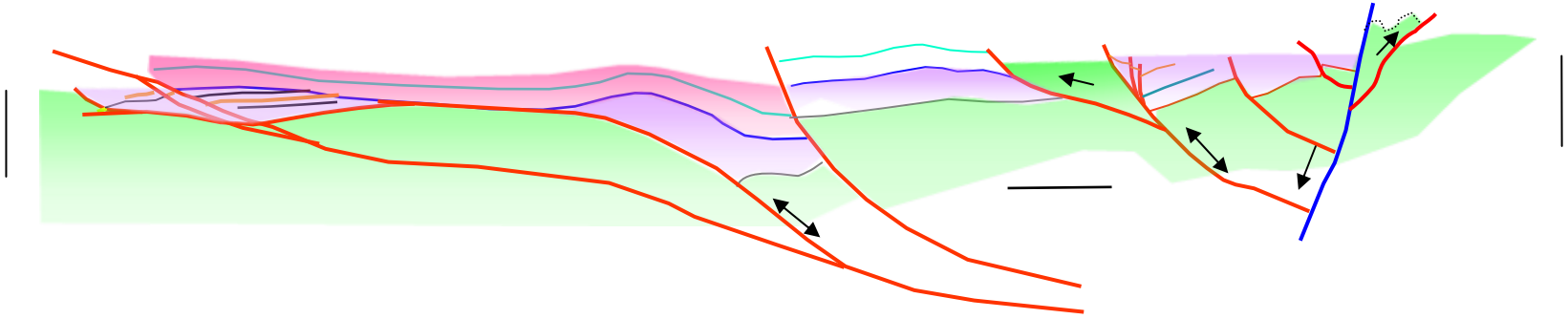
Plausible relationship of Gardenstown to New Aberdour coast section, to the Banff Fault system



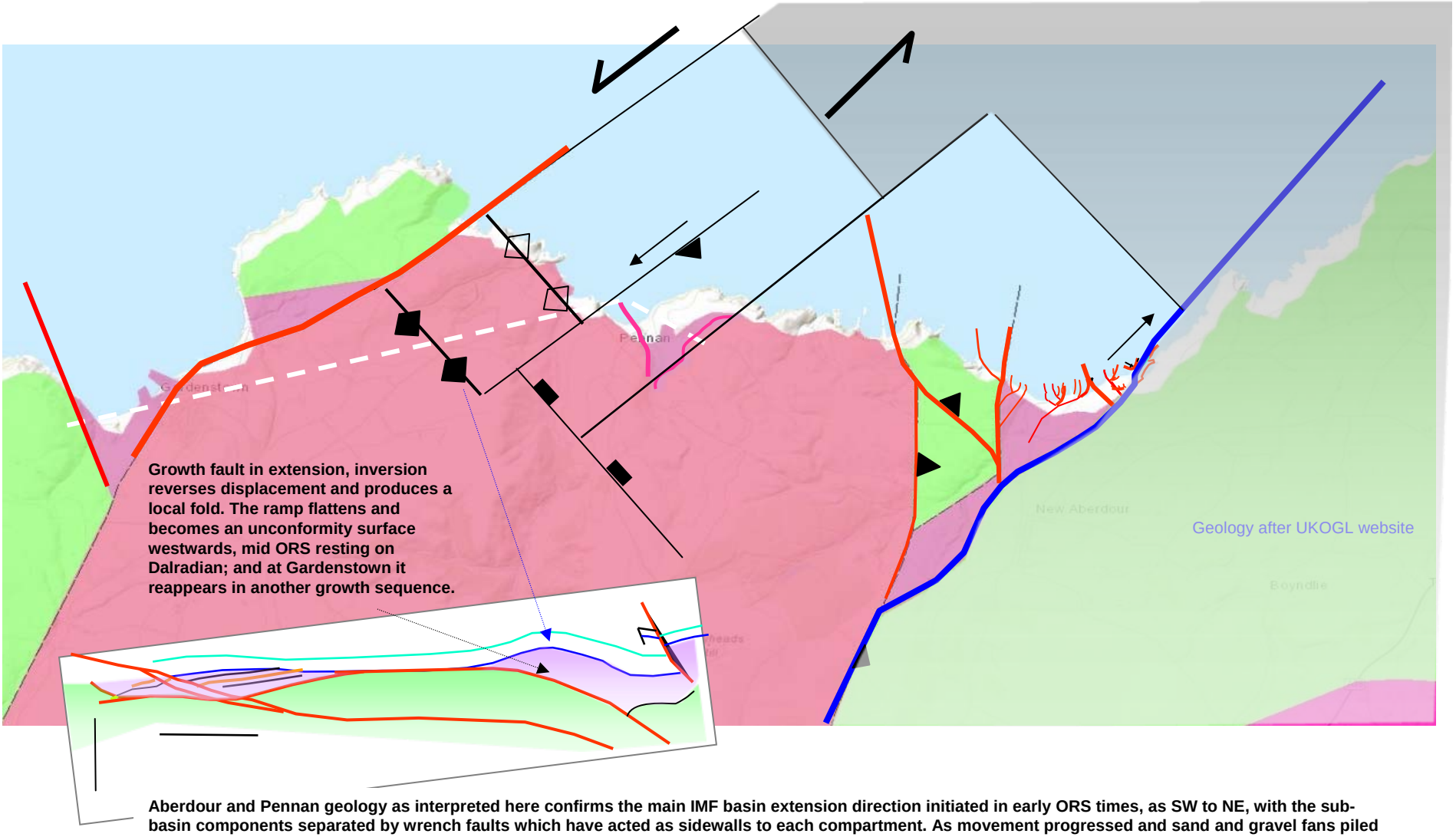
Offshore seismic profiles shot for oil exploration show that faults in the Inner Moray Firth basins are arcuate surfaces linked together by steep wrench faults which have both vertical and sideways displacement, and its those northeast-trending wrenches which controlled the history of the Old Red. They were established in Ordovician and Silurian crustal compression, when plates collided to form the Himalayan-scale Caledonian thrust-fold belt, and they were instrumental in the collapse and huge erosion which followed. The sediment piles resulting are the Old Red Sandstone. Strike-slip faults in the Moray Firth have continued moving for nearly 450 million years, first in Devonian rifting and later in the opening of the North Sea, and the Alpine collision of Europe and North Africa. Turriff Basin faults are part of that system, so here we develop a model for Turriff linking them with the Banff Fault. Using this we can draw cross-sections using the same geometric style. The underlying idea for all this, is that the major faults are linked by even bigger ones, which drive the opening of the basin. Opening direction for the Turriff is northeastwards, we think.



