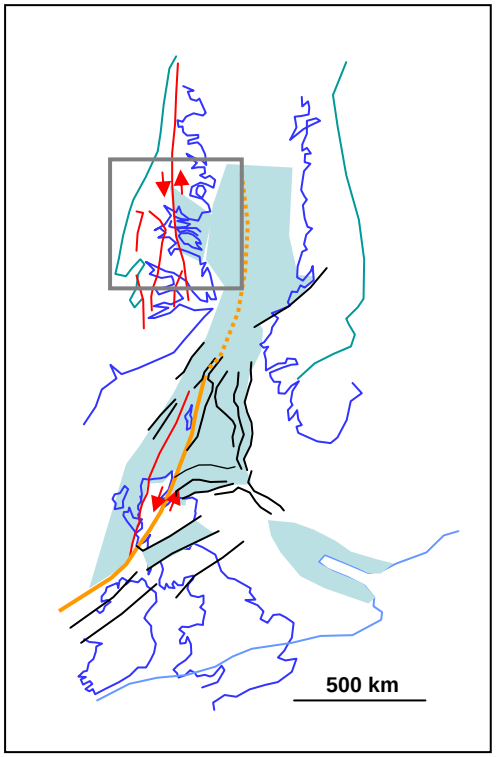
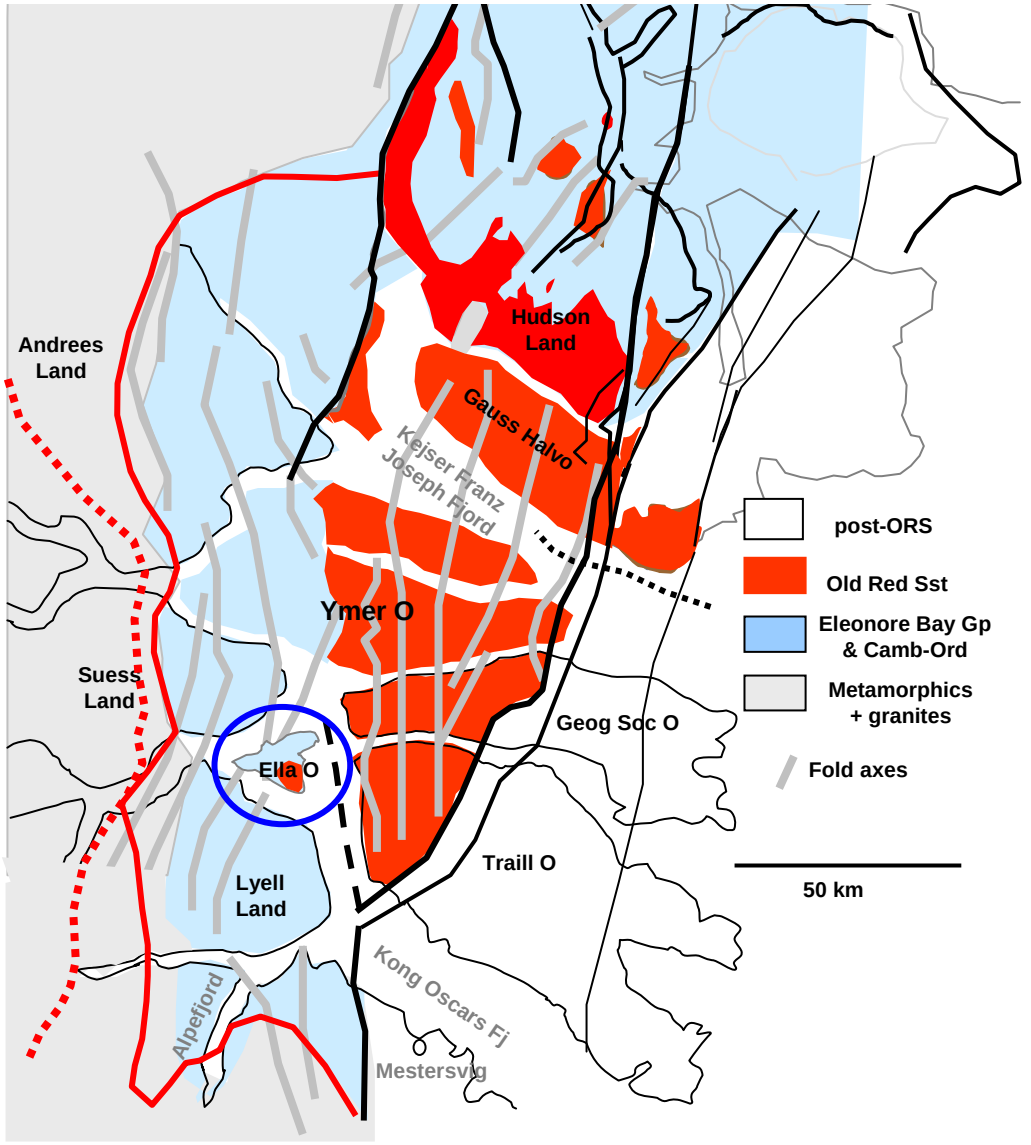
Old Red Sandstone Basins

Structure style examples in Central East Greenland

1. Ella Island's Middle Devonian basin

Old Red Sandstone basins of East Greenland and northern UK : common structure styles





The Old Red Sandstone basins of East Greenland and UK share very similar structural style. That suggests they have undergone similar formation processes. Central East Greenland Old Red has fabulous exposures, but no seismic in the fjords. UK basins have good to excellent seismic coverage, onshore exposure is variable and often limited. Comparing both provinces we can form and cross-refer new ideas and conclusions about both of them.

