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Hugh Miller the elder and the younger, a geological dynasty enabling a re-interpretation of the Middle Devonian fish-bearing beds of Cromarty.

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Abstract: The Victorian stonemason and polymath Hugh Miller's seminal 1841 book *The Old Red Sandstone* continues to attract critical acclaim due to its engaging delivery to the reader, of the science of geology as it was then understood, in eloquent and descriptive prose. Since Miller's time the study and elucidation of geological data has become far more sophisticated and focussed but due to the comparative lack of rigour in the formative years of the science some of his explanations of the Middle Devonian geology and palaeontology of Cromarty, have either become misunderstood or would benefit greatly from a refresh. Here we a provide a chronology of Miller's early discoveries and his evolving understanding of Cromarty geology and how it impacted his contemporaries, and subsequent researchers and the history of geological science. In particular the work of his son, as a surveyor with the British Geological Survey is described in the context of his role in Cromarty geology. We re-evaluate the literature which, in concert with fieldwork dating back to 1991, provides an up to date reconciliation of the Middle Devonian geology of the Cromarty area generally, including its historically and scientifically important fossil bearing fishbeds.

The Middle Devonian fossil fishbeds, ~382-393 million years old which are exposed in the Cromarty district of the Black Isle, about 25 km NE of Inverness (Fig. 2a), are internationally renowned for their historical and scientific importance and were extensively researched by the Victorian stonemason, accountant, devout Presbyterian, editor and avocational geologist, Hugh Miller (1802-1856). (

Miller's early career was that of a stonemason, having turned down the opportunity to further his schooling. However ill health caused by inhaling rock dust forced him to assume the post of accountant in the local bank in Cromarty, collecting fossils and writing in his spare time. Such was his esteem as a writer and Free Church of Scotland supporter that he was subsequently appointed editor of the *Witness* newspaper in Edinburgh. His fossil collection is largely housed in the National Museums Scotland (NMS) in Edinburgh.

Miller's work, especially his landmark 1841 book, *The Old Red Sandstone,* although scientifically outdated, remains historically important and recent accounts of his achievements and career have been published. For a biography and photograph of Miller see Taylor (2022). Taylor and O'Connor's invaluable critical study and edited facsimile copy of The *Old Red Sandstone* (Henceforth referenced as Miller 2023) is particularly recommended for consultation generally, while specific references are provided in the text below.

Objectives of the Present Study.

The present study undertakes to focus on the timeline of Miller's geological and palaeontological interpretations in order to elucidate Miller's evolving understanding of the scientific aspects of his work, with the aim of correcting misinterpretations of his geological writings that have crept in to our understanding over the years. The authors aim to do this by reconciling a re-appraisal of Miller's primary publications in the *Witness* newspaper (Miller 1840, 1845) with later accounts (e.g., Miller 1835, 1841, 1849, 1858, 1859) and thereafter with other expert analysis of the fishbeds of Cromarty. A key objective of the present work is

to clarify the chronology of his emerging scientific understanding in the period 1830-1845 which lead to publication of *The Old Red Sandstone* in 1841 (Miller 2023), culminating in the posthumous issue of *The Cruise of the Betsey with Rambles of a Geologist* (Miller 1858) and *Sketchbook of Popular Geology* (Miller 1859). Miller's influence on the work of subsequent researchers is also discussed. It is particularly surprising to note that no excursion guide or memoir has been published to date.

Despite Miller's work (Miller 1835, 2023 [1841], 1854, 1858, 1859) , emerging at a time crucial to the establishment of Devonian stratigraphy of Scotland, Miller himself cannot be regarded as an accomplished stratigrapher and did not claim to be, producing only outline geological sections, some confined to text descriptions (e.g., Miller 1841, pp. 30-33), and therefore the present study will avoid detailed analysis of his outline stratigraphy, but see 'Further Work' below.

Other Authors Contributions

The work of 20th century authors, some unpublished, will be re-examined in order to elucidate their relevance in the history of discovery and examples are summarised below.

The British Geological Survey (BGS) performed surveys in 1885 and 1969 and produced maps with varying resolution and detail (BGS 1889, BGS 1913 and BGS 1973).

The retired BGS geologist Benjamin Neeve Peach (1842-1926), while preparing a guide to the display of Hugh Millers collection in the Royal Scottish Museum, now National Museums of Scotland (NMS), consistently stated (Peach 1919-1920; Peach *et al.* 2017, pp. 381, 399) that they were collected from 'Old Red Sandstone cliffs' on both the north and south sides of the Cromarty Firth. Miller (2023) himself made no specific reference to collecting from cliffs, only from the beach exposures. Today the topography above the Cromarty Foreshore (South Sutor) adjacent to the Moine inlier is more akin to a hill rather than a cliff and is largely masked by woodland. The position on the Nigg Foreshore (North

Sutor), where Miller also collected, exhibits clearer topography and a partially exposed cliff is present which exhibits outcrops of Old Red Sandstone all the way to the top as recorded on BGS maps (the most recent being BGS 1973) which can still be seen and may facilitate reconciliation of Peach's statements.

Significant studies of fossil plant spores from Cromarty have been produced since Miller's time (e.g., Richardson 1960; Wellman 2022). One of these accounts however, (Richardson 1960) contains misleading stratigraphical data.

Hemmings' (1978, p. 9) provided a palaeontological account alluding to the locality from which Miller's type specimens of the armoured fish *Pterichthys* (Miller 2023, vol. 2, pp. 46-53, pls. I and II) were collected. Hemmings gave the general locality as the 'Cromarty Foreshore, 400-800 m east of Cromarty village', which requires further clarification.

Ross (2002) gave an unpublished sketch map of the Cromarty Foreshore, presumably describing the strata that he saw on that occasion. This is the most accurate description given up to that date but its readership was restricted to excursion delegates, at the author's direction (Ross 2002, p. 2) and is now finally discussed, with permission, below.

Ross and Taylor, in Miller 2023 (vol. 1, pp. A220-221) concluded that Miller's figured specimens in the NMS collection were from the Middle Old Red Sandstone of the Cromarty district including Eathie (Fig. 1) thereby indicating caution that Miller's (2023) use of the term 'Cromarty' in the geological locality sense followed the naming convention for the Cromarty district, in use at the time.

These authors more recent contributions complementing Miller's geological writings from 1835-1859, therefore merit a refresh and re-interpretation with updated information gathered by the present authors, for the benefit of today's Miller enthusiasts, researchers and the history of geology, in preparation for a companion study on the detailed geological stratigraphy of his Cromarty District fishbeds.

Deposition of the Fossil Fishbeds.

At the time of deposition of the Devonian fossil fishbeds, a great continental freshwater lake, or series of lakes named the Orcadian Lake or Lake Orcadie, existed in the area that stretches from the east of Gamrie (Gardenstown) in Abereenshire to the SW of Cromarty through Caithness and Orkney in the north (Fig.2a). The Cromarty, Eathie and Nigg fossil beds contain calcareous concretions that enclose the fish fossils and these were formed when the ancient Lake Orcadie's level rose, and periodically transgressed surrounding alluvial plains, thereby extending the range of its fish population to a shallower near shore environment (See Trewin and Davidson 1999, pp. 538-539 for a detailed account of the sedimentology typical of these beds). The substrate of this area was rich in calcium carbonate (Parnell 1983) which contributed to the preservation of fossil fish within concretions.

The Cromarty beds and all those on Fig. 2a, are correlated on a faunal and stratigraphic level with the deep water area of the same palaeoecosystem preserved in, the fossil bearing flagstones of Caithness, known as the Achanarras Horizon (Eifelian-Givetian) after the classic locality at Achanarras Quarry (Fig. 2a, A; Trewin 1986).

The terms 'nodule' and 'concretion' have come to be used interchangeably, and in this case comprise masses of calcium carbonate (limestone), in some cases exhibiting laminations, which, given the correct conditions, formed around a nucleus, which at these localities can be a plant fragment or fish carcass (Marshall and Pirrie 2013; Fig. 2b).

The Importance of the Cromarty Area Fossil Fish Fauna.

All the Devonian fish fossil localities above record mass mortality events caused by environmental catastrophes (Trewin 1986), that each of which Miller described as a 'platform of sudden death' (Miller 2023 [1841], pp. xxii, 232-236). The fishes however, were not confined to the waters of Lake Orcadie; the Lake was fed by rivers and streams represented by sandstones iwhich were deposited in fluvial conditions. These sandstones, e.g., those seen

at Eathie, Nigg, and at Cushnie farm near Gamrie, contain dermal plates of armoured fishes (Fig. 2c) indicating that at least part of the life cycle of some fishes was spent in the fluvial channels.

The Achanarras Horizon fossil fish fauna includes up to 18 genera of evolutionarily important fishes and an arthropod known from a single specimen, but not all localities (Fig. 2a) yield the entire suite. The Cromarty genera includes for example, the acanthodians (stem chondrichthyans, the group that includes modern sharks, [Burrow 2021]), *Cheiracanthus, Rhadinacanthus, Diplacanthus* and *Orcadacanthus* (previously *Mesacanthus,* Newman *et al.* 2023); the lobefin fishes, *Osteolepis, Gyroptychius*, *Glyptolepis* and the lungfish *Dipterus*; placoderms (extinct armoured fishes), *Pterichthyodes*, *Rhamphodopsis* and *Coccosteus;* and the early ray-finned (bony) fish *Cheirolepis.* In Miller's time (1841) the interrelationships of some of these creatures was still unravelling.

Nigg Foreshore Fishbeds (North Sutor).

The North Sutor fishbeds lie on the north shore of the Cromarty Firth opposite Cromarty village (Fig. 1a. and b.). The fishbeds lie beneath a hill or headland formed by a Moinian granitic and metamorphic inlier. An extensive sequence of Middle Devonian fossil fish bearing strata over ~362 m (1187 ft) thick BGS 1885, BGS 1913) drapes on the metamorphic inlier at a dip angle of ~75 degrees to the west (BGS 1973). The sedimentary sequence is composed of beds of a basal breccia surmounted by conglomerate with an overlying sandstone and are inclined at ~75 degrees throughout their entire thickness. Above these basal beds a succession of calcareous beds interbedded with sandstones can be seen in various places in the cliff. These strata contain at least two fishbeds, one near the base immediately above the sandstone and the other some 97 m (318 ft) above it stratigraphically. Most of the data on the local stratigraphy appears to have been gathered here by Miller (2023, vol. 2). The site was subsequently expertly mapped and published in detail on a large

scale BGS map (BGS 1913), albeit with the omnipresent impediment of transient shingle cover.

Cromarty Foreshore Fishbeds (South Sutor).

Today, the Cromarty Foreshore (Fig. 1) is much as it was in Miller's time. It lies to the east of Cromarty village on the southern shore of the Cromarty Firth and its basal feature is the similar, to the North Sutor, Moinian granitic and metamorphic inlier forming a second hill, the South Sutor (BGS 1973, Fig. 1b). Against this hill a partial sequence of Middle Devonian sedimentary rocks are draped at an angle of <80 degrees, these rocks consist of a basal conglomerate/breccia, overlain by sandstones and calcareous layers arranged in alternating beds, represented by Miller in Fig. 3b. At least one of the lowermost calcareous sequences is an outcrop of a fishbed (Fig. 3a sub zone 3) discussed below.

At ~76 m (249 ft) to the west of the junction of the Moine and Old Red Sandstone conglomerate/breccia, the dip of the beds decreases to ~45 degrees and a short distance further west the strata disappears under a covering of glacial deposits, sand, shingle and seaweed. At around 200 m further west a sub horizontal bed of calcareous shale and mudstone with abundant limestone nodules re-emerges from the shingle, spanning ~200 m to the west, but can only occasionally be seen, typically after a severe storm. This is Hugh Miller's celebrated fishbed from which he collected numerous fossils (Miller 2023, vol. 1, fig. 5).

Eathie Burn to Navity Fishbed Outcrops.

The Eathie locality lies ~3 km SW of Cromarty on the Moray Firth shore (Fig. 2a). Despite this outcrop of the Cromarty fishbed being poorly exposed currently, it is well documented by Miller (2023 vol. 1, fig. 2, Sections 3 and 4; Fig. 4a, Section A-B), and is also expertly mapped by the BGS (BGS 1889, BGS 1913, BGS 1973 and below)., They appear to be exposures of the five lowermost beds (Miller 2023, vol. 1, fig. 2 Sections 3 and 4) in the sequence (Fig. 3a, sub zones 1-5) although this remains to be tested, see below.

The Eathie shore fishbed measures a linear distance of ~1.59 km (0.99 miles) from the mouth of Eathie Burn to NE of Navity Farm Two faulted main outcrops exist (BGS 1913, BGS 1973), one on the beach and one in the cliff above, however they are both at the same horizon due to the connecting strata dipping ~10 degrees to the east, having been eroded out by waves breaking on this platform (Miller 2023, vol. 1, fig. 2, section 3, pp. 205-7). The seaward section of the outcrop can be seen today at low tide but little, if any of the cliff section has been seen in recent times due to overgrowth but future storms and dogged surveillance may provide opportunities. The cliff section was recorded in a ravine, due south of Navity Farm exposed inland in a westerly direction (BGS 1913) and to the SW of this, in the ravine of Eathie Burn, the outcrop could be traced inland in both sides of the Eathie Burn ravine, but is eventually cut off by faults. Miller (Fig. 4a) drew the beds at Eathie as uplifted where they abut the South Sutor from the south.

Miller's Collecting Range and Locality Naming Conventions.

Miller's collecting activities commenced at Eathie where he discovered fossils from the Lias, now upper Jurassic, and moved to the Cromarty Foreshore (South Sutor) in the expectation of finding more Upper Jurassic fossils but instead located Middle Devonian fishbeds. He was only to discover the Middle Devonian beds of the Nigg Foreshore (North Sutor) several years later.

The Middle Devonian sedimentary strata of each foreshore abuts the east flanks of their respective exposure of the unconformable North and South Moinian inlier. These two opposing Moinian headlands (Fig 1b) are together known as the 'Sutors of Cromarty' a term derived from local folklore.

These place names are used interchangeably depending on any necessary local emphasis (e.g., 'Cromarty Foreshore' in place of 'South Sutor' and vice versa).