Darker purple on the map and sections is Lower Old Red Sandstone, lighter purple is Middle ORS, green is Dalradian basement. Scale bars are 1 km.



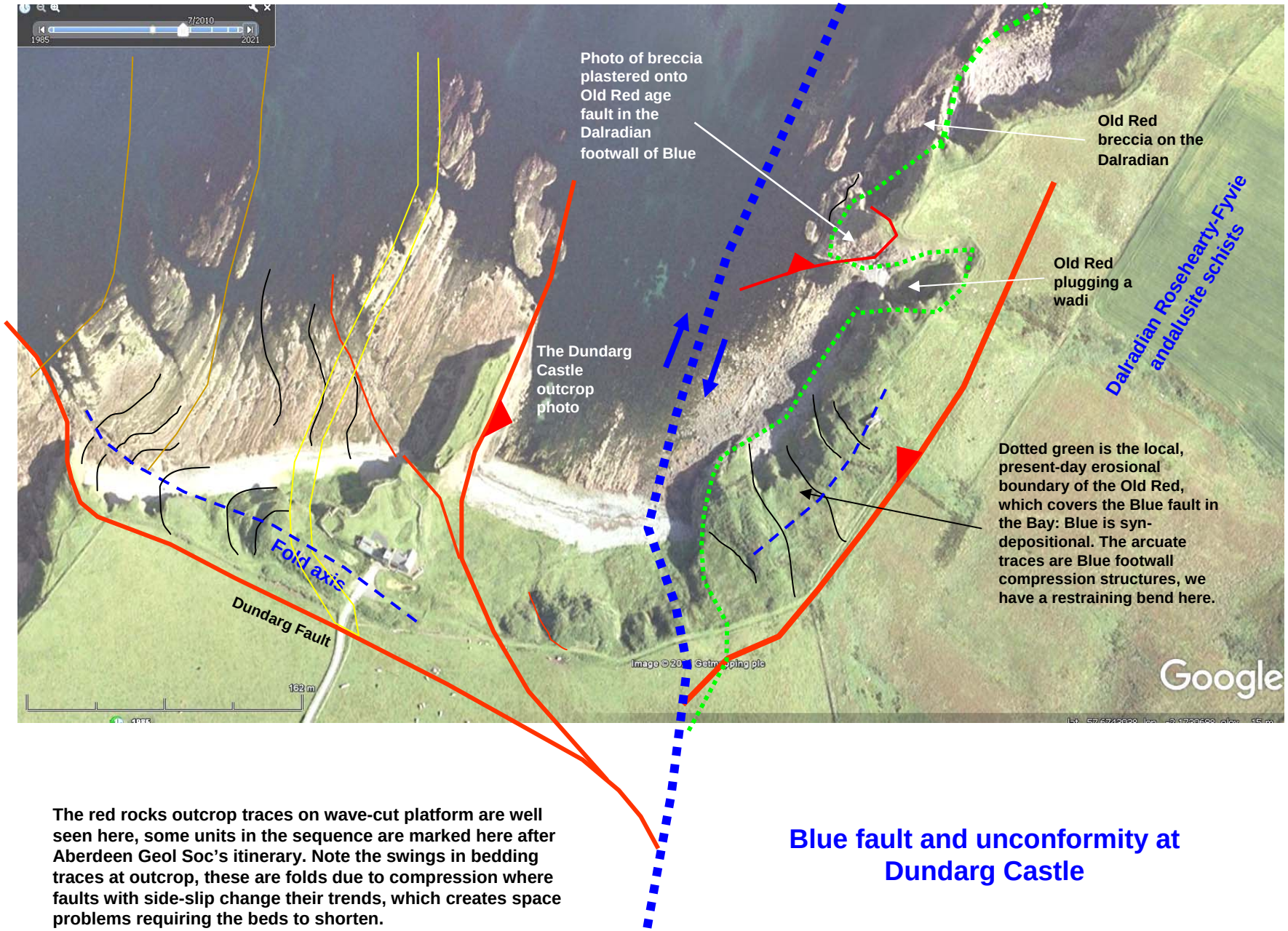
In basins controlled by wrench faults there is a mixture of extension and shortening structures, pullapart in one location creates compression in another. This cartoon is how we see the Troup to Quarry Point structure, its drawn here with the same staircase fault-shape pattern as is shown by seismic lines in the offshore Inner Moray Firth depocentres. Faults which controlled pull-apart made the holes for sediments to fill, and repeated displacement modified the picture as Moray Firth underwent further phases of extension with local intermittent compressional (shortening) inversion. Extension and shortening created thickness changes as sediments poured in, and folding. So, disconnected stick faults play no part in IMF basins: its a connected world.



Aberdour and Pennan geology as interpreted here confirms the main IMF basin extension direction initiated in early ORS times, as SW to NE, with the sub-basin components separated by wrench faults which have acted as sidewalls to each compartment. As movement progressed and sand and gravel fans piled into the accomodation space along with fluvial, wind and lake sediments, the various sub-basins elongated northeastwards. Speculatively, we draw a figurative approximation to how matters may have been arranged. Although the shear sense here may look left-handed actually its all relative movement, everything is travelling to NE. Some parts moved more effectively than others, some faults sticky, some stopped working.

Imagine the strike-slip faults were like sheets of corrugated iron: moving sideways on them would be difficult until local corners were eliminated, and as rock is weak the process would shear-off local bends. Where larger bends persisted, there would be space problems and "flower" fault arrays develop to move rock out of the way, upwards and sideways: which is why pips of basement got pushed over the Old Red west of Aberdour, and perhaps Troup is an example too. Over the ramps there are forced folds, as Old Red was progressively moved across curving floor faults interconnecting the sidewalls.

When the North Sea basins started to open the regional principal compressive shear direction changed several times, which led to collapse of the ramps used for the Devonian extension, breaking new rock where it was easier than to reverse existing fracture zones. And there was Alpine deformation too, major uplift.