In this series of notes, based on experience drawn from three field seasons' work in Greenland plus extensive review of the UK Moray Firth basins, we reassess aspects of Old Red structure in the two areas. Here we offer some new ideas on the Ella Island Middle Devonian depocentre and its likely relationship to the Kong Oscars Fjord rift faults.

Collision of Greenland and the Baltic Shield, peaking around 400 Million years ago in late Silurian to early Devonian times, created "Caledonian" thrust-fold belts. West of the Old Red in Greenland a series of enormous lower-crust extensional detachments was identified in the 1990s by Scandinavian expeditions, one of the biggest is the Fjord Region Detachment Zone (FRDZ) shown in the map. Massive erosion to expose this and the Fjord Zone (FJDZ), PLDZ and SAF deep surfaces is dated by Hartz et al (2000) to 430-375 Ma. These spreading surfaces active during regional uplift of the order of 25 km, became sole faults for the Old Red upper crustal pull-apart brittle fractures.

This process answers the question of how mid Devonian sediments came to be deposited in some places directly on lower-crustal migmatites.

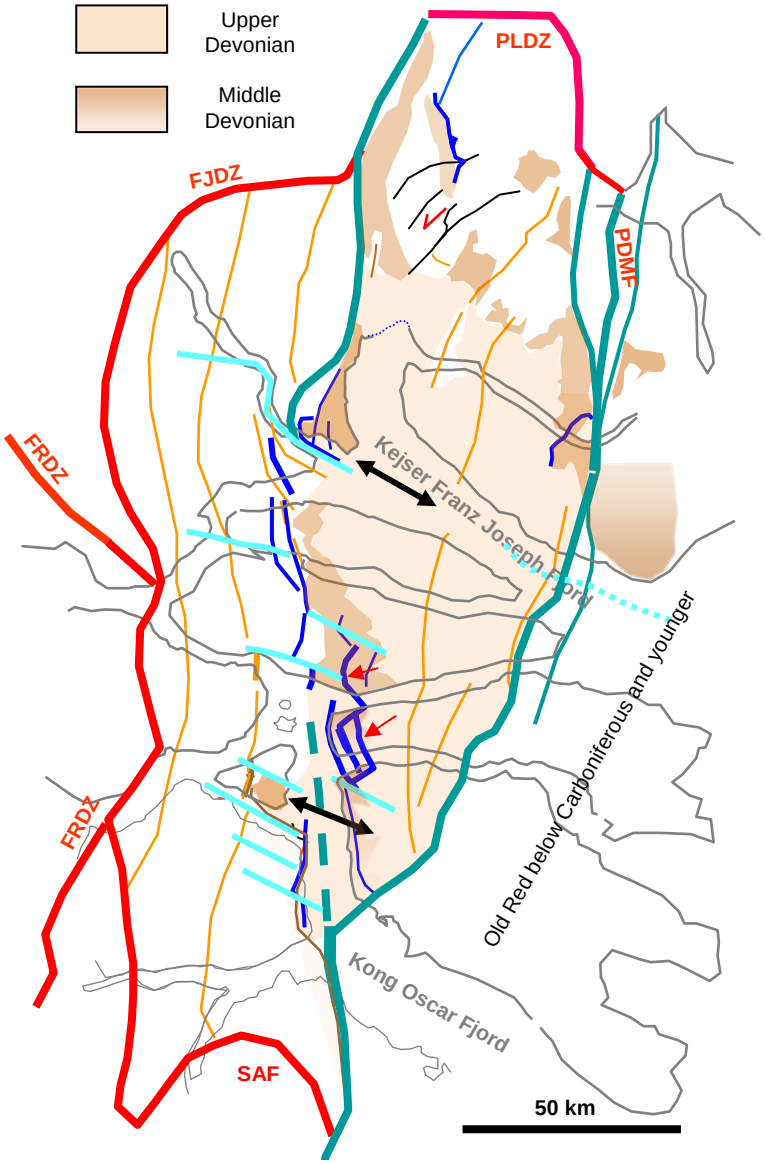
Following these post-Caledonian extensions, major rifting took over basin growth for some 70-80 million years, through mid-late Devonian and Carboniferous. Those faults floored, and controlled, the growth and boundaries of the local Old Red basins with their very thick successions, and also defined the Carboniferous basins to east of the present fjord Devonian areas.