In particular Miller singled out the central fishbed on the Cromarty Foreshore on the intertidal beach at the mouth of the Coal Heugh Burn (Miller 2023 vol. 1, p. A220; Fig. 2a), as the first found and most prolific Old Red Sandstone fishbed on this foreshore. In Miller's time this burn (stream) was known as Chapel Burn but has transitioned to Coal Heugh Burn due to its tributary feeding from the 18th Century Coal Heugh Well, sunk unsuccessfully for coal. Henceforth this fishbed locality is designated the Coal Heugh Burn Mouth Fishbed and is situated at NH 79539 67249 to NH79596 67258 as surveyed in 2024/25.

Miller's Disparate Geological Writings.

The Victorian period has been proclaimed the heyday of natural history (Barber 1980, pp. 184-206, 225-238) and geology was at its epicentre; Miller was a pivotal character, but his written accounts are today perhaps less accessible to a modern readership rather than his newly enlightened Victorian audience.

The Old Red Sandstone (Miller 2023) is not a fully comprehensive account and Miller's geological output including his important, but rudimentary, early geological sections are contained in various correspondence, books and articles. Consequently, subsequent researchers are obliged to navigate a path which is by no means clear. Perhaps due to this, there remains potential for misunderstandings e.g., Miller's use of the geological locality name 'at Cromarty' and 'in Cromarty' in his frontispiece caption (2023, vol. 1, fig. 2, fig. 5, vol. 2 p. xxi). This has come to imply that he is referring to the stretch of uplifted and inverted strata comprising layers of conglomerate/breccia, sandstones, limestones, and shales with limestone concretions to the far east of Cromarty on the rocky foreshore (Fig. 1).

Miller's findings in the study of geology and palaeontology of the environs of Cromarty have been largely frozen after his death in 1856 (Miller 1858, 1859), although

interest has never waned and his outcrops on the beaches at Cromarty remain a destination for geologists.

Miller's Early Accounts of the Cromarty Fishbed Localities and his 'Huge Spear'.

Miller's correspondence to others (e.g., H.M.L.B. 1840; Bayne 1871), and writing in general, is written in a style which may disorientate a modern reader. None more so than in a letter dated 31st May 1838 (H.M.L.B. 1840, no. 192) to celebrated Swiss palaeontologist Jean Louis Rodolphe Agassiz (1807-1873) (Andrews 1982a, pp. 7-9). Miller magnificently described the rocks from where his fossils were collected thus; 'a lofty promontory resembling a huge spear thrust horizontally into the sea…granitic gneiss forming the head and a long rectilinear line of Old Red Sandstone, the shaft. He went on to write that the Moray Firth lay to the south of this geological headland and the Cromarty Firth to the north, confirming that he was referring to the Cromarty Foreshore or Eathie fishbeds or both. He said that the fossils occurred in 'claystone beds' which occupied an 'upper place' on the sandstone spear-shaft and were underlain by red sandstone 'considerably more than 100yds' (300 ft, 91 m) thick and overlain by yellowish sandstone with a thickness of 60 ft (19 m). Miller went on to write in the same August 1838 letter that the fossiliferous claystone beds each measured 10-30 ft (3-9 m) in thickness. These stratigraphic descriptions present the requirement for interpretation, which is explored below.

Miller's subsequent observation in *The Old Red Sandstone* (2023, vol. 2, pp 108-110, 204-205) that the 'ponderous mass of granitic gneiss forming the head, and rectilinear line of Old Red Sandstone, more than ten miles in length, forming the shaft' appears incongruous. He particularly singled out a topographical ridge which 'runs from the South Sutor….. far interior of the county…..compared in a former chapter to the shaft of a spear', to a modern readership this could be a stretch of the imagination (compare to BGS 1973).

However Miller (2023, vol. 2, p. 109) wrote, while describing the positions of two quarries, which flank the 'shaft' to the north and south, the first of which 'opens on the

Cromarty Frith side of this huge spear shaft' west of Cromarty village, and the other, 'opens on its Moray Frith side' at Eathie. Subsequent BGS mapping (BGS 1889, BGS 1973 and BGS 2007) confirms deposits of Midde Devonian sandstone bedrock shore to shore across the Black Isle and extending more than 10 miles to the SW of the South Sutor. This is witnessed nowadays by the elusive Old Red Sandstone fishbed at Killen Burn, near Avoch, 8 km (5 miles) SW of Cromarty.

A similar locality occurs on both sides of the Kinkell road cutting on the A835, situated 2.2 km SE of Conon Bridge, 27 km (17 miles) SW of Miller's spearhead on the Cromarty Foreshore (2023 vol. 2) of which a section sketch was recorded on the south side at NH566537 in 2002 (RGD) in the company of the well-known fossil fish collector Mrs Jean Hole (1925-2011). Mrs Hole had collected a specimen of *Coccosteus sp*. from this locality as recorded by RGD, at the time of writing a search to locate this specimen is ongoing due to its potential stratigraphical importance.

In March 2025 the present authors revisited the same south side locality and a unique specimen of an acanthodian fish (Acanthodian indet.) frustratingly consisting of broken cross sections of small scales and a fin spine fragment was found in a loose nodule. The matrix of laminated grey limestone with black bone is reminiscent of other Moray area nodules e.g., Cromarty, Eathie and Edderton (Davidson *et al*. 2024).

These data collectively suggest that the geology of the entire peninsula was what Miller (2023, vol. 2, pp 108-110, 204-205), was alluding to, demonstrating his keen sense of observation.

***The Old Red Sandstone* (2023, [1841]) 1st Edition, and 19th Century Biostratigraphy.**

The evolution of *The Old Red Sandstone* (Miller 2023 [1841]) from, among other things, a series of the *Witness* newspaper articles to a fully developed and illustrated treatise is given in Miller 2023 (vol. 1, pp. A86-91, A256 and Appendix 1 and vol. 2). Note that the first edition

of Miller's book of 1841 (2023, vol. 1, fig. 2) contains the original and most accurate geological sections, while some later editions contain errors in the frontispiece.

In the frontispiece to the 1st edition of *The Old Red Sandstone*, Miller gives a set of hand coloured geological cross-section sketches (Miller 2023 vol. 1, fig. 2, Sections 1, 3, 4 and fig. 5) of the fishbed strata. In fig. 5 Miller drew a section labelled 'Lower Formation as Developed at Cromarty' reproduced here as Fig. 3a, along with 2 sections at the nearby outcrop at Eathie. It is interesting to observe that despite Miller's collecting range including the Nigg Foreshore (North Sutor), this locality is not specifically mentioned in these frontispiece sections, but is specifically referenced in the text (e.g., Miller 2023 vol. 2, pp. 30-33).

Miller, in 1841 (Miller 2023, vol. 2) described the stratigraphy of the Old Red Sandstone as Lower, Middle, and Upper formations supported by the evidence of perceived diagnostic zone fossils in a simple biostratigraphy, assembled in ascending but erroneous order. The lungfish, *Dipterus* signified the lower formation, the primitive jawless fish *Cephalaspis* the middle, and the apex predator, *Holoptychius* defining the upper formation (Miller 2023, vol. 1, fig. 2 Section 1, vol. 2, pp. 140-145).

This was in accordance with the stratigraphical doctrine of geologist Sir Roderick Impey Murchison (1792-1871). Murchison's (1839) stratigraphical interpretation of the Old Red Sandstone of England evidently influenced Miller to correlate it with the Old Red Sandstone of Scotland (Miller 2023, vol. 1, fig. 2, Sections 1 and 2, pp. A204-A210, table 4.2). The assignment of *Holoptychius* to the upper formation is correct but Miller's (2023, vol. 1 fig. 2) placement of *Dipterus* in the lower formation and *Cephalaspis* in the middle (Malcolmson 1842) was later established as being the wrong way round, a fact that Miller would subsequently help resolve (Miller 2023, vol. 1, pp. 207-208; Trewin and Davidson 1996, 1999).

More recent work on the relationships of the group containing *Cephalaspis*, the osteostracans, is revealing a more complex taxonomic and stratigraphic situation (Traquair 1893; Janvier and Newman 2005; Keating *et al.* 2012) but none of this had been recognised in the mid-19th Century and does not affect the biostratigraphical situation.

Today the Scottish Old Red Sandstone rocks are known as Lower, Middle and Upper Devonian.

The affinities of the fishbeds of the Cromarty Foreshore have been pondered over since the mid-1800s as shown in Miller's correspondence, e.g., in a letter to Miller of 3rd July 1839 from John Fleming (1785-1857), (H. M. L. B. 1840, no. 200). Fleming expressed annoyance at his own doubts regarding the 'relation of the horizontal fishbeds to the highly inclined sandstones' and wrote that 'I hope by this time that you have satisfied yourself…… having from the state of the beach seen…. the junction of the two series of beds…. or detected the same organisms in the vertical as in the inclined strata'. The lack of sub-horizontal beds on the Nigg Foreshore (BGS 1913), confirms that he is referring to the Cromarty Foreshore and that the understanding at this early juncture was that more than one fossil fish-bearing horizon probably occurred but that their relationships were not well understood.

Analysis of Miller's Early Accounts.

As early as 1830 Miller was recording the sequences of rocks that he saw on Cromarty Foreshore and was to publish this in text, albeit retrospectively in *The Old Red Sandstone* (Miller 2023 vol. 2, pp. 110-115). In the same volume he published his hand-coloured geological cross section of 'Lower Formation as developed at Cromarty' (Fig. 3a), which provides greater relative detail, but unfortunately without a scale. This however, was relatively common practice at the time (Davidson *et al.* 2024).

Miller drew fourteen discrete sub zones (Fig. 3a) but identified only six with letters and numbers, h, g, f 1, 2, 3, and e, as his conglomerate, sandstone bed and interbedded sandstone and shale beds which correlates with his general stratigraphy of the Old Red Sandstone of Scotland (Miller 2023, vol. 1, fig. 2, section 1).

In Miller's 1838 letter to Agassiz (H. M. L. B., no. 192) he described the fishbeds of the Cromarty Foreshore (South Sutor) as part of his 'huge spear'; the red sandstone bed underlying the fossil bearing 'claystones' was given as 100 yards (300 ft, 91 m) thick which does not match any of his later descriptions of the same bed (Tables 1 and 2) and appears to be an extrapolation. There is no sandstone bed of this description at this position on the Cromarty Foreshore which sheds further doubt on his description of the Cromarty Foreshore being the source of his section (Fig. 3a), which is dealt with below.

Miller's Correlation of the 'Cromarty' Fishbeds.

In creating his stratigraphical sketch (Fig. 3a) of the 'Cromarty' section, Miller lettered and numbered the various beds in ascending order as follows, 'h'. The great conglomerate; 'g'. Coarse gritty sandstone; 'f'. A series of 11 alternating bands of sandstones and calcareous beds as follows; 'f 1'. Alternating bands of sandstones and clay containing limestone concretions (labelled the fishbed); 'f 2'. Yellow sandstone; 'f 3'. Limestone and shale resembling fishbeds; The remaining sequence of calcareous and sandstone beds of unit 'f' are not numbered; 'e'. Red Sandstone.

The fishbed sequence at sub zone 3 (Fig. 3a) does not correspond to his 'claystone beds' on the Cromarty Foreshore relayed in his 1838 letter to Agassiz (H.M.L.B. 1840, no. 192). He recounted that they are uniquely underlain by red sandstones whose thickness is 'considerably more than 100 yards' (300ft, 91 m).

The earliest diagrammatic interpretation of the Coal Heugh Burn Mouth Fishbed's relationship to the steeply inclined east beds, was produced by Miller in a letter to

Murchison in either December, 1838 or January, 1839 (H.M.L.B. 1840, no 212) and is given in Fig. 3b. It lacks any horizontal or vertical scale but its proportion and naming of the two streams in the area confirm that it is the Cromarty Foreshore viewed from the north. It bears a close resemblance to Miller's text description (Miller 2023 vol. 2, pp. 110-115), but little to his 'Lower Formation as developed at Cromarty' (Fig. 3a). The two sections (Figs. 3a and 3b) appear to be describing two different localities. It appears therefore, on this evidence that the strata on Cromarty Foreshore (Fig. 3b) as seen by Miller in 1830-1840 and the present authors cannot be totally reconciled with Fig. 3a.

Miller mentions both 'Cromarty' and the 'Northern Sutor' (2023, vol 2, pp. 30-33) in describing the stratigraphy of basal conglomerate thus; 'is represented in the Cromarty section underneath the Northern Sutor' overlain by 'bands of sandstones, stratified clays, and bituminous and nodular limestones'. Miller's sketch (Fig. 3a) may be a composite section, but see below.

Reference to Miller (2023, vol. 1, fig. 2, vol. 2, p. xxii) reveals that the beds exposed at Eathie (beds h, g, and f 1-3) were correlated to the other beds in the area by Miller (2023, vol. 2, pp. 119-120). He does not apply any scale to any of his geological cross-sections (Fig. 3), but also describes a 'Cromarty' section in the text (Miller 2023, vol. 2, pp. 30-33) which is presented in Table 1, 'as represented in the Cromarty section under the Northern Sutor' with a total thickness of <764 ft (233 m). He significantly describes the great conglomerate as 251 ft (77 m) thick and the overlying sandstone as 114.5 ft (35 m) thick (see also Miller 2023, vol. 2, p. 131-132). His text description (Miller 2023, vol 2, pp. 30-33) (Table 1) is vague with respect to the overlying strata and their thicknesses as he groups interbedded layers of 'alternating bands of sandstones, stratified clays and bituminous and nodular limestones', which form a sequence with a total thickness of 355ft (108 m).

Miller's Retrospective Account of the Cromarty Foreshore originally published in the *Witness* newspaper (Miller 1840).

Miller (2023, vol. 2, pp. 111-115) had first, but only briefly described this stratigraphic sequence on the Cromarty Foreshore, as it was in 1830 (Table 3), in the *Witness* in just ~300 words, in his engaging journalistic style (Miller 1840). In contrast his description of the same strata in *The Old Red Sandstone* (2023 pp. 110-117) from which Table 3 is an extract, numbers an augmented ~2,000 words in his pictorially descriptive style, but without adding further geological detail.

Miller (1840) described; the apparently isolated but rich, sub-horizontal exposure of the Coal Heugh Burn Mouth Fishbed in a tiny 'bay' on the beach adjacent to the mouth of the Coal Heugh Burn (Chapel Burn). He went on to describe the angle of dip as 8 degrees rather than 80 degrees (Miller 2023, vol. 2, p. 115) in comparison to the beds abutting the South Sutor and remarked that 'The rocks of the little bay must have lain beyond the disturbing uptilting influence of the granitic wedge', and 'the bed formed the top of the formation' (2023, vol. 2, p. 121), observations that would provide major clues to the stratigraphy in the hypothesis that was to appear later in the *Witness* (Miller 1845) and issued posthumously in *The Cruise of the Betsey* (Miller 1858), but see below. Note that this first edition (Miller 1858) is more conveniently accessed in Miller (2022 edited facsimile copy) and will be referenced accordingly henceforth.