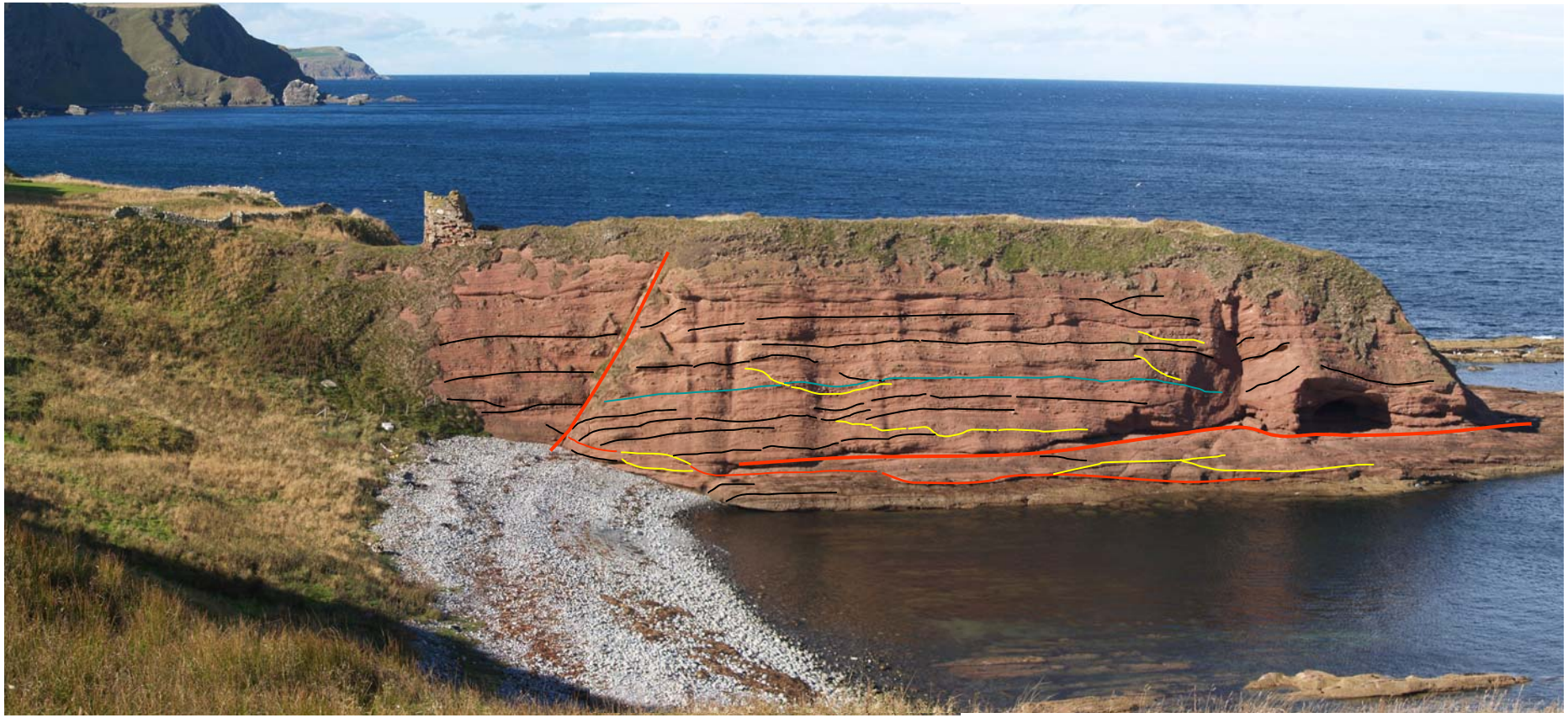
The red rocks outcrop traces on wave-cut platform are well seen here, some units in the sequence are marked here after Aberdeen Geol Soc's itinerary. Note the swings in bedding traces at outcrop, these are folds due to compression where faults with side-slip change their trends, which creates space problems requiring the beds to shorten.

Blue fault and unconformity at Dundarg Castle

East margin for this part of the enormous Old Red basin complex, viewed from vicinity of Dundarg Castle. The Dalradian Rosehearty-Fyvie rocks are strongly deformed, but large fault and folds indicated here in white don't have Caledonian style: in the background headland there seem to be chevron folds. Large faults like the one in the centre of the photo also don't have the complexity expected of Caledonian thrust-folding. We suggest these are compressional footwall structures developed as the Blue fault operated in sidewall mode, to extend the Old Red depocentre. That's a characteristic of strike-slip faults which have a significant bend.

The patches of Old Red in mid-photo are unconformable on the exhumed fault, which became exposed by intra-Devonian uplift and erosion. The inlet in shadow at right has been interpreted hitherto as an erosion gulley, plugged with Old Red sediments, which is probably correct. See Geol Soc of Aberdeen's itinerary here, for details on this locality.

Base breccia of the Old Red Sandstone here, about 10 metres or so thick, is followed by the Dundarg Castle pebbly sandstones, its all attributed to the Lower Devonian Crovie Group. Lacking definitive fossils to date the rocks, Old Red fans which change very quickly in thickness and may have different source areas for their sediments, can be hard to correlate with confidence. Anyway, its a beautiful unconformity with the Dalradian. Without a boat, take care scrambling down here!