The Old Red basin rift faults have strike-slip as well as dip-slip elements, so they are mixed-mode with both extension and compressional styles. There are places where major faults are well seen, but some particularly important ones are located in the fjords and we know little of what they look like in detail. As we have no seismic, analogues from elsewhere are the best we can do to suggest likely geometries. With these faults rapid facies and thickness changes are the rule and its a problem to relate successions laterally, with any confidence. Localised unconformities have been used to sub-divide the Greenland Old Red, but they don't support sequence correlation over significant distances.

The present western limit of ORS is largely erosional. A major Carboniferous inversion called the Ymer Phase led to reversal of some detachments and to new, footwall fracturing faults, with removal of much of the Old Red from the western side of the basins. Fault and fold structures in the Caledonian basement where the Old Red is now missing, may belong to the Devonian-Carboniferous rifting although they now affect only Pre-Cambrian to Ordovician rocks. We think the Ymer inversion and its thrusting and folding, was a lot more important than numerous papers have suggested.

Background and a large bibliography to all this, is given in Rotevatn, A., Kristensen, T. B., Ksienzyk, A. K., Wemmer, K., Henstra, G. A., Midtkandal, I., Grundvåg, S.-A., & Andresen, A. (2018). Structural inheritance and rapid rift-length establishment in a multiphase rift: The East Greenland rift system and its Caledonian orogenic ancestry. *Tectonics*, *37*, 1858–1875.

So, let's look at Ella Island Old Red geology and see if we agree with the way its been presented hitherto (hint: we don't); and how did the rift fault zone in Kong Oscar Fjord control the structure at Ella?

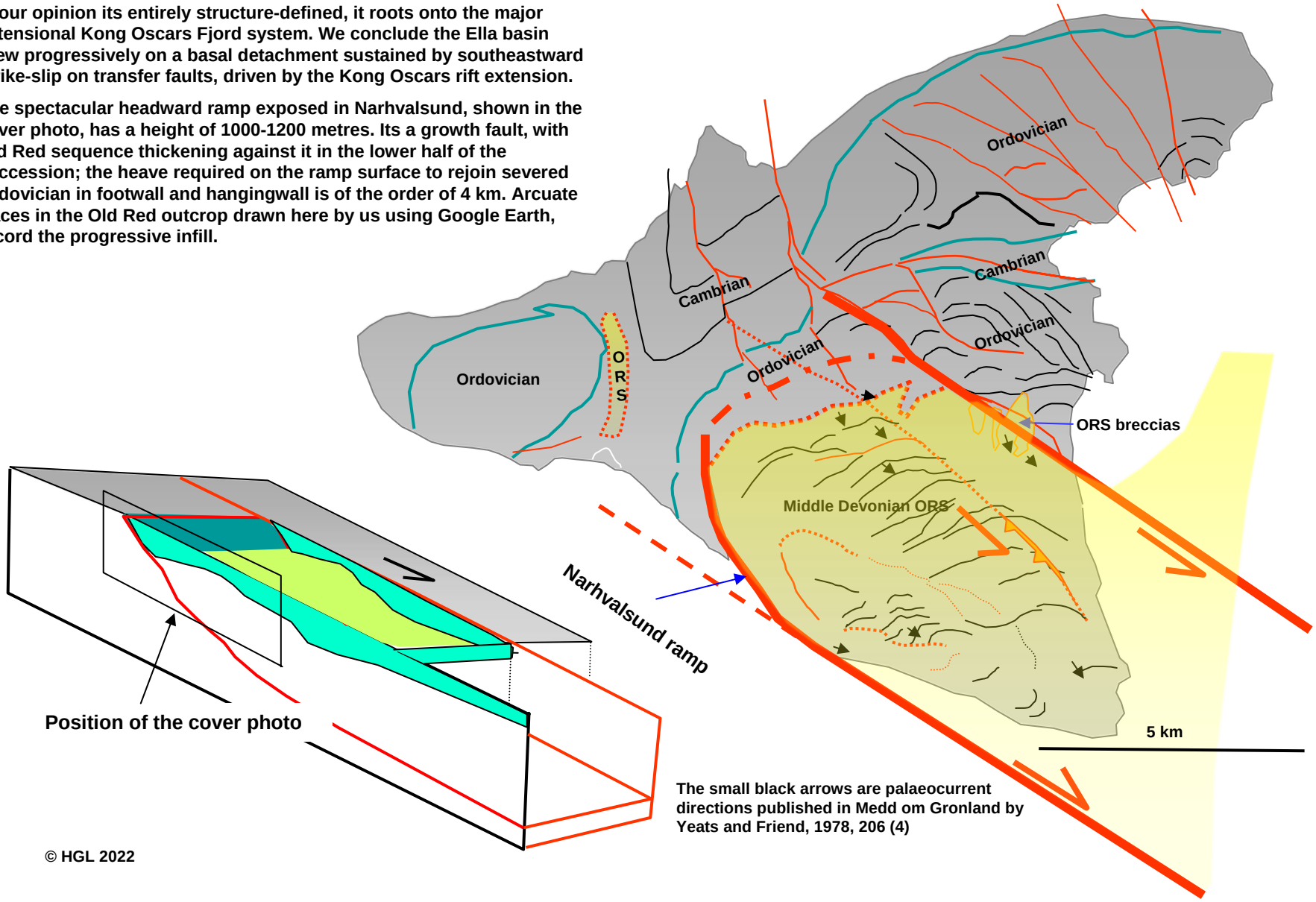


North-south faults drawn in green are Old Red master rifts, rooting on the red, lower-crustal extension surfaces. Pale blue faults are sidewalls for ESE pullapart of Old Red depocentres. Dark blue lines are SW to W-vergent inversion surfaces of the Carboniferous Ymer compression.