Miller gave differing accounts of the outcrop as 'a patch little more than forty yards square' (Miller 2023, vol. 1, pp. A220), and in his earlier letter to Agassiz (H. M. L. B., no.192) 'hardly more than forty square yards'. He also wrote that the dimensions of this productive outcrop were 'an area across which two average sized (herring?) fishing nets would extend' (Bayne 1871 vol. II, p. 380), this is dealt with below. Over a twelve year period this patch of beach provided Miller with hundreds of specimens.

A Fishbed in Abutment with the Lias at Eathie?

Miller (2023, vol. 2, p. 122) stated that he found an Old Red Sandstone Eathie fishbed 'in conjunction with the Lias', and underlying it, but did not name its precise locality, which may show this. In *The Cruise of the Betsey* (2022, pp. 171-173) it is recorded as 'a bed that abuts on the Lias' and intriguingly remarked that it was at a higher level than the other Eathie Devonian fishbeds.

Apparently contradictingly, reference to Figs. 4a and 4b indicates that Miller (ELGNM 1839) extended the Eathie fishbed SW to laterally overlap the position of the 'Lias' outcrop but he stated (2022, pp. 171-173) that this continuous outcrop was the 'lower platform', he did not draw a second fishbed abutting the 'Lias' but he did include a 'Lias' outcrop to the north of the Navity foreshore. No southerly or northerly Old Red Sandstone fishbed abutting the Lias appear on subsequent BGS maps (BGS 1889, BGS 1913, BGS 1973). However, on BGS 1913 a bed is included within the 'Lias' south of Eathie Burn, in the style and pigment used for the fishbed but clearly marked 'LIMESTONE' presumably to differentiate it. An Eathie 'Lias' limestone was described by Miller in *Sketchbook of Popular Geology* (1859, pp. 156-158). For the time being therefore, this purported Old Red Sandstone fishbed abutting the 'Lias' remains elusive.

Miller's January 1839 Letter and Map to Patrick Duff.

Miller produced several hand drawn sketch maps which he sent to various recipients. One of the clearest of which is in the postscript to a letter (Fig. 4a), now in the Elgin Museum (ELGNM) archives, that Miller (ELGNM 1839) sent to his friend, Elgin Town Clerk, Patrick Duff (1791-1861) on 27th January 1839.

This fishbed is illustrated as a pale blue patch on the eastern outskirts of the town on the beach at the Coal Heugh Burn Mouth Fishbed (Fig. 4a and b), which, if the scale of 'one inch to a mile' is applied literally is represented as considerably more than forty yards square

or indeed forty square yards, but may simply be exaggerated for clarity. The same pale blue colour is shown immediately inland to the south over an area which stretches either side of the Coal Heugh Burn (Chapel Burn) indicating that Miller was aware, at this time, of exposures of the fishbed in the grounds of Cromarty House (Miller 2022, p. 326) and adjacent to St Regulus Churchyard to the west and fossiliferous shales in the meadow to the east. Notably, Miller (Fig. 4) curtailed this feature at the eastern formation named 'Inferior Old Red' with no further detail. Interestingly, Miller (2023) does not identify the Coal Heugh Burn Mouth Fishbed as a separate unit in his 'Cromarty' section (Fig. 3a, Tables 1 and 2), it therefore provides insight that Miller's recording of the nature of the various outcrops was still in a state of flux in January 1839.

It seems significant that Miller (ELGNM 1839) did not mark any fish bearing strata on the North Sutor (Fig. 4b), nor the almost vertical beds at the eastern end of the Cromarty Foreshore abutting the South Sutor, only annotating them as 'Inferior Old Red'; importantly, he did not figure his 'Cromarty' section (Figs. 3a and 3b) on his map to Duff. The fact that he marked only two fishbed localities is explained by him not yet having resolved the detailed geology of the other areas and that he was still working out their affinities, as explained below.

At Eathie Burn and Navity Shore, collectively known as Eathie, Miller (Fig. 4b) implements the same blue pigment to describe the fishbed in the intertidal zone, confirming that the use of blue pigment was deliberate and confined to the fossiliferous beds. Miller shows two parallel fishbed outcrops along the coast at these localities, one in the cliff and one in the intertidal zone in Section A-B (Fig. 4a). These are described above as one and the same, the intervening outcrop having been eroded out by wave action (Miller 2023, vol 1, fig. 2, Section 3 and vol. 2, pp. xxii, 205-207).

The southern extent of the fishbed is not clear from Miller's (ELGNM 1839) map but both the later BGS 1913 and BGS 1973 maps curtail the fishbed within a series of faults in the ravine of Eathie Burn.

Section of the Nigg Foreshore (North Sutor) published in 1859.

According to John Grant Malcolmson's (1802-1844) memoir of the Moray Firth areaMiller furnished the details of a section at the North Sutor (Malcolmson 1859, p. 352, unlabelled table) reproduced here in Table 2. Malcolmson claimed 'The following section on the south side of the North Sutor of Cromarty for which I am indebted to my friend Mr Miller' the timing of this must have been late 1839/early 1840, before Malcolmson left Scotland forever in spring 1840. Since Miller only discovered the Nigg Foreshore fishbed in winter 1839 (Miller 2023, vol. 2, p. 131-133), the coincidental timing of these events, therefore would have been a challenge, especially as Malcolmson's paper was finished on June 4th and read on June 5th 1839 to the Geological Society of London (GSL) (Andrews 1982a, p. 24).

Despite 'finishing' the paper in 1839 Malcolmson had intended to continue working on the final draft in early 1840 in London (Andrews1982a, p. 26) and it could have been in this period that Miller's section (Table 2) was appended to the original manuscript, however there is no record of this.

Disappointingly, the provenance of Malcolmson's (1859) paper is shrouded in controversy (for a full account please refer to Davidson *et al.* 2024, pp. 2-3). Malcolmson's original manuscript lodged with the BGS in 1839/40, was seriously mishandled and finally three versions of the paper were published (Gordon 1859; Malcolmson 1859; Wallace 1921), none of which were complete and only the most decimated version (Malcolmson 1859) carried the data in Table 2. However, here too exists conflicting evidence; an editor's note states that a palaeontological appendix to the paper was never prepared but an Appendix containing the data in Table 2 is given in pp. 350-352 (Malcolmson 1859), which, on balance may be an unauthorised inclusion.

This section (Table 2) appears incomplete but contains a little more detail than that of Miller (Table 1) in that the beds of sandstones, stratified clays and nodular limestones are delineated but not given individual thicknesses, but are grouped as about 300 ft (92 m). In comparison to Miller's 'Cromarty' section (Fig. 3a), attempted lithological correlation to sub zones 1-8 including field survey data, indicates that some sub zones are lacking (compare Table 2 to Fig. 3a). There are other differences too; the great conglomerate is given as 100 ft thick (31 m) which is the measurement that he gave for the conglomerate on Cromarty Foreshore (Table 3) and the entire section is only about 500ft (153 m) in thickness; since the thickness of the great conglomerate in both Tables 1 and 2 is claimed to derive from the North Sutor it is difficult to fully reconcile Table 2 with Tables 1 and 3 and the provenance of the data in Table 2 remains unsafe.

Hugh Miller the younger and BGS mapping.

Of particular interest is that the BGS surveyor for the first geological map of Cromarty produced on the Ordnance Survey template (BGS 1889), was none other than Hugh Miller F.R.S.E., F.G.S., (1850–1896), Miller the elder's son; (Peach *et al.* 2017, p. 313, fig. 20).

Original field slips are non-peer reviewed and typically not readily available but can contain the greatest of detail and can be sourced directly from the BGS on request. Miller the younger's field slips for BGS Ross and Cromarty Sheet 94 (BGS 1889; Fig.5; BGS 1885) were retrieved from BGS archives on 19th March 2024 at the request of the authors.

On the Cromarty Foreshore (South Sutor) field slip (BGS 1885) he drew the eastern most fishbed (Fig. 3a, sub zone 3) within a short exposure of folded and uplifted beds (Fig. 5), but with limited detail. At the westward Coal Heugh Burn Mouth Fishbed he annotated that the strata comprised dark red shale passing down into olive green and buff sandstone and clay rich shales. The fishbed he described as 'Psilophyton chiefly in the shales. Fishbed just under bed of stream', *Psilophyton* is a fossil plant taxon. This indicates that at the time of his

survey, the fishbed was not widely exposed. Probably as a result, he did not apply the blue coloured lithology of 'Fishbeds and Psilophyton Shales' (BGS 1889, Legend) annotated to the east. He also annotated 'Psilophyton Beds' a short distance inland in the meadow to the east of the Coal Heugh Burn which would have been under the raised beach deposit of this area.

On his field slip for the Nigg Foreshore (BGS 1885), Miller the younger gives a very detailed text table of the North Sutor fishbed sequence figure in manuscript (ms) form which illustrates 22 beds of breccia, conglomerate, sandstones, shales and calcareous beds, but on the field slip pictorial map itself he reduced this to 14 beds, and this 22 bed ms data is not noted on any successive BGS map, see below. This 22 bed field slip data also presents the earliest demarcation of the breccia and conglomerate beds, indicating '7 ft of breccia at base' (BGS 1885). He marked the beds on the Nigg Foreshore, extending into the tidal zone and the total thickness shown on the Nigg Foreshore as ~368 m (1187 ft) which is considerably in excess of his father's measurement of 282 m (764 ft), see below, and the entire sequence is folded and uplifted to 70-75 degrees angle of dip to the west which is in stark comparison to the similar but truncated Cromarty Foreshore beds abutting the South Sutor.

In 1889, based on Miller the younger's field slips, the BGS produced a 1:63,360 (1 inch: 1 mile) geological map of the area of the Black Isle containing the above outcrops on BGS Ross and Cromarty, Sheet 94, (BGS 1889) an extract of which is given in Fig. 5. This map depicts, for the first time, steeply dipping beds on both the South and North Foreshores but shows only limited stratigraphy on the extreme east end of the Cromarty Foreshore outcrops including basal breccia/conglomerate overlain by an interbedded sandstone and shale sequence with concretions, described in the map Legend as 'Fishbeds and Psilophyton shales'. The remainder of the outcrop is masked by shingle.

On the other hand, the Nigg Foreshore mapping depicts a far more developed stratigraphy with multiple 'Fishbeds and Psilophyton shales' (Fig. 5) outwith the shingle cover.

The Lack of a BGS Memoir for the Northern Area of the Black Isle.

A memoir was produced by the BGS later in 1923 for the adjoining sheet 84 (Horne, J. *et al*.1923) but it only covered the territory of *'The geology of the lower Findhorn and lower Strath Nairn including part of the Black Isle at Fortrose'* it did not extend further north to include Eathie and the South and North Sutor areas, and Miller the younger therefore was not included in the list of contributors.

In 1913 the BGS published a 'County Series' geological map (BGS 1913) at a scale of 1:10,560 (6 inch: 1 mile). Due to its larger scale this map is the most useful guide to the detailed stratigraphy as it was then known.

BGS' Cromarty Foreshore Description.

The eastern fishbed(s) abutting the Moine inlier (South Sutor) and central fishbed on the Cromarty Foreshore, the Coal Heugh Burn Mouth Fishbed (Fig. 6b) are marked on both BGS 1889 (Fig. 5) and BGS 1913 (Fig. 6b), but with no annotations on the steeply inclined easterly calcareous fishbed rendered in blue pigment. The beds intervening between the eastern beds and Cromarty village, including the central Coal Heugh Burn Mouth Fishbed were apparently partly obscured and this bed's position is only alluded to as annotated text on BGS 1913 (Fig. 6b), despite pinpointing it 'just beneath the bed of the stream' on his field slip (BGS 1855). Note that it is marked in slightly different positions on BGS 1889 and BGS 1913. (compare Figs. 5 to 6b). It is interesting to observe that the area containing the fishbed contains structural symbols for convoluted, anticlinal and vertical beds BGS 1913 Legend).

Nigg Foreshore

The map (BGS 1913; Fig. 6a) faithfully reproduces, at the same scale, all the pictorial fishbed sub-zones from the 6 inch: 1 mile field slip of the Nigg Foreshore (BGS 1885). It comprises 14 sub zones of discrete basal breccia overlain by conglomerate, sandstones, shales and calcareous beds with additional annotations of the horizons containing fossil fish remains (Fig. 6a). This correlates convincingly to the 14 sub zone lithofacies of Fig. 3a stratigraphically, witnessed by the detail recorded on his field slip (BGS 1885). One can only speculate whether Miller the younger sought endorsement from his father's stratigraphy (Fig 3a), notwithstanding having seen the outcrops for himself.

Nigg Foreshore Breccia/Conglomerate Anomaly?

Interestingly Miller the younger's configuration of a basal breccia overlain by conglomerate is unique in that it differs to all other accounts (e.g., Miller 2023 vol. 2; Richardson 1960; Armstrong BGS 1973; Ross 2002). On his Nigg Foreshore field slip (BGS 1885) in his expanded 22 beds ms table he listed the lowermost sedimentary rocks as 'Conglomerates: with 7ft breccia at base'. On the 6 inch: 1 mile map (BGS 1913; Fig. 6a) the text annotation 'BRECCIA' is marked at the base of the conglomerate.

John Richardson's 1960 Section.

In 1960 respected palynologist John B. Richardson (1935-2021) published a palynological (fossil plant spores) study of the fishbeds on the Cromarty Foreshore. Richardson's naming of the fishbed localities on his map (1960, text-fig. 2) differs, to an extent, from other authors in delineating the fishbed exposures from which he collected as 'Eathie Burn' and to the north at 'Navity Shore'. At the sub horizontal Coal Heugh Burn Mouth Fishbed on the Cromarty Foreshore he used the name 'Miller's Bay' and the inland exposures to the south of this 'Coal Heugh'. This appears to have been a strategy to clearly identify the outcrops from which he collected. Richardson did not specifically mention the important fishbed outcrop at the eastern end of Cromarty Foreshore as one of his sampling localities, but did mention collecting from 'arenaceous shales of the Cromarty and Navity shores'.