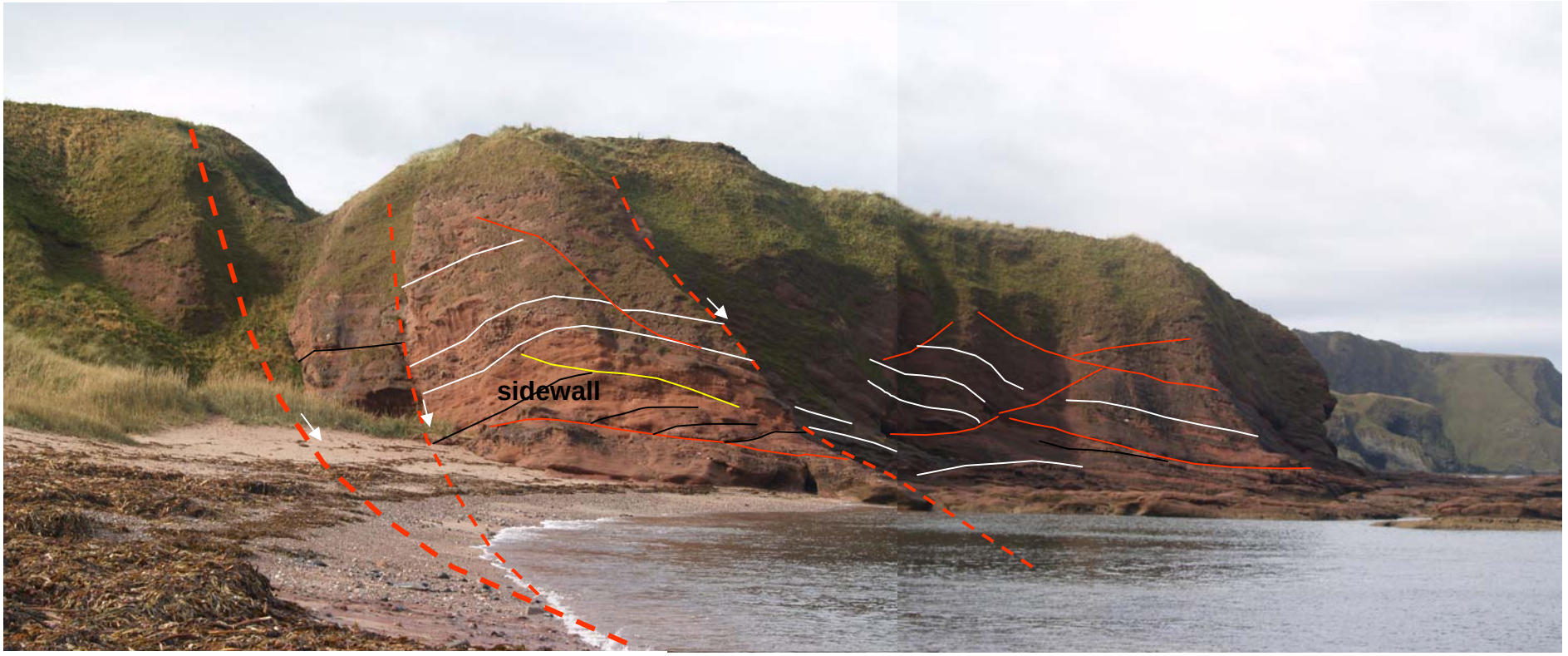


Lower ORS Crovie Group conglomeratic sandstone unit at Dundarg Castle is around 100 metres thick and dips at about 30 degrees away from the eye, northwest, so this is a strike section. Rocks we are on are Dalradian.

The fractures eroded out at base of the Dundarg cliff are plausibly reverse, westerly-vergent fractures creating the away-from-the-eye westerly dip, they root onto Blue fault, we think, dipping towards us. Blue is a syn-depositional fault, its reasonable to suggest it retains a thin ORS cover in the bay: in which case, is the ORS here really Lower Old Red? Perhaps someone will find dateable fish remains.

Bedding continuity (green) is broadly good for an alluvial fan, some downturn is evident showing lenticular sand heaps controlled by stream channel scours (yellow), which have some local pebble concentrates.