The Middle Devonian (Givetian) of Ella Island shows spectacular unconformity, here we discuss its nature and fundamental features of this local basin.

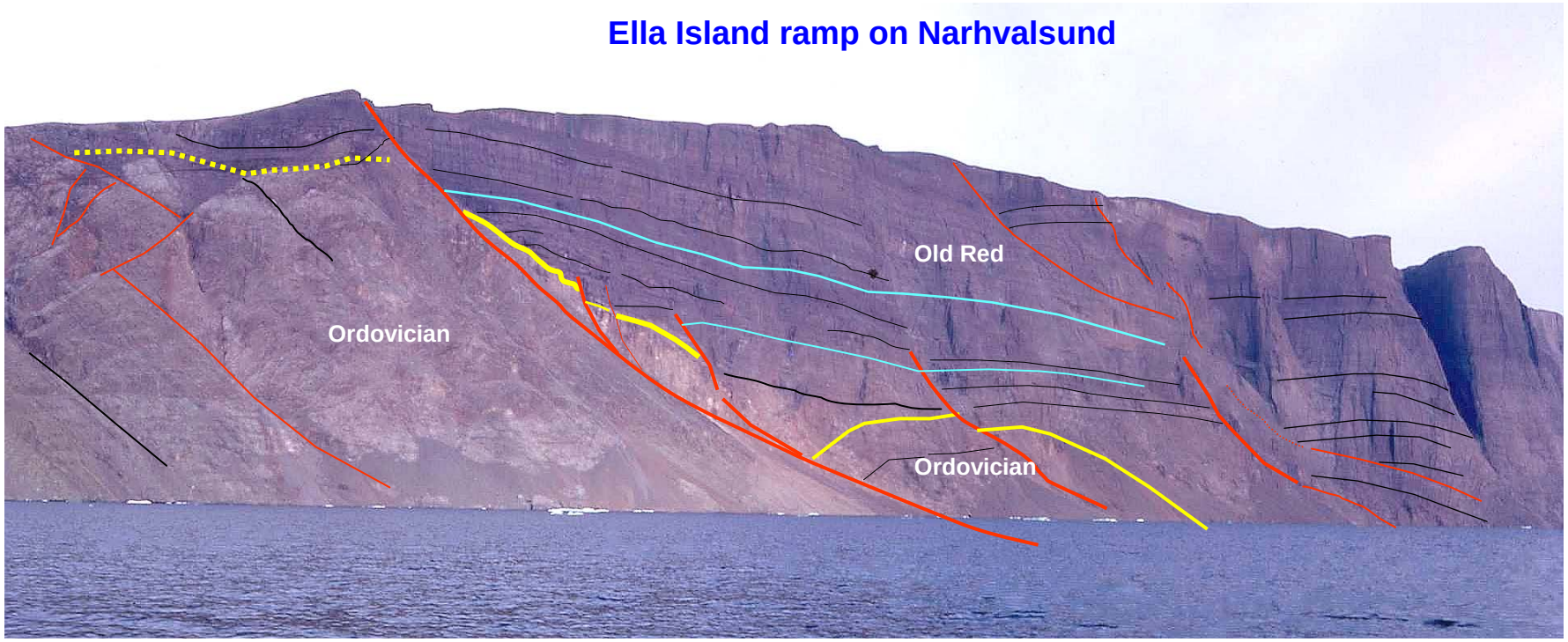
In our opinion its entirely structure-defined, it roots onto the major extensional Kong Oscars Fjord system. We conclude the Ella basin grew progressively on a basal detachment sustained by southeastward strike-slip on transfer faults, driven by the Kong Oscars rift extension.

The spectacular headward ramp exposed in Narhvalsund, shown in the cover photo, has a height of 1000-1200 metres. Its a growth fault, with Old Red sequence thickening against it in the lower half of the succession; the heave required on the ramp surface to rejoin severed Ordovician in footwall and hangingwall is of the order of 4 km. Arcuate traces in the Old Red outcrop drawn here by us using Google Earth, record the progressive infill.