Interestingly, Richardson (1960, p. 47) described the Old Red Sandstone Cromarty beds as 'approximately 150-250 ft (46-76 m) thick in the neighbourhood of Cromarty'. This suggests that he confined his estimate to the eastern beds abutting the South Sutor (Fig. 1, Fig. 6b).

He produced a composite section of four sedimentary units (1960, text-fig. 1) incorporating the biostratigraphy of Westoll (1937, 1951) which, when compared to the 14 sub zones of Miller the elder and the younger (Fig. 3a, Fig. 6a), indicates that his three lowermost beds (1960, text fig. 1, Units 1-3), loosely compare to Fig. 3a, sub zones 1-3 and specifically described his unit 2 with intercalations of red shale that can be observed *in situ* today. Richardson (1960, text fig. 1) includes an 'intercalation of black shale with calcareous nodules' as a thin bed, which he collected from, within a basal breccia (1960, text fig. 1, Unit 1).

However his uppermost beds are incorrect as he places the beds at 'Eathie Burn' and 'Navity Shore' (1960, text fig. 1, Unit 4) higher up in the sequence than the Achanarras Horizon to which they most certainly belong, and which Miller described as a 'lower platform' (Miller 2022, vol. 2, p. 172). Richardson (1960) confusingly correlates these Eathie beds with a stratigraphically younger fish fauna in accordance with Westoll's biostratigraphy (1937, 1951).

BGS' 1973 Revised Map and Some Anomalies.

Miller the younger's map (BGS 1889) was reformatted and partly revised geologically under the auspices of BGS surveyor Matt Armstrong (BGS 1973), assisted by A. L. Harris in their 1969 survey of the area. No memoir to this map was published therefore we are unable to determine further details e.g., how much outcrop was exposed or what was carried over from BGS 1889 or BGS 1913, particularly at Eathie which appears to be a faithful reproduction of Miller the younger's mapping (BGS 1889, BGS 1913).

The adjustments made in the Cromarty area included curtailment of the steeply dipping outcrops on both Foreshores to the high-water mark (Fig. 7) not into the tidal area as Miller the younger did (Fig. 5) and Armstrong also curtailed the exposure of conglomerate/breccia and calcareous beds to the base of the cliff abutting the South Sutor. Whereas Miller the younger had reduced the Nigg Foreshore calcareous beds to 3 units (Fig. 5), presumably due to the 1 inch: 1 mile scale, Armstrong further reduced these to two (Fig. 7). In the map Legend, Armstrong (BGS 1973) designated the near vertical, blue shaded beds 'Fine grained sandstone, siltstone and shale commonly with limestone concretions' indicating concurrence with Miller the younger's description. Both Miller the younger (BGS 1889, 1913) and Armstrong's (BGS 1973) description of these almost vertical, interbedded sequences underscore that these blue coloured linear features are not individual beds as both1 inch; 1 mile maps might suggest at first glance, rather they are interbedded sequences of sandstone and calcareous beds.

Note that the linear nodule bed feature at the east end of the Cromarty Foreshore (Fig. 7) is coloured in the same blue designating 'Fine grained sandstone, siltstone and shale commonly with limestone concretions' but is masked unfortunately, by an Ordnance Survey (OS) major grid line.

Reference to Fig. 7 indicates that Armstrong also made a small adjustment to the sedimentary sequence on the Nigg Foreshore clarifying the transition of the conglomerate to sandstone, compare Fig. 5, and normalised the local angle of dip to 75 degrees. Armstrong, like Miller the younger (BGS 1913), did not make any clarification of a succession from conglomerate to sandstone on the Cromarty Foreshore and therefore did not enter any boundary between the 2 beds, suggesting that this thick sandstone bed was not recognised by either party, (Figs. 5, 7b and 8).

Neither on his field slip (BGS 1885) nor on the 2 subsequent BGS maps (BGS 1889, BGS 1913) did Miller the younger accurately mark the area or position of the Coal Heugh Burn Mouth Fishbed, he only alluded to it by writing 'Fishbed' and 'Cromarty Fishbed' in, or adjacent to, the general vicinity on the beach.

Armstrong, presumably because of better exposure at the time of his survey, deliberately delineated the Coal Heugh Burn Mouth Fishbed, albeit with a dotted line (Fig. 7), as a horseshoe shaped sub horizontal outcrop some 240 m wide as 'Fine grained sandstone, siltstone and shale, commonly with limestone concretions' (BGS 1973, Legend) along with further inland exposures a short distance to the south at a slightly raised topographic level in stream gullies. He also marked the Coal Heugh Burn Mouth Fishbed as a bedrock deposit boundary on Sheet 94, Drift Geology (BGS 1972).

Along with his clearer definition of the Coal Heugh Burn Mouth Fishbed, Armstrong corrected apparent anomalies that Miller the younger made; at a point adjacent to the easterly edge of the Coal Heugh Burn Mouth fishbed (Fig. 6b), symbols had been entered signifying localised 'anticlinal axis', 'contorted' and 'vertical' strata (BGS 1889, BGS 1913, Legend) and Armstrong removed these features which requires clarification.

Armstrong (BGS 1973) depicted the Nigg Foreshore (Fig. 7) conglomerate and overlying fossiliferous beds (Fig. 3, sub zones 1-13) with a total thickness of ~280 m (918ft) which is less than Miller the younger at ~369 m (1209 ft) and greater than Miller the elder at ~232 m (764 ft). The reason for these differing measurements is not clear.

Note that BGS 1889 (Fig. 5) and BGS 1973 (Fig. 7) both being at 1 inch: 1 mile scale are unable to resolve the intricate detail of BGS 1913 (Fig. 6) which, at 6 inch: 1 mile scale allows the six individual fishbed sequences to be rendered. Both the authors of BGS 1889 and BGS 1973 were obliged to combine these beds for illustration purposes.

The Storm of 2002.

In 2002 a major storm stripped the eastern part of the outcrop of seaweed and shingle and presented one of the best opportunities to examine and record on a field sketch the stratigraphy of the apparent lower part of Miller's 'Cromarty' section (Fig. 3a) . In November that year a partial series of beds were well exposed over some 35 m (115 ft) in an east-west direction with occasional less well exposed sandstone and shale beds to the west. A limited amount of the strata could also be seen in the bank at the top of the beach at NH800672.

The sequence was underlain by partly obscured breccia/ conglomerate near the eastern base of the outcrop abutting the metamorphic inlier, the South Sutor, in the region of a localised but uncertain fault boundary (BGS 1973; Ross 2002). Above these basal beds, sandstones, interbedded with shales, mudstones, nodular limestone beds and concretion bands, totalling >17 discrete beds, as exposed at that time were recorded. The exposed strata collectively regarded as or containing, the fishbeds (e.g., Fig. 3a, sub zone 3), were noted within the unobstructed sequence (see also BGS 1973, BGS 1913 and BGS 1889). The beds are upturned to an angle of ~80 degrees at the easternmost (basal) end abutting the Moine inlier, reducing to >45 degrees some 35 m to the west where the beds disappeared in the shingle. Sandstones and shales could occasionally be seen in the moving shingle some tens of metres to the west of the more moderately inclined interbedded units, which presumably represents *in situ* strata higher up in the sequence, see below. There is also some limited similarity in the interbedded layers to Tables 1 and 2 and Fig. 3a (e.g., sub zones 3-8) but the fact that this truncated expanse contains more discrete beds than previously published (Fig. 3a; BGS 1973), suggests that this semblance may be superficial. However, the occurrence of sandstone beds interbedded with shales, mudstones and calcareous bands demonstrates that greater detail than previously recorded, can be gleaned in this foreshortened expanse, drift deposits and seaweed permitting.

Sinclair Ross' Work and Comparison to that of Miller the Elder.

In June 2002, five months prior to our survey the meteorologist and respected amateur geologist, Sinclair Ross (1926-2013) produced an unpublished excursion guide to Ross and Cromarty which covered a large area around Inverness (Ross 2002) from Strathpeffer in the west to Tarbat Ness in the north. Ross included a paragraph of text and hand annotated map of the Cromarty Foreshore (2002, p. 7, fig. 4). Ross' Cromarty text and sketch map are more detailed than any hitherto prepared, but citation by others was prohibited (Ross 2002, p. 2) and permission was sought from the Ross family to cite it in the present study. Ross provided brief annotations on the strata over some 500 m (1640 ft) on his map (2002, pp. 7-8, fig. 4) and described the sequence as 'poorly exposed'.

Taken literally, Ross' description appears to loosely concur with some of Miller the elder's' sub zones (Fig. 3a) but close scrutiny reveals differences. Ross wrote (2002 p. 8, fig. 4) that the near vertical conglomerate(s) grades upwards into sandstones and marly laminated mudstones and shales decreasing in dip angle to 45 degrees to the west.

Note that, as with Miller the younger and Armstrong (Figs. 5 and 8), Ross did not differentiate a thick red sandstone bed overlying the conglomerate (Fig. 3, sub zone 2) implying that he too, did not recognise this bed on the Cromarty Foreshore.

Ross (2002) described the overlying strata as dominated by sandstones (estimated by us to span ~200 m), grading to dominant shales before fining upwards to flat lying mudstones containing fish bearing nodules (Coal Heugh Burn Mouth Fishbed), strata that do not feature on Miller's section, (Fig. 3a) Ross described the intervening sandstones as a mixture of continental and freshwater deposits thus; 'beach, aeolian dune and interdune sandstones as well as fluvial and lacustrine deposits', but gave no direct citation for this.

At the Coal Heugh Burn Mouth Fishbed where Ross (2002) describes the strata as flat lying mudstones and shales containing bands of fish bearing concretions, it was in this area

that Miller the younger's maps (BGS 1889, BGS 1913) contained the curious mapping symbols subsequently removed by Armstrong (BGS 1973). He noted that the fishbed extended 200 m to the east of the Coal Heugh Burn and demarcated it with an oblique dotted line to the SE, and names it the 'Cromarty Fishbed' as Miller the younger did (Fig. 5). It is not clear whether Ross (2002) was able to view the entire fishbed outcrop, although this is quite probable given the prevailing weather conditions in 2002. His ability to provide more detail on the beach along its entire length than other authors implies that the shingle cover was more sparse than usual. His extent of the fishbed contrasts significantly to Miller the elder's description of '40 yards square' (Miller 2023, vol. 1, p. A220). This is the only fossil bearing horizon that Ross mentions.

A Re-Evaluation of Miller the Elder's Evolving Understanding of his Fishbed Localities.

The evidence thus far enables some clarity of Miller the elder's appreciation of the affinities of the Cromarty fishbeds which changed little since 1830 (Miller 2023, vol. 2, pp. 110-111; Table 3). In the postscript to his letter to Duff of 27th Jan 1839 (Fig. 4a) Miller the elder's sketch map (Fig. 4b, extract) contains the Cromarty area fishbeds as he understood at the time, using a pale blue pigment to designate the fishbed only at Cromarty and Eathie. Perhaps crucially, the section that Miller gave in the *Old Red Sandstone* frontispiece (Fig. 3a) does not appear on his January 1839 map (Fig. 4) to Duff, only in his yet to be published book in 1841 (Miller 2023).

In the same letter to Duff (ELGNM 1839) Miller describes the geology of the North Sutor as 'the immense section of gneiss, conglomerate and sandstone exhibited by the 'Hill of Nigg' omitting references to calcareous shales and mudstones. His omission of calcareous shales and mudstones on the Nigg Foreshore indicates that he had yet to examine the North Sutor sedimentary sequence in detail.

Given that both Malcolmson's section (1859; Table 2), provided to him by Miller and the letter and map (Fig. 4), dated January 27th 1839, to Duff (ELGNM 1839) presents a quandary as to why Miller would have communicated two different accounts of the North and South Sutor's stratigraphy to Duff and Malcolmson.

It appears however, that Miller the elder's appreciation of the geology of the area was about to consolidate and that later in 1839, after he sent the letter and map to Duff, he learned the true nature of the North Sutor and South Sutor easternmost fishbed deposits, and that Malcolmson was to be sent the updated information (Table 2) at a later date in 1839.

Clear evidence for the above can be found in *The Old Red Sandstone*, in 1841 (Miller 2023, vol. 2, pp. 110-111). Miller the elder wrote that in August 1830 he set out on an excursion of the Cromarty Foreshore where, near the base of the sequence 'I crossed over strata of an impure grayish limestone and slaty clay abounding, as I long after ascertained, in ichthyolites and vegetable remains'.

Miller the elder's Epiphany.

Miller the elder wrote in *The Old Red Sandstone* (2023, vol. 2 pp. 131-133) of his problem in the early winter of 1839 'the exact place of the ichthyolites was still to fix' and that he was spending a day 'among the nearly vertical strata that lean against the North Sutor'. He went on 'Immediately above the conglomerate there is a hundred and fourteen feet of coarse sandstone…….and then twenty-seven feet additional of limestone and stratified clay' which he had examined some 20 times before 'in vain'; these beds presumably correspond to sub zones 1,2 and 3 in Fig. 3. On this occasion however, he found well preserved fossil fish remains including 'a Coccosteus, well-nigh entire'; he concluded 'I had at length, after a search of nearly ten years, found the true place of the ichthyolite bed'.

This suggests the date of Malcolmson (1859, p, 352; Table 2) receiving the information as winter 1839, immediately after Miller the elder (2023, vol. 2) had worked out a preliminary fishbed stratigraphy of both the North and South foreshores and Eathie.

Despite claiming in *The Old Red Sandstone* (2023, vol. 2, pp.131-133) that in late 1839, he had found the position of the fishbed near the base of the strata (Fig. 3a), it was much later in 1858 in *The Cruise of the Betsey* (2022, p. 171-173) that a reconciliation of the stratigraphy of the entire sequence on the Cromarty Foreshore appeared. This was based on a previously published *Witness* article (Miller 1845). He denoted that there were two fishbeds at different stratigraphical levels; the eastern inclined interbedded sandstones and shales were at a lower horizon than the Coal Heugh Burn Mouth flat lying shales and mudstones. As far as we can determine, no stratigraphical cross-section and no justification have come to light in the course of the present study, he simply made a statement lacking his usual diligence which therefore, should be regarded as a draft hypothesis for the time being. Notwithstanding the fact that he had identified the fishbed near the base of the sequence in 1839 (Miller 2023, vol. 2, pp. 131-133), he did not find the upper fishbed, on the Nigg Foreshore, until 1843 (Bayne 1871, Vol. II, pp. 378-379) allowing him to piece together his correlation of the Nigg Foreshore fishbeds with those on the Cromarty Foreshore and Eathie, which requires further testing.