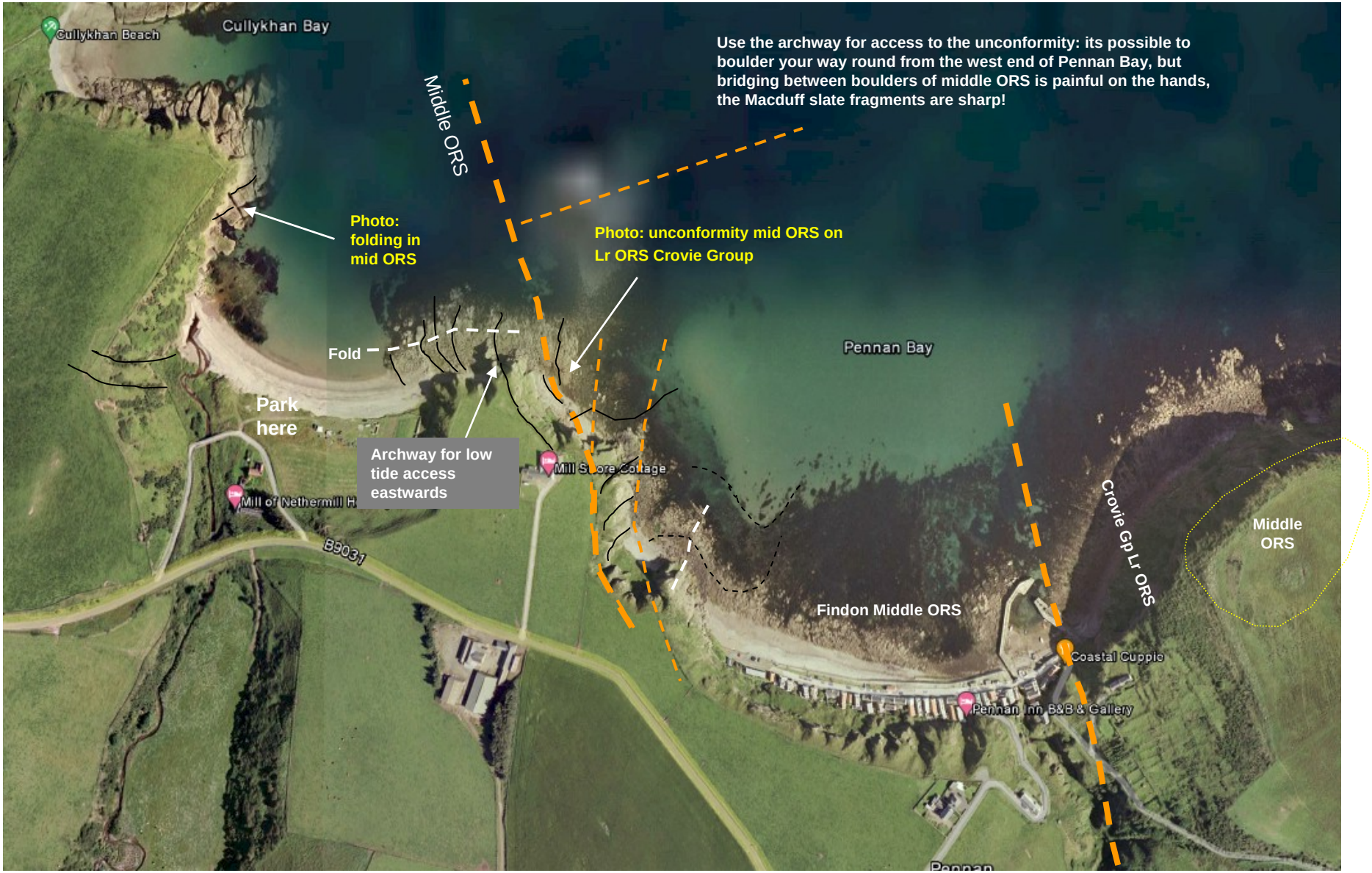
The castle was shot to pieces some time around 1335 by people who had acquired new technology, cannons.