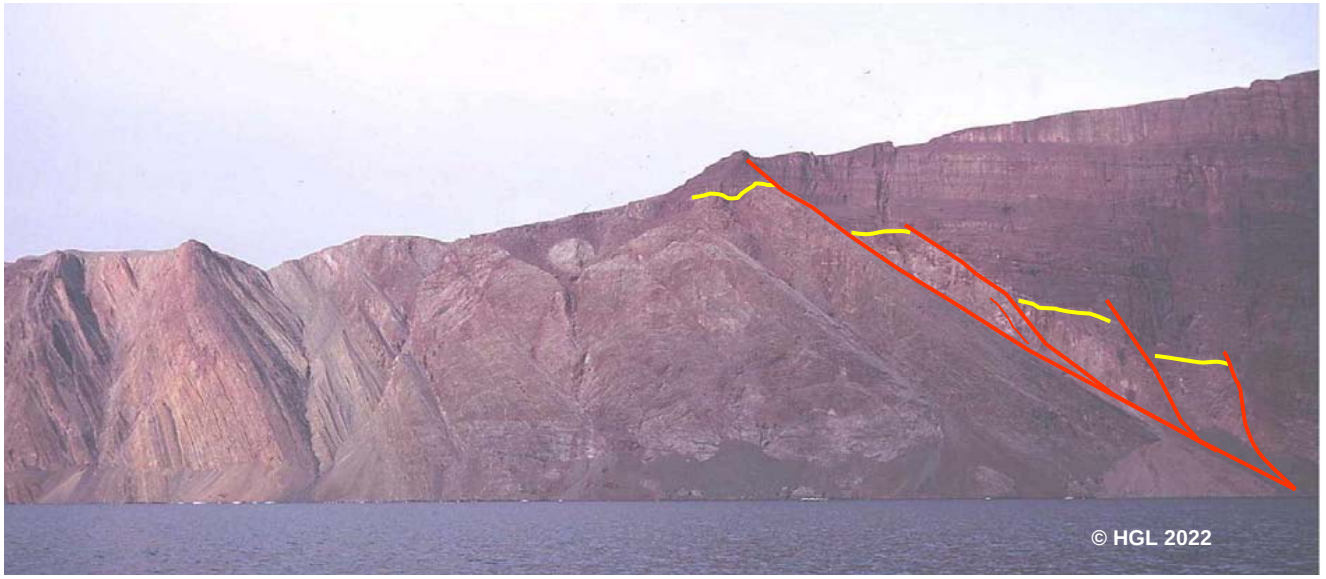
The small black arrows are palaeocurrent directions published in Medd om Gronland by Yeats and Friend, 1978, 206 (4)