The Development of Miller the elder 's Palaeontological Understanding.

Miller the elder 's (2023) struggle with the affinities of the armoured fishes now known as *Pterichthyodes* and *Coccosteus* are well documented (Austen and Austen 2014, pp. 26-35; Andrews 1983, pp. 22-23) but little known other facets of the protracted, unravelling nature of the evidence being studied by Miller the elder (2023) were his wranglings with the fossil acanthodian fishes *Acanthodes*, *Cheiracanthus* and *Diplacanthus* (Miller 2023, vol. 1 pp.

A185-6, vol. 2, pp. 88-93; ELGNM 1839). *Acanthodes* and *Cheiracanthus* both sport single dorsal fins, but *Diplacanthus* belongs to a dual dorsal finned family of acanthodians called the Diplacanthidae, or diplacanthid fishes (Burrow *et al.* 2016). The first clues lie in Miller's 1839 letter to Duff (ELGNM 1839) where he described some new fossil fish finds and compared them to the acanthodian fish *Acanthodes* (ELGNM 1839, pp. 2-3), a number of which he wrote were in his collection. The genus *Acanthodes* has been assigned to many species worldwide (Burrow 2021, pp. 70-76), but current understanding is that it does not occur in the Middle Old Red Sandstone of Scotland. However in Miller the elder's time the name had been attached to the smallest of the Scottish acanthodian fishes and was later formally described as *Acanthodes pusillus* by Agassiz (Agassiz 1844).

Somewhat tortuously, Miller the elder (ELGNM 1839) described to Duff a newly discovered acanthodian fish, found up to then only as fragmentary remains, the affinities of which he seemed to struggle with. Despite seeing that it possessed two dorsal fins and robust pectoral bones, typical of the Diplacanthids, he finally identified it not as *Acanthodes* but, for obscure reasons, as *Cheiracanthus* (ELGNM 1839, pp. 3-4), to which it bears only a superficial resemblance.

There are several species of the acanthodian fish, *Cheiracanthus* at the Achanarras horizon, each of which consistently has a single dorsal fin and longitudinal grooves on their scale crowns (Burrow 2021). *Cheiracanthus flabellicostatus* is one of the rarest and is known in the Cromarty fishbeds from a single specimen (NMS G.2019.14.36) collected by one of the authors (S.D.J.).

In the 1839 letter to Duff (ELGNM 1839, p. 7) Miller described another specimen; thus, 'I picked up…. another specimen of *Cheiracanthus* [sic] which shows me much better than the first the nature of the scales. They are minutely furrowed like those of the *Acanthodes* [sic] but the 'furrows' instead of running longitudinally, are concentric. The scale too is a smaller one'. His observation that the scale crown grooves were concentric, more

correctly described as radiating laterally (Fig. 8a), indicates that this is not *Cheiracanthus* rather it is a member of the Diplacanthids, in this case being the species *Diplacanthus crassisimus* due to it being unique in the Scottish Old Red Sandstone in having lateral grooves on its scale crowns.

It appears that in 1839, Miller had not yet recognised *Diplacanthus* as a different genus, but sometime between 1839 and publication of *The Old Red Sandstone* he became aware of the differences, as he published his admission of mixing the single dorsal and dual dorsal finned forms up (Miller 2023, Vol. 2 p. 117) along with a figure of a specimen (2023 vol. 2, pl. VIII, figs. 2 and 4) as 'NEW' and 'Ichthyolite not yet furnished with a name'.

The original specimen that Miller the elder figured in 1841 (Miller 2023 vol. 1, fig. 48) is in the NMS (NMS G.1953.4.4) and bears a label annotated by Miller 'First specimen of Diplacanthus ever found', ironically however, he had unwittingly discovered it from fragments in 1838/9 and for some reason mis-identified it to Duff (ELGNM 1839) as *Cheiracanthus*. Later, in 1842, Duff was to provide a preliminary description of *Diplacanthus crassisimus* (Duff 1842, pl. 10, fig. 2) but with erroneous scale crown morphology for the species, evidence that other early workers were experiencing the same pitfalls.

By 1841 Miller the elder appears to have honed his analytical skills e.g., in *The Old Red Sandstone* he observed that fossil fish specimens of the same age as the Cromarty fauna, that he saw from Lethen Bar, SW of Nairn, (2023, vol. 2 pp. 254-255) were preserved in hues of purple, red and white 'from the presence of iron' (Davidson *et al.* 2024, p. 3, fig. 2). He compared these to the differing colouration of the Cromarty fishes ' I need hardly add…..that all this variety of colour is, like the unvaried black of the Cromarty specimens, the result…..of a curious chemistry' (Davidson and Trewin 2005).

His descriptive skills, articulating histological descriptions and supplanting the word 'furrows', while elucidating the scale crowns, for the more scientifically descriptive 'striae'

(Miller 2023, vol. 2, p. 91) indicates increasing familiarisation with anatomical description. He may also have gained access to more advanced optical technology as he had acquired a more accurate appreciation of the affiliations of *Cheiracanthus* and published a set of drawings of a specimen (Miller 2023 vol. 2, pl. VII, figs. 1 and 2; NMS G.1953.4.2) with quite distinct scale crown morphology, although Miller did not give the species name. His descriptions of both *Cheiracanthus* and the unnamed Diplacanthids (Miller 2023, vol. 2, pl. VIII, figs.1, 2, 3 and 4) now carried morphological and histological descriptions (Miller 2023, vol. 2, pp. 89-94) of scales and fin spines and pectoral and head bones, much more insightful than in his letter to Duff (ELGNM 1839).

In 1841 (Miller 2023, vol. 2, p. 91-92, pl. VIII figs. 1 and 3) describes another specimen of a Diplacanthid (NMS G.1953.4.3) found 'about 3 years ago' indicating 1837-8. The signature character of the Diplacanthids, the presence of two dorsal fins, is present but Miller the elder describes the scales as 'like that of the *Cheiracanthus* with minute scales, of the same scallop like pattern' and provides a figure. Here we find evidence of Miller the elder's early, but understandable, limited anatomical appreciation of the acanthodian fishes group as a whole (Fig. 9), and the confusing nature of acanthodian scale morphology presented to the earliest workers, as scales can present upside down or in a damaged condition and differ in size and morphology according to the position on the creature's body from where they originate.

Whereas many worldwide species of acanthodian scales are bestowed with longitudinal patterns, or striae (Burrow 2021; Young 1995) on their scale crowns, which appears to be a derived hydrodynamic feature, there are subtle variations that contribute to species diagnosis. For example in the case of *Cheiracanthus murchisoni* the thin striae can number typically twenty on a scale crown (Burrow 2021, p. 68, Fig. 30, A) but Miller's diplacanthid fish (Miller 2023, vol. 2, pl. VIII, fig. 3) exhibits only 9-12 which is significant today in acanthodian fish taxonomy (e.g., Fig. 8c). This fish was published by Miller again un-

named and as 'NEW' (Miller 2023, vol. 2, pl. VIII, figs. 1 and 3) and was to be erected later in 1844 as the species *Rhadinacanthus longispinus* by Agassiz (1844), based on Miller's discoveries.

A third Diplacanthid fish occurs at Cromarty; *Diplacanthus tenuistriatus* exhibits a modified scale crown morphology the type of which was not figured or alluded to by Miller. This fish is the rarest of the Diplacanthids and was only described in 1894 long after Miller's death. Despite Miller (2023) not recognising or encountering this fish as a separate form it may have, in the mix, contributed to his confusion.

To observe that Miller the elder was confused is no criticism however, as witnessed by Duff's own confounding of scale crown morphology of *Diplacanthus crassisimus* in his description of the species (Duff 1842, pl. 10, fig. 2). If we examine the convoluted evolution of the naming of the smallest of Middle Devonian Scottish acanthodians, *Acanthodes pusillus,* (Agassiz 1844), which ensued long after Miller's death we find an iterative timeline of taxonomical description familiar to a modern palaeontologist.

In 1861, Baronet, MP and palaeontologist Sir Thomas Malpas de Grey Egerton (1806-1881) named newly discovered specimens of the form as *Acanthodes Peachi* and *Acanthodes coriaceus* (Egerton 1861a, b.). Subsequently, Scottish palaeoichthyologist Ramsay Heatley Traquair (1840-1912) considered there were enough character differences to place *Acanthodes pusillus* in a new genus, *Mesacanthus* (Traquair 1888). Traquair deduced that there were only two valid species, *Mesacanthus pusillus* and *Mesacanthus peachi,* the situation remained thus until the 20th Century when others raised doubts over this speciation (Trewin and Davidson 1999; Baron 2015). After a morphological and histological re-appraisal Newman *et al.* synonymised *M. pusillus* and *M. peachi,* not as a single species but in a new genus, *Orcadacanthus pusillus* (Newman *et al.* 2023). Hence from Miller's time until the

present it has taken almost two centuries to consolidate the presently understood relationships of this little fish.

Past Inconsistencies in the Expanse of Miller the Elder's Coal Heugh Burn Mouth Fishbed.

Miller the elder (1854, p. 503) described the western Coal Heugh Burn Mouth Fishbed (Fig. 7) interchangeably as a patch approximately 40 yds square or 40 square yards confusingly suggesting either an area of 40 sq. yds or 1,600 sq. yds, and also described it in 1841 as being surmounted by an erratic boulder, weighing a few tons (Miller 2023, vol. 2, pp. 86-91) (Fig. 3b) which he used as a rustic anvil and desk to process his nodules, which can still be seen today. Miller the elder also drew the fish bed in a blue pigment on his letter to Duff (fig. 4a) and to Murchison (Fig. 3b) both of which appear to be greater expanses than his written estimates. Quite what the reason is for Miller the elder's use of two widely differing measurements and even suggesting it being exhausted ten years after he left Cromarty is unclear (Miller 1854, p. 503) but moving seaweed and shingle cover is a probable factor as he described in *The Old Red Sandstone* (Miller 2023, pp. 113-114, 116).

Miller the younger (BGS 1889, BGS 1913, Fig. 5) did not draw this western fishbed using the blue coloured bed symbol he used for 'Fishbeds and Psilophyton Shales' to the east (BGS 1889, Legend); instead he indicated its position 'CROMARTY FISHBED' (Fig. 5) so it is unclear what he regarded its dimensions to be and that all or most of it may have been obscured by shingle during his survey, as witnessed by the note on his field slip (BGS 1885) that the fishbed was only visible just under the bed of the stream.

Armstrong (BGS 1973; Fig. 7) elaborated, depicting it as a ~240 m wide, horseshoe shaped sub horizontal bed of 'sandstones, siltstones and shales with limestone concretions' (BGS 1973, Legend) with an uncertain boundary along with another exposure of the fishbed in the stream cuttings adjacent to St Regulus graveyard a short distance inland to the south

(Fig. 7). It appears that Armstrong mapped this west Foreshore bed directly and that a considerable area of the outcrop was detectable at the time of his survey.

Ross (2002, pp. 7-8, fig. 4), in turn augmented Armstrong's (Fig. 7) interpretation and described the east beds on the Foreshore as 'almost vertical' where the conglomerate abuts the metamorphic inlier, grading westwards into sandstones and marly shale which 'dip west at 45 degrees' and finally 'flat lying shales with concretion bands' at the Coal Heugh Burn Mouth Fishbed. It appears that Ross may have seen much of the outcrop directly due to a temporary absence of shingle related perhaps as a result of the storm that year, as he somewhat precisely gave it as ~200 m in a west-east direction and his observation that this was a good place to collect fossiliferous concretions.

The inconsistency in measurements of the Coal Heugh Burn Mouth Fishbed by the four authors above appears to be, in part, due to storm controlled transient shingle and seaweed cover through the years.`

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The Provenance of Miller the elder's 'Lower Formation as Developed at Cromarty'.

One of the main drawbacks to interpretation of Miller the elder's section (Fig. 3a) is that in his stratigraphic sketches, he gave no scale and apparently estimated relative thicknesses of some of the beds that he drew.

The caption that Miller the elder applied to his 'Cromarty' section (Fig. 3a) has led to confusion and misunderstanding to some workers over the years as to the exact locality that this section represents. The section clearly contains 14 sub zones of strata (Fig. 3a); in naming it 'Lower Formation as Developed at Cromarty' the implication can be taken is that this is the strata on the Foreshore to the east of Cromarty village, which it only superficially resembles.

These beds are confined to a limited expanse to the east abutting the metamorphic inlier, the South Sutor; the remainder of the strata inferred on Miller the elder's section (Fig. 3a) is obscured by shingle beyond the sequence to the west (NH 800627) and only sub zone 1, the basal breccia and conglomerate and perhaps sub zone 3, the fishbed, (Fig. 3a) can be correlated with hesitation.

Miller the elder's vivid description (Table 3) illustrates that the stratigraphy he described on Cromarty Foreshore does not match Fig. 3a, or Tables 4 and 5, the detail at Table 3, unit ii. being much thinner and v. and vi. being absent in all cases.

Miller the younger was to update his father's early work and his field slip (BGS 1885) contains a comprehensive manuscript (ms) section of the Nigg Foreshore succession (Table 4) with discrete beds broken down into individual units. Table 4 demonstrates that, in his BGS 1885 survey, Miller the younger recorded 22 separate units including beds between 1-9 ft thick on the ms section.

Miller the younger recombined some of these thinner beds while retaining a similar total thickness of the strata, resulting in fourteen sub zones and transferred this on to his field slip map in diagrammatic form at the 1:10,560 (6 inch: 1 mile) scale, which is tabulated in Table 5. This interpretation was subsequently upheld by the BGS, at the same scale, and published on BGS 1913 (Fig. 6).

Miller the Elder's Resolution of the 'second platform of death'.

On 19th July, 1843 Miller wrote in a letter to his wife Lydia (Bayne 1871, pp. 378-379) that on a return visit to Cromarty, while prospecting in the rocks of the Nigg Foreshore 'I discovered today in this section that there are two platforms of death equally abundant in organisms, the one 318 feet above the other'. Notwithstanding that this is apparently uncorrected for the local dip angle to the west of 75 degrees, this is a relatively precise measurement given Miller the elder and his peers' predilection for looser measurements (Fig. 3, Tables 1 and 2)

or even estimates. The existence of this second fishbed was a revelation to him as two years before, in 1841, he had published *The Old Red Sandstone* (Miller 2023, vol. 2) with only one such 'platform of death' in his stratigraphic column (Fig. 3a, sub zone 3).