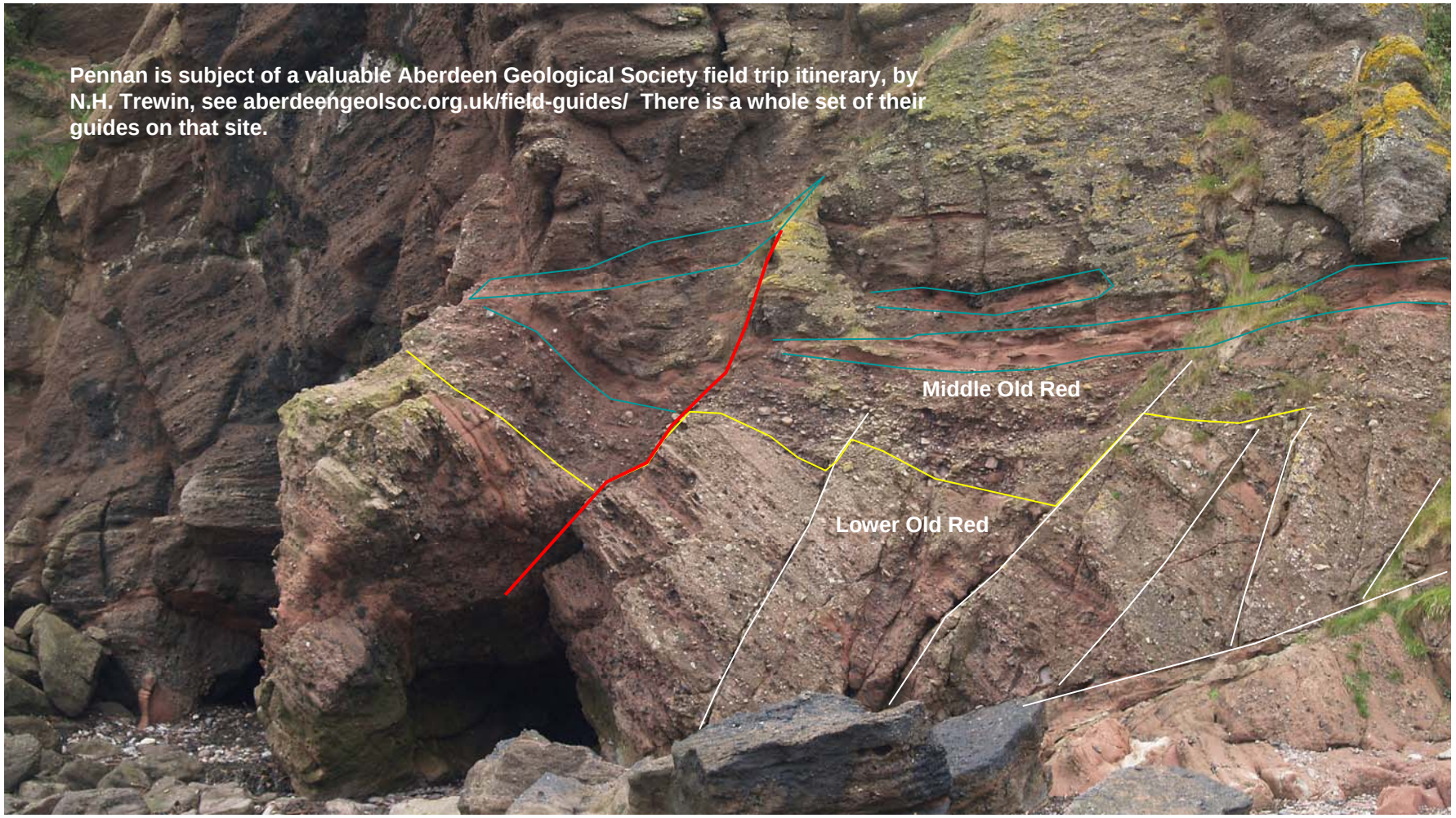


The next bay west of Dundarg, here the ORS fault block is rotationally back-tilted showing that the fault surface it rides on is curved. The bright face and the main cliff in shade are both fault surfaces, they are intersecting at almost right angles, bright face is a sidewall probably linked onto the dashed detachment, which will flatten on top of Dalradian. A local fold may be shaped by an antithetic small back-fault rooting onto the shaded face fault surface.

On a calm day its a nice project to see all this from a boat, landing in the bays and drifting from Dundarg to Pennan should show the sidewalls.