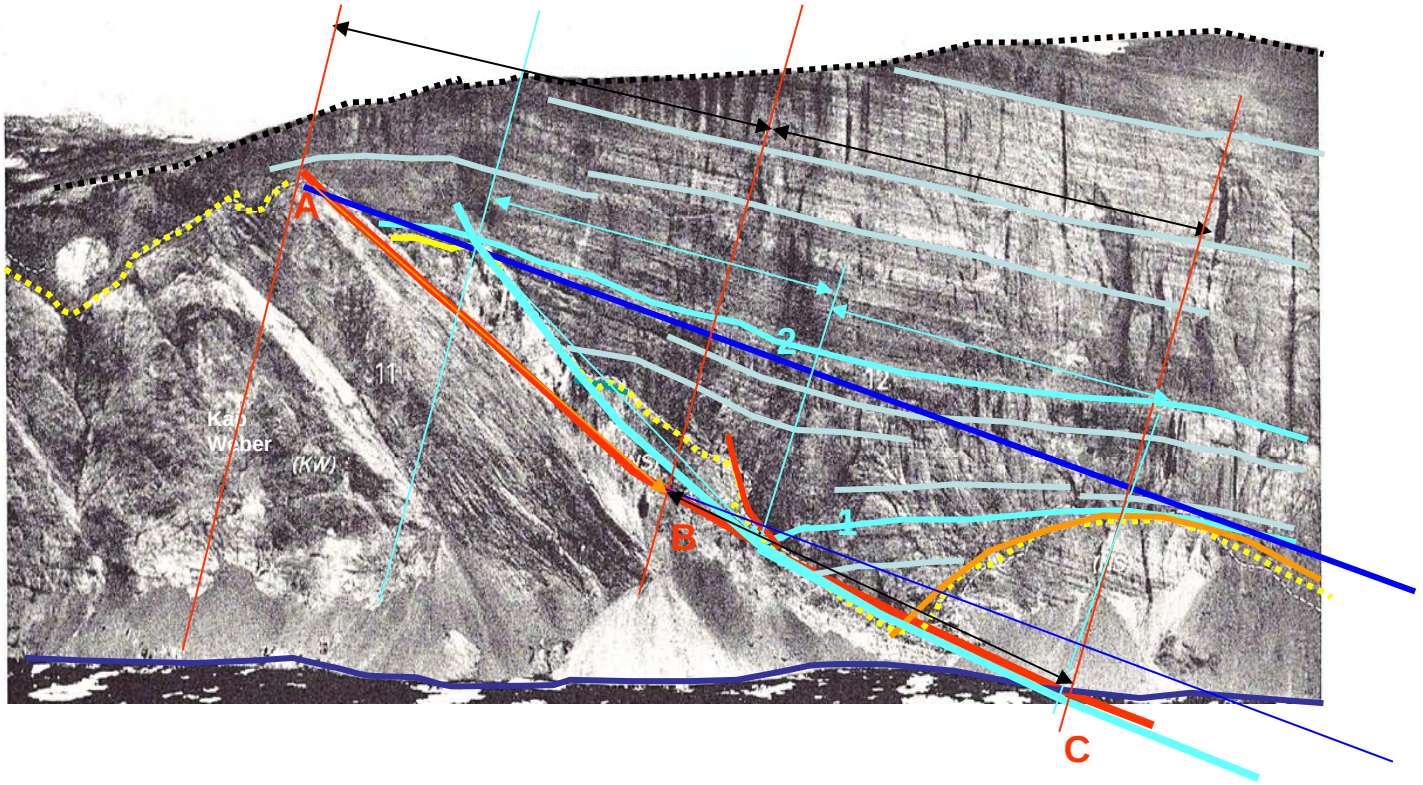
Ella Island ramp on Narhvalsund



Yellow marker (defined by geological mapping) is the top of Ordovician limestone. Our view is, its shape is not erosion-controlled: it comprises fault-separated blocks riding on the master ramp surface, the main block is rolling over in the hangingwall because the ramp is flattening southwards.

The upper photo is oblique to the giant ramp from this angle, and some detail is also scree-masked. The lower, footwall photo is more square-on and we see that faults rooting onto the ramp are syn-sedimentary, dying out in the Old Red.

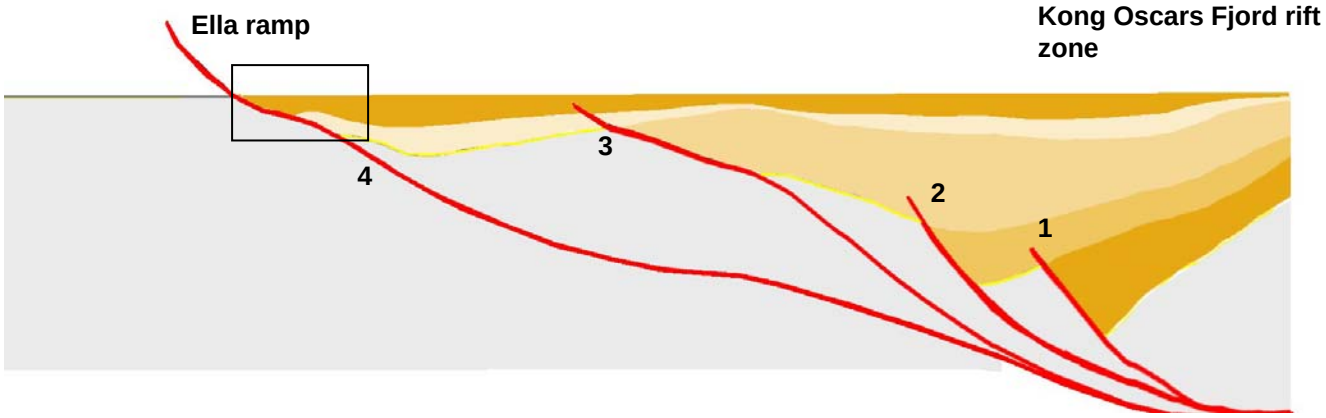




The best photos of the Old Red face and ramp are those taken from floatplanes during Lauge Koch's expeditions in the 1950s. This one was published in the magnificent "Geology of the East Greenland Caledonides", by John Haller, Wiley 1971, and the picks given by him for top of limestone in dotted yellow are used here to estimate the shape of the ramp. There are two ways we can do this.

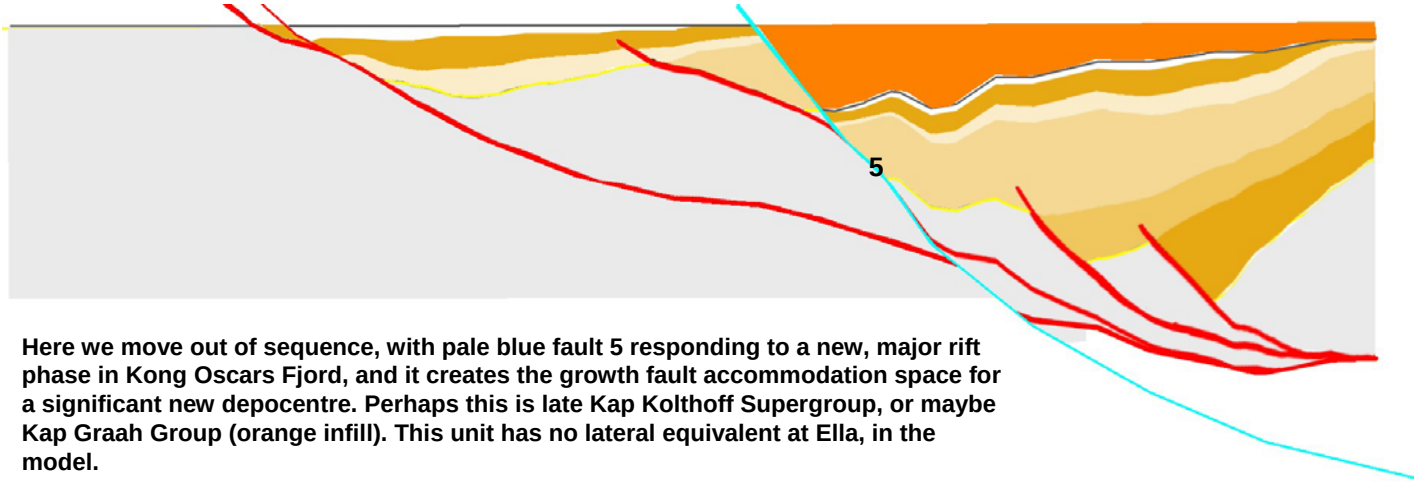
First, if we recognise a divergent pair of markers like 1 and 2, pale blue, the upper bed 2 at the time of its deposition is a regional to bed 1 and the separation of the two beds at the fault defines the heave at time 2. With this value known the next leg of the fault can be drawn, using the same heave. (As the heave is large, this calculated leg is a rather crude approximation).