Miller the elder published this new discovery later in the *Witness* (Miller 1845, paras. 1-6) but without geological cross sections, only in text. In the compendium volume *The Cruise of the Betsey,* issued posthumously in 1858, Miller the elder reproduced the *Witness* article (Miller 1845) without further elucidation.

The Cruise of the Betsey Editing Issues?

The 1858 compendium of *Witness* articles *The Cruise of the Betsey* (Miller 2022) was edited by the geologist and Reverend W. S. Symonds (1818-1887) a friend of the Miller family, living in Malvern, Worcestershire. Symonds stated (Miller 2022, preface, p. i- ii) 'The style and arguments of Hugh Miller are peculiarly his own that I have not presumed to alter the text'. He then went on to write that he had 'corrected some statements incidental to the condition of geological knowledge at the time this work was penned'. which appears to infer a significant contradiction. He also wrote that he had 'expunged *some* passages', an apparent, but not conclusive, reference to Miller's content on the Disruption of the Church of Scotland. However due to the near verbatim reproduction of the witness article (Miller 1845) in *The Cruise of the Betsey* (Miller 2022) this particular passage of geological description appears unaffected.

By the time of preparing the manuscript for *The Cruise of the Betsey* (2022), Miller the elder claims, somewhat cryptically, that he had resolved the position of the two 'platforms of death'. He stated that those in 'the immediate neighbourhood of the town', presumably the Coal Heugh Burn Mouth Fishbed, which he regarded as 'the top of the formation' (Miller 2023, p. 121) along with 'a bed that abuts on the Lias at Eathie' belong to the upper platform (Miller 2022, pp. 171-3) while those which appear in Eathie Burn and

along the shores at Navity ‘belong to the lower’ without further explanation of his deduction. Confusingly Miller (2022, pp. 171-3) appears to omit from his hypothesis, the position of the important Cromarty Foreshore fishbed (Fig. 3, sub zone 3) in the eastern steeply dipping strata. This is not an editing issue and could be an oversight stemming back to the 1845 *Witness* article.

Subsequently, Miller the younger (BGS 1913) delineated six calcareous horizons on the Nigg Foreshore (Fig. 6a) as his father did (Fig. 3a). The occurrence of a body fossil of *Cheiracanthus* and a fish coprolite in Miller the younger’s sub zone 18 (Table 4) may shed light on the position of Miller the elder’s second fishbed some 318 ft above the known fishbed (Fig. 3, sub zone 3). With the caveat that Table 5 has undergone correction, with some beds having been recombined, but total thickness remained effectively unchanged, the thickness between the fish bearing beds, sub zone 3 and sub zone 18 is ~328 ft, a significantly close concurrence between father and son’s measurements. Given that this is correct, Miller the elder’s ‘second platform of death’ (Bayne 1871, vol. II, pp. 378-379) can be tentatively correlated with the western tunnel excavation detailed above and with either sub zone 11 or 13 on Table 5 and sub zone 11 or 13 near the top of Fig. 3a.

These omissions and obtuse references along with a lack of a formally described section demonstrating both lower and upper platforms, underscores the requirement that Miller’s draft stratigraphy remains hypothetical and unproven until further field work and detailed stratigraphical analysis confirm this, or otherwise. See ‘Further Work’ bel **below.**

Nigg Foreshore (North Sutor) Reconnaissance 2013.

In a transcript of an email from the late N. H. Trewin (N.H.T. to R.G.D. July, 2013) Trewin described the strata observed during reconnaissance of the Nigg Foreshore as ‘very different from that on the south side’ and that a thick conglomerate was present along with a fishbed which ‘was excavated when the tunnels were dug into the N Sutor’.

The conglomerate is visible today, underlain by a thin (~7ft [2.1 m]) breccia at the extreme easterly extent of the outcrop draped against the Moine intrusion.

The tunnel to which he was referring is preserved today at NH804689 as the abandoned, flooded and inaccessible 1970's concrete structure at the opposite west end of the steeply dipping outcrop of sandstones interbedded with shales and calcareous beds. These almost vertical beds, being relatively fresh, are clearly visible behind netting above the tunnel entrance and spoil from the excavation is dumped on the foreshore at the high water mark. The spoil contains fish bearing nodules and nodular limestone which Trewin wrote were 'not like the nodules on Cromarty shore' and which can still be collected today. Trewin concluded that the tunnel was driven into what, in Miller's time, was a cliff, which appears to support Peach's observations (Peach 1919-1920; Peach *et al.* 2017, pp. 381, 399)

2024 Field Work and a Re-evaluation of the Cromarty and Nigg Foreshores.

In winter 2023 the powerful storm 'Babet' and her kin battered the Cromarty coastline and one of the authors (S.D.J.) observed that the storm had helpfully cleaned strata that had been partially covered previously, thereby allowing more detailed examination.

At the far eastern end, abutting the South Sutor, the storm had further revealed the basal strata of the succession and the junction with the Moine inlier, which Ross (2002) described as obscured by debris, at the top of the beach, enabling more data to be added to the section recorded by us in 2002. Miller described (2023 vol. 2) (Table 3, units i and ii) the basal beds as ~100ft (31 m) of conglomerate overlain by a 'thick' sandstone.

The augmented data reveals that the basal unit is a 25 m (82 ft) thick breccia/conglomerate containing eroded angular clasts with occasional rounded types which is overlain by 7 m (23 ft) thick yellow sandstone containing pebbles at its base and two bands of gritty red shale as recorded by Richardson (1960). This in turn is overlain by 68 m (223 ft) of ~21 discrete beds of interbedded sandstone and shales containing nodules and two platey

limestones which allows correlation with our section recorded in 2002 confirming that the beds exposed in 2024/25 span ~100 m (328 ft) before disappearing under a field of glacial deposits.

The sub horizontal Coal Heugh Burn Mouth Fishbed emerges from the covering of glacial deposits and shingle ~ 200 m to the west and has been only partially exposed over the years. The fishbed was still partly clear of obstruction in 2024/25, (Fig. 10). The site is protected by law as a Site of Special Scientific Interest (SSSI) but not for any geological interest at this foreshore, however certain activities may require permission and hence no excavation of the outcrop should be performed without the sanction of NatureScot and the landowner, but loose concretions were found on surface. The sub horizontal shale bed containing the nodules as exposed in summer 2024 measures an average of ~200 m long by ~50 m wide and extends further west than Ross delineated.

However, on closer examination it can be seen that within the sub horizontal bed, the actual abundance of *in situ* nodules is variable. The main concentration in 2024/25 is at the Coal Heugh Mouth Burn Fishbed with only rarer *in situ* occurrences beyond this immediate area. Miler the elder also described the area of the fish bed as the area of two herring fishing nets (Miller 1849) the combined area of which of which presumably would have been 64 yds by 16 yds (58 m by 14.6 m). This broad level of variation was later witnessed by Miller the younger in recording the outcrop only under the bed of the stream (BGS 1885). On our survey the exposed extent of the *in situ* nodules presented differently on three separate days, two of which were consecutive, in February to October 2024, thereby hindering accurate measurements and demonstrating that exposure can change rapidly. Miller the elder's 10-12 years of collecting experience and his 'fishing nets' based measurements (58 m by 14.6m), from our observations, appears the most reasonable estimate for a concentrated area of *in situ* nodules but may vary with differing tidal conditions.

The concretions seen *in situ* and loose on the surface of the outcrop generally are regularly shaped with distinctive laminations (Fig. 10), indicating deposition in a lacustrine environment.

New Evidence from the Nigg Foreshore.

On our 2024 surveys, some strata on the Nigg Foreshore had been stripped presumably by Storm Babet and here could be seen partial sections of the fishbed at the base of the cliff, which could be traced in the vegetation to the clifftop. The 'rediscovery' of the fishbed strata in the cliff above the tunnel described by Trewin in 2013 adds considerably to future interpretation. Complex folding and disruption of the strata seen on the foreshore adds potential new information to previous understanding of the strata mapped by the BGS (BGS 1889, 1913, 1973). Interestingly, the diagnostic Coal Heugh Burn Mouth Fishbed type of nodules (Fig. 2b) have not been found on the Nigg Foreshore to date which also requires further investigation.

Misinterpreted Strata.

Miller the elder's sub zone 2 (Fig, 3), a 'thick' sandstone (Table 3, Unit ii), appears considerably reduced in thickness from our field survey of the Cromarty Foreshore, 23 ft (7 m) vs 70ft (22 m), (Table 2) or 114.5 ft (35 m), (Table 1). It is interesting to note that neither Miller the younger (BGS 1889, BGS 1913) nor Armstrong (BGS 1973) marked this bed as a discrete stratum on the Cromarty Foreshore, but both emphatically marked this bed on the North Sutor. Ross (2002, pp. 7-8) did not specifically mention this bed in his description of Cromarty Foreshore, only the conglomerate and less significant sandstones and marly shales. Miller the elder (Miller 2023) regarded the strata at Eathie, and the Cromarty and Nigg Foreshores as exposures of the same rock sequence but the evidence now suggests differences in lateral continuity may occur. Furthermore the sub horizontal Coal Heugh Burn Mouth Fishbed is reported by Armstrong (BGS 1973) as about 240 metres wide in an east to

west direction which, had it appeared on the section (Fig. 3), it would be the most prominent feature of the stratigraphy.

The most useful map to depict the above is the larger scale, 1:10,360 (6 inch: 1 mile) County series Ross and Cromarty Sheet 67 (BGS 1913). This map replicates the truncated expanse of the Foreshore (Fig. 6b) of steeply dipping strata which is curtailed quite sharply. The same map presents a much better developed stratigraphy of these beds on the Nigg Foreshore (Fig. 6a) where the same steeply dipping features can be seen but over a much wider distance and inland to the north with far more interbedded sandstones, mudstones and calcareous shale units.

A Reconciliation of the 'Lower Formation as Developed at Cromarty' (Fig. 3a).

As discussed above, Tables 1 and 2 cannot be correlated with the 14 sub zones on Fig. 3a, or in the field on the Cromarty Foreshore. Table 5 and Fig. 6a provide the best correlation with Fig. 3a in that all three exhibit 14 sub zones, all with the same lithologies, in the same stratigraphical order, thereby allowing the resolution to this anomaly, that Fig. 3a more closely resembles the section on the Nigg Foreshore, not the Cromarty Foreshore.

There remains the question of the bed thicknesses not being in alignment as Miller the elder (Miller 2023) did not provide a scale to his 'Cromarty' section (Fig. 3) but this may be explained by loose geological mapping practices (e.g., Tables 1 and 2) still prevalent at the time amongst Miller the elder and his peers (Davidson *et al.* 2024).

Evidence from the Concretions and Notes on Collecting.

Observance of the Scottish Fossil Code (2023) is crucial in collecting fossils at this and any locality. The code provides guidance to the legal aspects, including obtaining permission to collect, and practical advice for the collection and curation of material.

In March 2025 a rescue dig was performed at the Coal Heugh Burn Mouth Fishbed by a team from the NMS assisted by the authors. The objective was to secure representative and diagnostic nodule samples with accurate provenance. Approximately 200 samples were collected and are now stored in the NMS but as yet no accession numbers have been issued. This work was done with the permission of the landowner and the sanction of NatureScot.

Concretion Diversity.

The mineralogy that can be observed internally from freshly split, concretions demonstrates a diversity to be found in the shingle at Cromarty Foreshore, Nigg Foreshore and at Eathie, and it must be expected that most concretions will be barren at a macro level. Parnell (1983, pp. 200-201) mentioned two forms of concretion, which occur in the Cromarty area localities, 'Carbonate concretions formed in two contrasting environments in lacustrine laminites and as calcretes in alluvial plain mudstones…..commonly in alternating beds'. Visual examination demonstrates that further subdivisions can be made, and characteristics may include the presence of a fibrous calcite coat, hardness, purity, colour, fossil content and presence of laminations etc. Where a calcite coat is present it is generally the same colour as the matrix.

The concretions also commonly exhibit recent borings by rock boring bivalves (piddocks), probably *Hiatella arctica;* one striking occurrence of this feature is that the unconformable Jurassic concretions at Eathie appear more prone to mollusc attack, some having multiple deep borings, giving a 'swiss cheese' like appearance.

On the Nigg Foreshore, nodules bearing similarities to some of those in the Cromarty Foreshore occur but importantly a different type of fish bearing concretion and concretionary limestone can be found in the spoil below the westerly excavation for the

concrete tunnel. The beds from which they are presumably derived can be clearly seen in the freshly exposed cliff above but access to these beds is currently not possible.

In the transcript of an email (N.H.T. to R.G.D July, 2013), Trewin wrote that the fishes contained in these nodules were 'Virtually all *Osteolepis* and not like the nodules on Cromarty foreshore'.

These nodules are of a black matrix heavily encrusted with a hard crystalline calcite jacket of a dark grey to black colour and may be diagnostic, suggesting the presence of a discrete concretion band that supports this mineralogy or that concretions occur outside the main concretion bearing horizons as is the case at Tynet Burn (Trewin and Davidson 1999, pp. 538-539).

Discussion and Further Work.

The present study has focussed on a reconciliation of geological discovery from Miller the elder' s work commencing in 1830 supplemented by BGS surveys in the 19th and 20th centuries to present day fieldwork, which presents further opportunities for resolution of the detailed stratigraphy of the Cromarty District fishbeds which has not been possible until now.

Due to the transient nature of the drift deposits, different researchers may have been presented with different evidence at different times. This has been the experience of the present authors since 1991. Potentially this explains the reason that no excursion guide, or memoir, on the Cromarty district's geology and palaeontology has been formally published and some misconceptions have inevitably crept in to general understanding over the years.

A multidisciplinary team has been assembled and a companion study is under way to consolidate the detailed stratigraphy of both foreshores.

This work will include detailed stratigraphical analysis, aerial imaging and photogrammetry and potential mineralogical and morphological analysis of concretions for

possible correlation to their source beds. The work is designed to test past hypotheses and produce a clear understanding of the stratigraphy of the Cromarty strata including its fishbeds.

Conclusions.