Pennan itinerary, photo locations

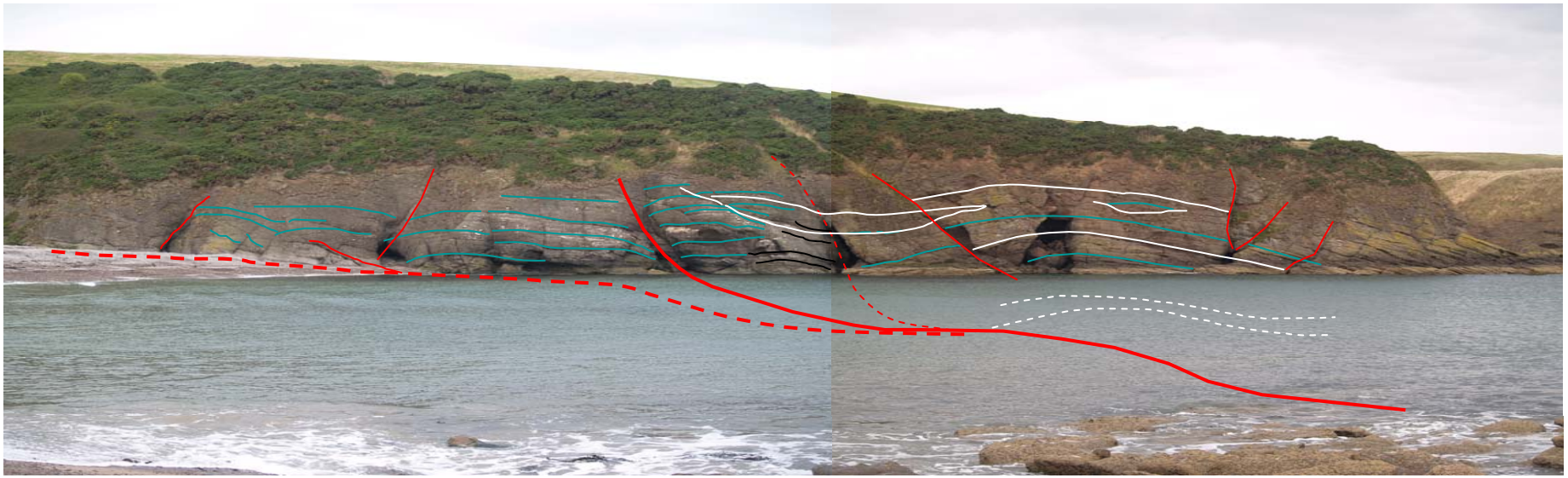


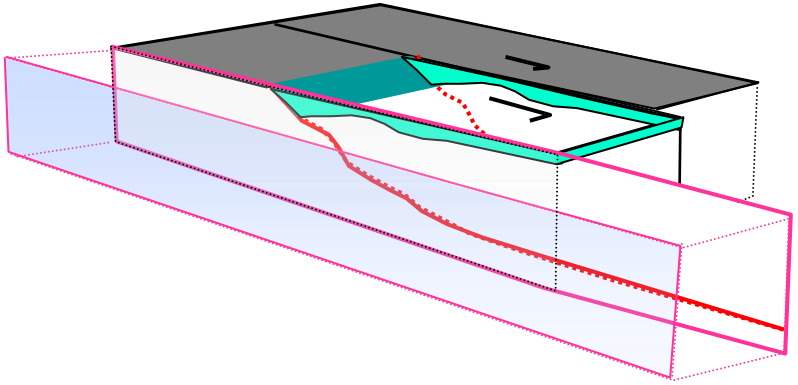


The erosion-reduced Old Red in Turriff sub-basin is about a kilometre thick, divided by field workers into Lower (Crovie) and Middle (Findon) groups by a major basin-wide break in deposition. This photo is the key unconformity location cited, at the west side of Pennan Bay (access at low tide, from Mill Shore beach), its the yellow surface here and its been proposed on the basis that faults are truncated by it (some, like red, aren't); there is a big dip change between Middle and Lower Old Red; and the Crovie gravels are dominated by granitic and quartzite pebbles whilst the Middle Old Red clasts are mainly Dalradian Macduff Slate.

Is this outcrop good enough evidence to confirm a basin-wide break? Considering the structure model with strike-slip controlled ramps detaching at various levels, local syn-depositional pop-up wedges, and that the amount of reversal on ramps varies from fault to fault, all these aspects find an explanation in ongoing strike-slip controlled basin development.

Folds develop during sedimentation, by extension between sidewalls





The west side of Mill Shore comprises Middle Old Red alluvial fan sequences, with local folding forced by extensional displacement on ramp and flat faults, perhaps as sketched in red.

New Perspectives

We've explained that our approach is based on knowledge of the offshore Inner Moray Firth, with the assumption that a structure style commonality exists between Old Red depocentres: everything is interlinked.

We see these local basins as only a tiny part of the huge Old Red basin system, which includes East Greenland and western Norway as well as the UK, all were components of the Old Red continental mass which broke up and its parts became separated. So there is a very much bigger picture, we can look not just to offshore Moray Firth but also to analogues in Greenland for ideas to apply and test in this tiny corner of Scotland.

There are alternatives to what we present here, in particular there is the traditional notion that the onshore basin and the adjoining Rhynie depocentre were formed as "half-graben" with a fault on one flank and the other side is unconformity. In that model the basins are simple pull-aparts, they extend across-ways with only one main active fault.

Thinking about how the Old Red rocks developed, asking what were the processes that operated to deposit and deform them, adds another dimension to walking these shorelines and looking at the cliffs. So, we hope you will visit this coastline, enjoy the geology, draw some sections on the beach with a piece of driftwood, maybe come up with a new model! The gannets and terns will be watching!