Another constant-heave, equal-area simple-shear construct can be done, using dark blue as a regional projected from the top of the rollover (smoothed as orange) to the top of the footwall at left, presuming that dark blue does define the Ordovician's top position in pre-fault restoration: and that the movement is entirely in the plane of this section. A-B is the red observed fault, B-C is calculated red assuming the same heave for the next sector. These two versions of the same method are summarised in our website advice notes, in the extension/inversion module.

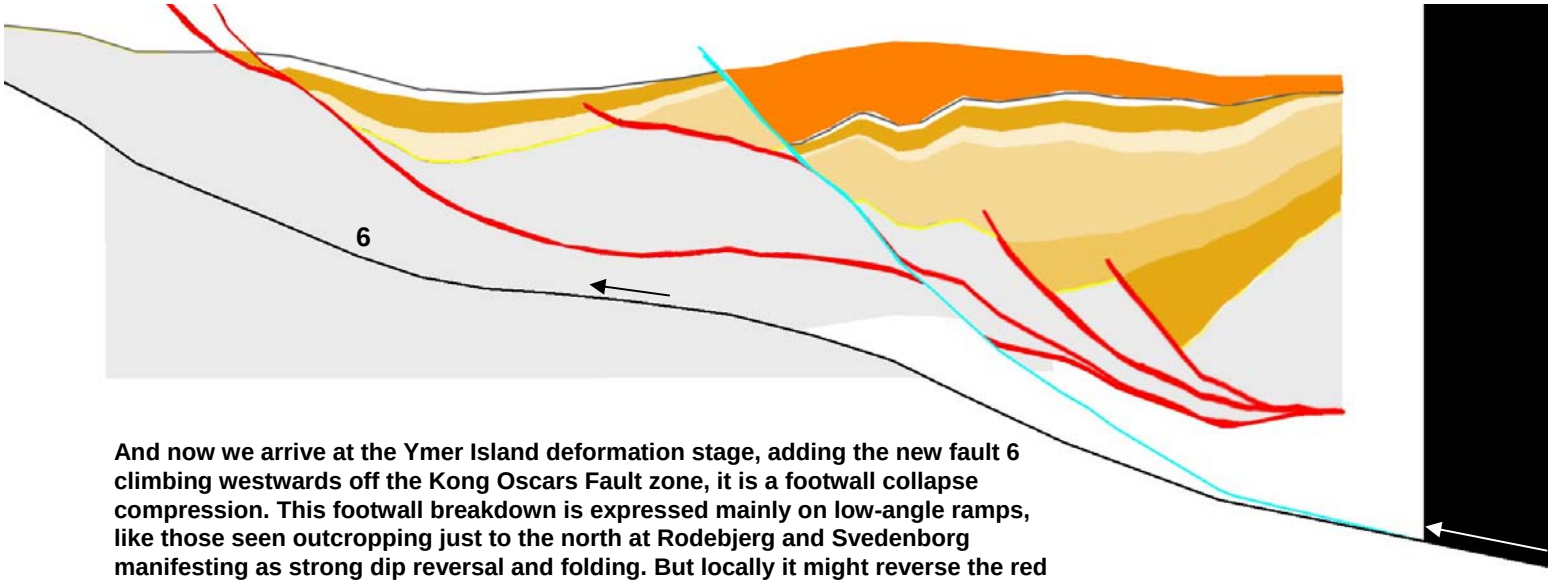


How might a cross-section between Ella Island and Kong Oscars Fjord be plausibly drawn? This is one possible sequence of Middle Old Red progressive fault growth and sedimentation, operating initially in the main rift and gradually propagating westwards to Ella in the order shown. All this sediment might be early to mid-stage Kap Kolthoff Supergroup. The evolving geometries presume 2D equal-area simple shear, syn-sedimentary infill is controlled by shape, spacing, and the amount of movement on the red surfaces which are growth faults, they switch off in turn, in this model, but an alternative is that they operated more or less together.