Miller the elder used the term 'Cromarty' in the geological sense to encompass the fishbeds exposed at Cromarty, Eathie and Nigg as a stratigraphic continuum, consistently referring to the conglomerate and overlying beds adjacent to the North Sutor as the source of his stratigraphical descriptions but presenting conflicting data. This may have been compounded in his time by the Cromarty Foreshore strata being poorly exposed, as they were on subsequent surveys, however recent serendipitous storm damage has enabled further stratigraphic revelation on both the Nigg (North Sutor) and Cromarty (South Sutor) Foreshores.

Miller the elder's scientific understanding of the Cromarty fishbeds and their fauna evolved gradually in the period 1830-1839. This is reflected in *The Old Red Sandstone*, as his circle of learned correspondents broadened. This was to consolidate in 1839-1845 with his final realisation of the different acanthodian fish genera *Cheiracanthus, Diplacanthus* and *Rhadinacanthus*, although he was not to name them. This was supplemented by his stratigraphical hypothesis of lower and higher fish mass mortality horizons published in the *Witness* and issued posthumously in *The Cruise of the Betsey*.

The new evidence on diagnostic nodule morphologies potentially being bed specific and nodules collected *in situ* presents a potential methodology for contribution to an analysis of the fishbed stratigraphy on the Cromarty Foreshore in comparison to the Nigg Foreshore and may also enable the localising of museum specimens.

On the accumulated evidence, despite some similarities, the situation on the Cromarty Foreshore is that due to the inconsistences in how the basal breccia/conglomerate and sub-horizontal beds have been recorded in the past, lack of outcrop and the reduced thickness of the sandstone marker bed above the breccia/conglomerate; it now appears that some lateral discontinuity occurs allowing only a tentative correlation near the base of the sequence abutting the South Sutor to similar strata at the North Sutor.

The evidence now confirms that Miller the elder 's 'Lower Formation as Developed at Cromarty' section is not, as the caption suggests, derived from the Cromarty Foreshore as notwithstanding transient obscurement by drift deposits the upper strata depicted are not present at this locality. The County Series BGS map derived faithfully from the field slip by Miller the younger provides the best stratigraphical match to Fig. 3a, but only at the Nigg Foreshore (North Sutor) outcrop, indicating that this locality is the source of all, or most of these data.

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Author Contributions RGD: conceptualization (lead), data curation (lead), investigation (equal), methodology (equal), writing-original draft (lead), writing-review and editing (equal). **SDJ**: data curation (supporting), investigation (equal), methodology (equal), writing-review and editing (equal).

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Data availability Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

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Figure captions

Fig. 1. a. Map of Miller's fossil collecting localities in the vicinity of Cromarty. North Sutor (NH805689), Cromarty, (NH794673 and NH800672) and Eathie (NH783640-NH790645). Grid squares = 1 km. OS Landranger, Sheet 27. Crown copyright and database (2024) rights Ordnance Survey 100021290. **b**. View of the headlands known as the Sutors of Cromarty to the east (mid channel) the South Sutor is to the right. Distance between Sutors = 1.64 km (~I mile). The fish beds are draped against both headlands (facing). Photo, S.D.J.

Fig. 2. Depositional environments and preservation modes**.** (**a**) Map of Lake Orcadie or the Orcadian Lake in the Middle Devonian, superimposed on the modern map of Scotland. The 'Cromarty' locality is shown as 2 sites, the South site includes Cromarty Foreshore and Eathie (South Sutor); the North site is the Nigg Foreshore (North Sutor). Source; After Burrow et al. 2020. (**b**) Cromarty Coal Heugh Fishbed rounded/ovoid nodule or concretion often containing fish fossils. Note parallel laminations. Scale bar = 20mm, nodule thickness 43 mm.(**c**) Armoured fish bony plate in sandstone at Eathie in 2013. Pre 2017 coin diameter = 22.5 mm. Both photos S.D.J.

Fig. 3. a. Miller's original frontispiece section (1841, fig. 5, more conveniently accessed as an enlarged facsimile in Miller 2023 vol. 1, fig. 2, fig. 5) with sub zones 1-14 appended by the present authors. Sub zone 1 (h) is the basal breccia and conglomerate and sub zone 2 is a thick red sandstone marker bed. Sub zone 3 is a sequence of thin sandstones interbedded with calcareous shales, the fishbed, and sub zone 4 is another significant yellow sandstone

marker bed referred to by Miller. The remainder are unquantified medium to thick sandstones (sub zones 6,8,10 and 12) again interbedded with thin calcareous beds (sub zones 5,7, 9, 11 and 13) the entire sequence is capped by a thick sandstone (sub zone 14). Modified after Miller (2023, vol. 1, fig. 2, fig. 5). **b.** Miller's section of the Cromarty Foreshore in a letter to Murchison in 1838/39. Chapel Burn is now known as the Coal Heugh Burn and today Crook Burn retains its 19th century name. Modified after H.M.L.B 1840, no. 212.

Fig. 4. a. (ELGNM 1839) Miller's sketch map of the Cromarty fishbeds as he understood in January 1839. **b.** Extract, with annotations by the authors, from the same map showing only 2 fish bearing nodule bed localities, Coal Heugh Fishbed to the north and Eathie, to the south, as he understood them prior to winter 1839. Photo, A. Wright; Elgin Museum.

Fig. 5. Enlarged extract from BGS Ross and Cromarty Sheet 94, 1:63,360 (1 inch:1 mile), (BGS 1889) by Miller the younger depicting near vertical strata at both the North and South Sutor Foreshores containing fossil fish bearing nodule beds, adjacent to conglomerate and sandstone beds and extending up the cliffs at both localities.

Fig. 6. Enlarged extracts from BGS Ross and Cromarty Sheet 67 (County Series) at 1:10,560 (6 inch: 1 mile) scale which allows greater detail to be resolved. **(a)** The map (BGS 1913) depicts

the strata on the North Sutor Foreshore extending from the base of the conglomerate and breccia some 1,187ft (as measured by Miller the younger [BGS 1885]) to the overlying sandstone to the west, comprising 6 calcareous beds and 8 breccia/conglomerate and sandstone beds, a total of 14 sub zones (compare Fig. 3a). **(b)** Cromarty Foreshore (South Sutor) showing a truncated expanse of conglomerate and interbedded sandstone, shales and calcareous beds, demarcated by the linear blue feature adjacent to (above) the conglomerate occurring at the east end of the beach abutting the fault with the metamorphic inlier. Note the inclusion of symbols indicating anticlinal and convoluted beds in the fishbed sediments.

Fig. 7. Enlarged extract from BGS Ross and Cromarty Sheet 94 1:63360 (1 inch:1mile). Grid squares = 1 km , 1973 by M. Armstrong depicting near vertical strata at both the North and South Sutor Foreshores containing fossil fish bearing nodule beds, marked with nodule symbols, adjacent to basal conglomerate and to the sub horizontal horseshoe shaped fishbed outcrop on the central Cromarty Foreshore, and inland exposures. Note that Armstrong removed the structural symbols in the fishbed sediments (compare Fig. 7).

Fig. 8. Comparison of Diplacanthid scales to those of Cheiracanthus. a. Diplacanthus crassimimus Duff, 1842, (NMS G. 2014.33.10) from Corbie Den near Gamrie, exhibiting laterally radiating or ‘concentric’ (ELGNM 1839) crown striations, the arrow indicates the

anterior (front) edge of the scale immediately below it. Scale bar = 0.1 mm. b. Cheiracanthus murchisoni, (NMS G.1892.8.1) from the Edderton nodule bed, the direction of the anterior edge of the scales is to the left. Scale bar = 1.0 mm. c. The diplacanthid Rhadinacanthus longispinus (NMS G.2002.59.142pt) exhibiting longitudinal crown striations, from Cushnie Burn near Gamrie; the direction of the anterior edge is to the left. Scale bar = 1 mm. a., c. After Burrow et al. 2016. b. After Burrow et al. 2020.

Fig. 9. Acanthodian fishes from Cromarty. A. Orcadacanthus. B. Cheiracanthus, both Burrow 2021. C. Diplacanthus. D. Rhadinacanthus, both Burrow et al. 2016.

Fig. 10. Miller's fishbed exposed at the Coal Heugh Burn (NH 794673). Nodules (or concretions) can be seen (arrowed) loose on surface and in situ, concentrated in an area adjacent to the mouth of the Coal Heugh Burn. Photo: S.D.J.

Table captions

Table 1. 'Cromarty section under the Northern Sutor' described in text by Miller in 1841 (2023 , vol 2, pp. 30-33) with Miller's thicknesses in feet and the present authors' inferred sub zones (Fig. 3) and a total thickness of <764ft (233 m), (Compare Fig. 3a) including the Great Conglomerate as measured 'underneath the Northern Sutor' (Miller 2023, vol. 2, p.31).

Table 2. 'North Sutor' section putatively communicated by Miller in 1839 (Malcolmson 1859 p. 352) with Miller's

description of lithofacies and thicknesses. The present authors' inferred sub zones are annotated. Note the reduced thickness of the 'Great Conglomerate' and the overlying 'Reddish yellow sandstone' compared to Table 1 suggesting that this may contain elements of the North and South Sutor outcrops.

Table 3. Miller 's retrospective account of the beds on the Cromarty Foreshore (South Sutor) as he saw them in 1830 in The Old Red Sandstone in 1841 (Miller 2023, vol. 2, pp. 111-115), prior to him recognising unit iii (Miller 2023, vol. 2, pp.131-133) as the fishbed. Compare to Fig. 3b.

Table 4. Miller the younger's detailed ms section of the North Sutor Foreshore from his field slip (BGS 1885) as measured by Miller the younger, showing the present authors' inferred 22 sub zones, which Miller the younger subsequently recombined to 14 sub zones (Table 5).

Table 5. Miller the younger's mapped section with some beds re-combined, tabulated from BGS 1913, supplemented by the present authors' sub zones.

Note: Measurement of 'Thin' bed thickness from the hand annotated map is considered unreliable, therefore approximate total thickness is measured from BGS 1913.

Table 1

Lithofacies	Thickness ft (m)	Sub zone Fig. 3
'Unfossiliferous sandstone'	>80 (24.5)	14?
'Alternating bands of sandstones, stratified clays and bituminous and nodular limestones'	355 (108)	3-13?
'Red and yellow arenaceous stone'	114.5 (35)	2
'Great conglomerate bed'	215 (66)	1

Table 2

Lithofacies	Thickness ft (m)	Sub zone [Fig. 3]
Drift		
Crimson and brick red sandstones		?
Yellow sandstones		8
Limestone and clay	300 (92)	7
Yellow sandstones in thick beds		6
Limestone and shale resembling fishbeds		5
Yellow sandstones		4
Shales and a few concretions with fish and plants of the same kind as Cromarty, Lethen &c.	(Thin)	3
Reddish yellow sandstone	70 (21)	2
Great Conglomerate	100 (31)	1
Gneiss, broken up: veins not seen at junction, but numerous at a little distance	N/A	

Table 3

Unit	Miller's Description in Ascending Order i-vi.
i.	'I first crossed the conglomerate base of the system, here little more than a hundred feet in thickness' (Fig. 3, sub zone 1), almost vertical.
ii.	'I next passed over a thick bed of coarse red and yellowish sandstone' (Fig. 3, sub zone 2), almost vertical.
iii.	'I then crossed over strata of an impure grayish and slaty clay', almost vertical, the fishbed as he would much later realise, (Miller 2023, vol. 2, pp 131-133) see below.
iv.	'I next crossed over a series of alternate beds of coarse sandstone and stratified clay' (Fig.3, sub zones 4-?), almost vertical decreasing to <45 degrees angle of dip.
v.	'and then lost sight of the rock altogether in a wide waste of shingle and boulder stones, resting on a dark blue argillaceous diluvium' [sic] a feature that does not appear on Fig. 3a.
vi.	'I passed onwards and reached a little bay…The rock laid bare in the little bay… abounds in calcareous nodules…The rocks of the little bay must have lain beyond the disturbing uptilting influence of the granitic wedge'. Here he is describing the Coal Heugh Fishbed on the beach, which is sub horizontal (~8 degrees) and undisturbed and which again does not appear on Fig. 3a, but is included in Fig. 3b..