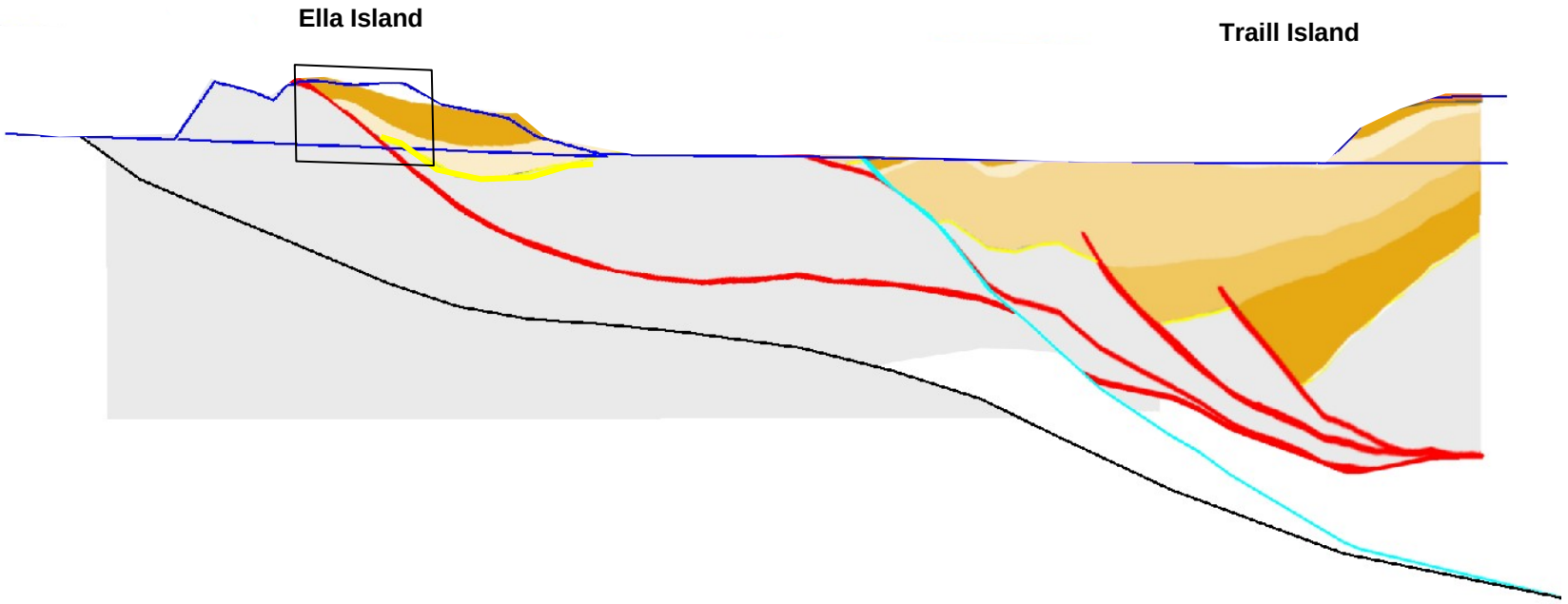
So, this model by fault 4 time would have the Givetian Ella depocentre established a few million years later than the mid-fjord, middle Devonian axial fans, which are exposed today in Kongeborgen's cliffs and are not readily correlated back to Ella.



Here we move out of sequence, with pale blue fault 5 responding to a new, major rift phase in Kong Oscars Fjord, and it creates the growth fault accommodation space for a significant new depocentre. Perhaps this is late Kap Kolthoff Supergroup, or maybe Kap Graah Group (orange infill). This unit has no lateral equivalent at Ella, in the model.



And now we arrive at the Ymer Island deformation stage, adding the new fault 6 climbing westwards off the Kong Oscars Fault zone, it is a footwall collapse compression. This footwall breakdown is expressed mainly on low-angle ramps, like those seen outcropping just to the north at Rodebjerg and Svedenborg manifesting as strong dip reversal and folding. But locally it might reverse the red faults where their dips are flatter. It is a regional uplift, effecting the erosional removal of Old Red along the west margin of the Devonian basins. It imposes the easterly dip of the Old Red at Narhvalsund, the erosion of Old Red there, and loss of orange Kap Graah equivalent sequence immediately south of Sophia Sund.



Its sobering to consider the constraints suggested by this model, in making lithostratigraphic correlations of the Middle Devonian sequences exposed on opposite sides of the East Greenland fjords and glaciers.

Highly detailed published studies of sedimentary environments of deposition and palaeocurrent directions don't give stand-alone answers to Old Red basin development: such work must be based on and go together with effective structural analysis, to validate its conclusions. To reliably relate sequences which are separated by 5-10 km gaps between outcrops, we need to know the controlling syn-sedimentary fault positions, their shapes, and their displacement histories: which of course is information we are not likely to have unless there is seismic available, and we know how to pick it. Otherwise, its guesswork.

Typically, there is a general correlation challenge for nearly all of the East Greenland Devonian sequences. Mount Celsius Supergroup, which has very distinctive formations, is the only exception. Even where excellent continuous outcrop is available, its still a demanding exercise to interpret lateral variation of sequence and to convincingly relate successions from place to place. The same is true of other Old Red Basins, such as the Inner Moray Firth of UK, and that's a topic we will explore in further blogs.