Table 4

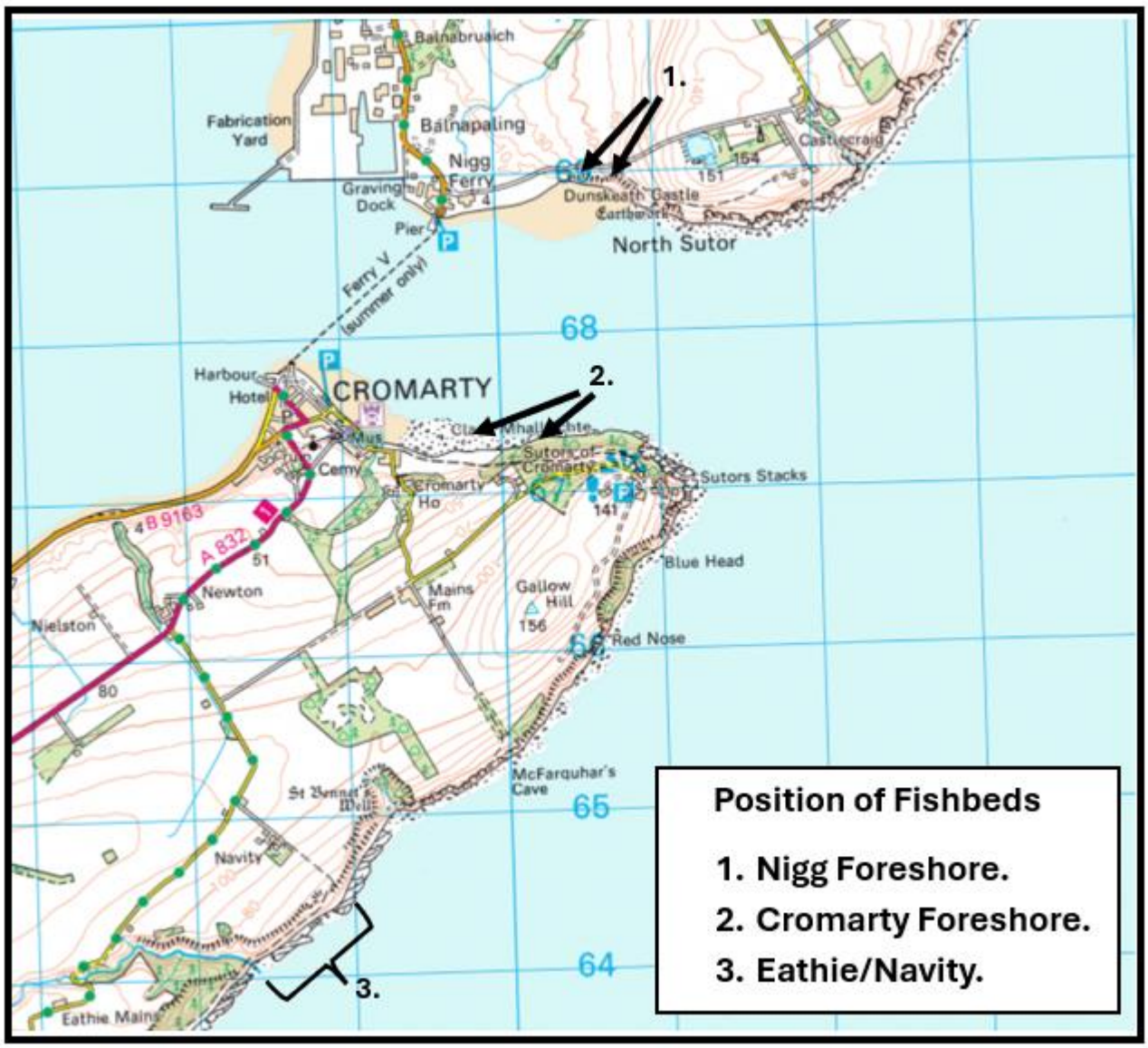
Lithofacies	Thickness ft (m)	Sub Zone
Red sandstone	420 (128)	22
Red sandstone with marly shale	10 (3)	21
Purple/green shale with limestone nodules	10 (3)	20
Sandstone, red in upper part	80 (24)	19
Purple/green shale with limestone nodules. *Cheiracanthus,* fish coprolite	9 (2.75)	18
Yellow sandstone	65 (20)	17
Shale with barren nodules	5 (1.5)	16
Yellow sandstone, occasional pebbles	17 (5)	15
'Obscure'	12 (3.65)	14
Sandstone	1 (0.3)	13
Flaggy limestone with fish (acanthoid) scales	4 (1.22)	12
Purple/green shale with some limestone nodules.	7 (2.13)	11
Yellow sandstone	34 (10.36)	10
Red/green shale with calcareous nodules	5 (1.5)	9
Yellow sandstone with a few pebbles	144 (44)	8
Red/purple/green shales with barren nodules	8 (2.44)	7
Yellow sandstone, green galls	12 (3.66)	6
Green shale with thin nodules	8 (2.44)	5
Yellow sandstone marbled red	6 (1.83)	4
Green shale with limestone bands, sun cracks?	15 (4.57)	3
Sandstone, numerous pebbles	105 (32)	2
Conglomerate with 7ft of breccia at base	210 (64)	1
TOTAL THICKNESS	**1,187 (362)**	**1-22**

Lithofacies BGS 1913 Legend	Thickness ft (m)	Sub Zone
Sandstone	~555 (169)	14
'Fishbed and psilophyton shale'	Thin	13
Sandstone	~67 (20.42	12
'Fishbed and psilophyton shale'	Thin	11
Sandstone	~45(13.8)	10
'Fishbed and psilophyton shale'	Thin	9
Sandstone	~111 (34)	8
'Fishbed and psilophyton shale'	Thin	7
Sandstone	Thin	6
'Fishbed and psilophyton shale'	Thin	5
Sandstone	Thin	4
'Fishbed and psilophyton shale'	Thin	3
Sandstone	~90 (27.44)	2
Conglomerate	~244 (74.39)	1
TOTAL THICKNESS	**~1,209 (369)**	**1-14**

Table 5. Miller the younger's mapped section with some beds re-combined, tabulated from BGS 1913, supplemented by the present authors' sub zones. Note: Measurement of 'Thin' bed thickness from the hand annotated map is considered unreliable, therefore approximate total thickness is measured from BGS 1913.

Fig. 1.

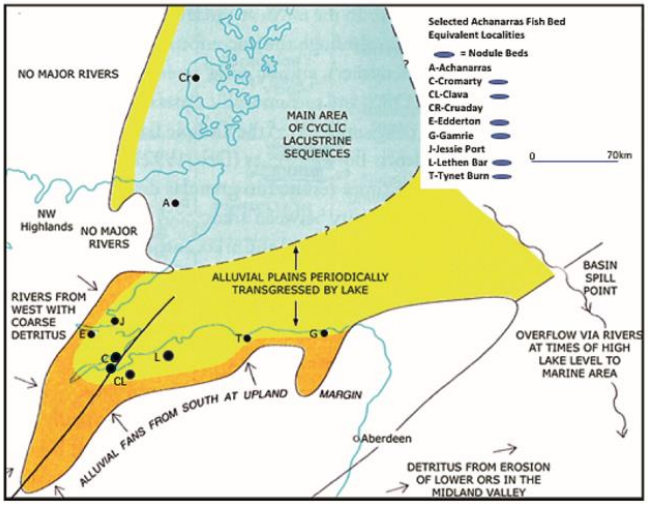
a.



b.

Fig. 2

a.

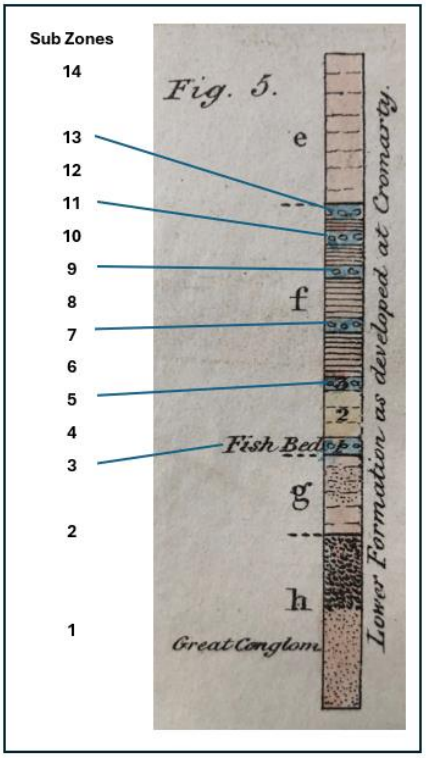


b.

c.

Fig. 3.

a.



b.

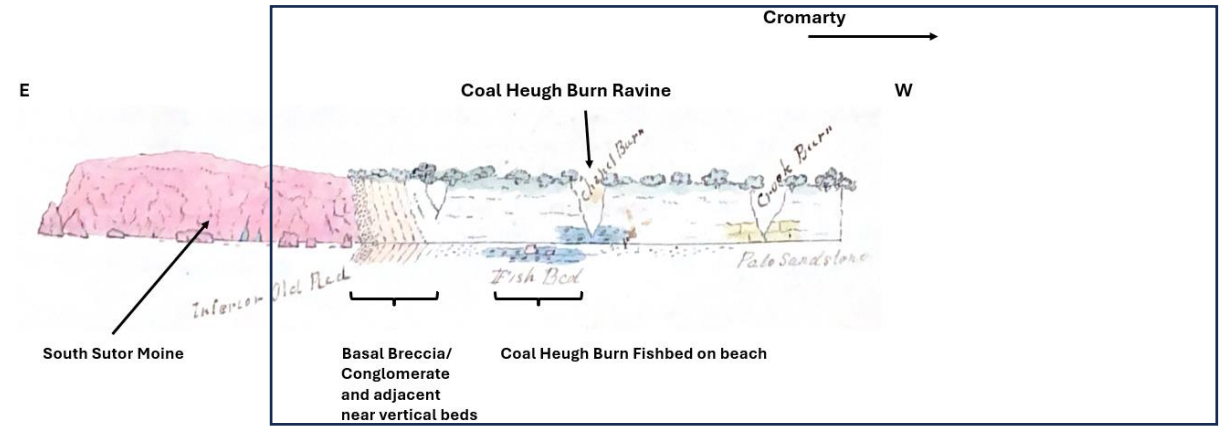


Fig. 4

a.

b.

Fig. 5.

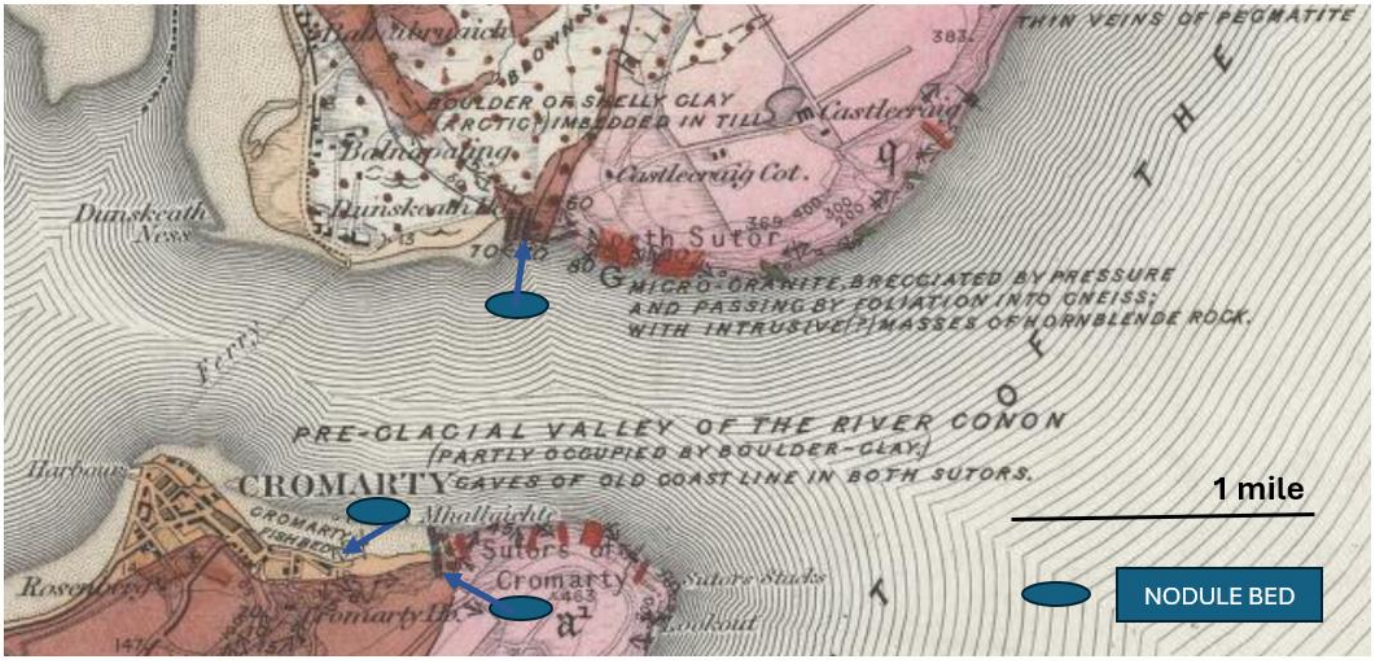
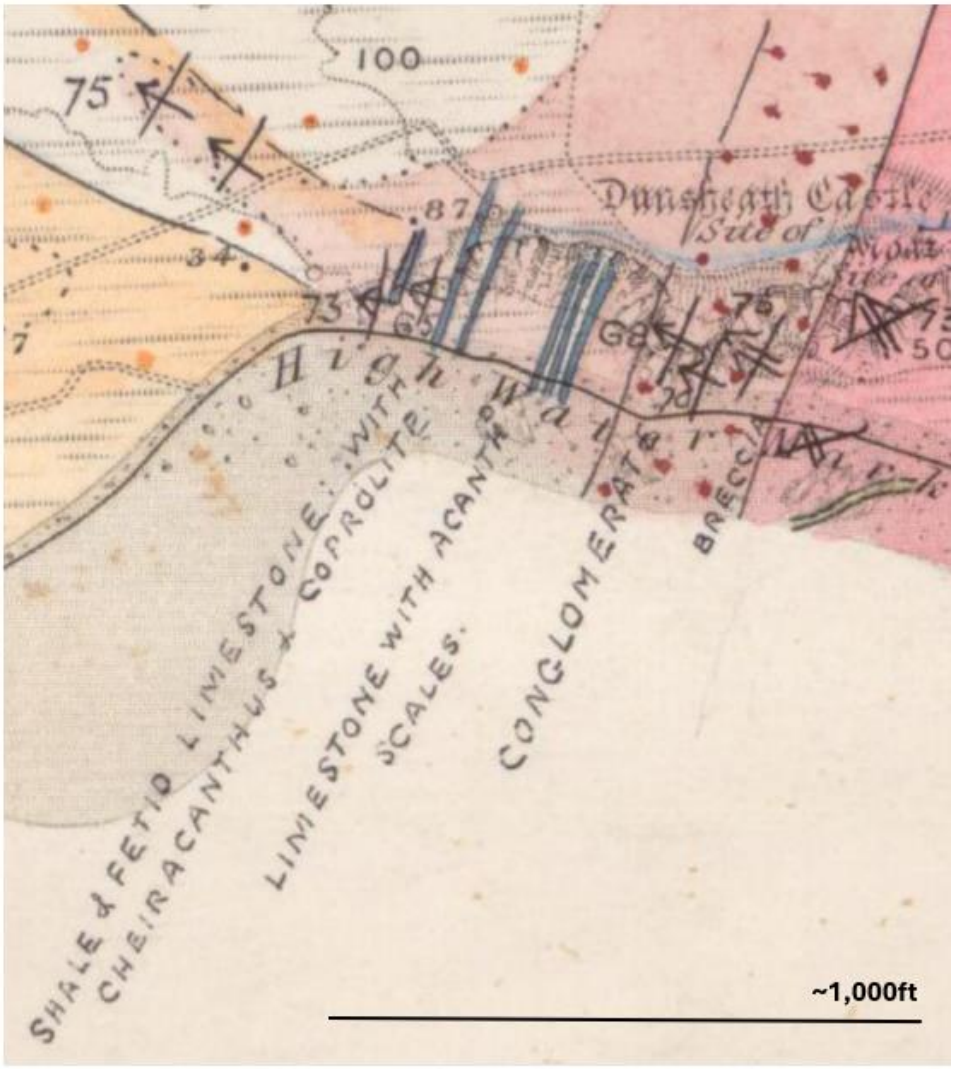


Fig. 6.

a.



b.

Fig. 7

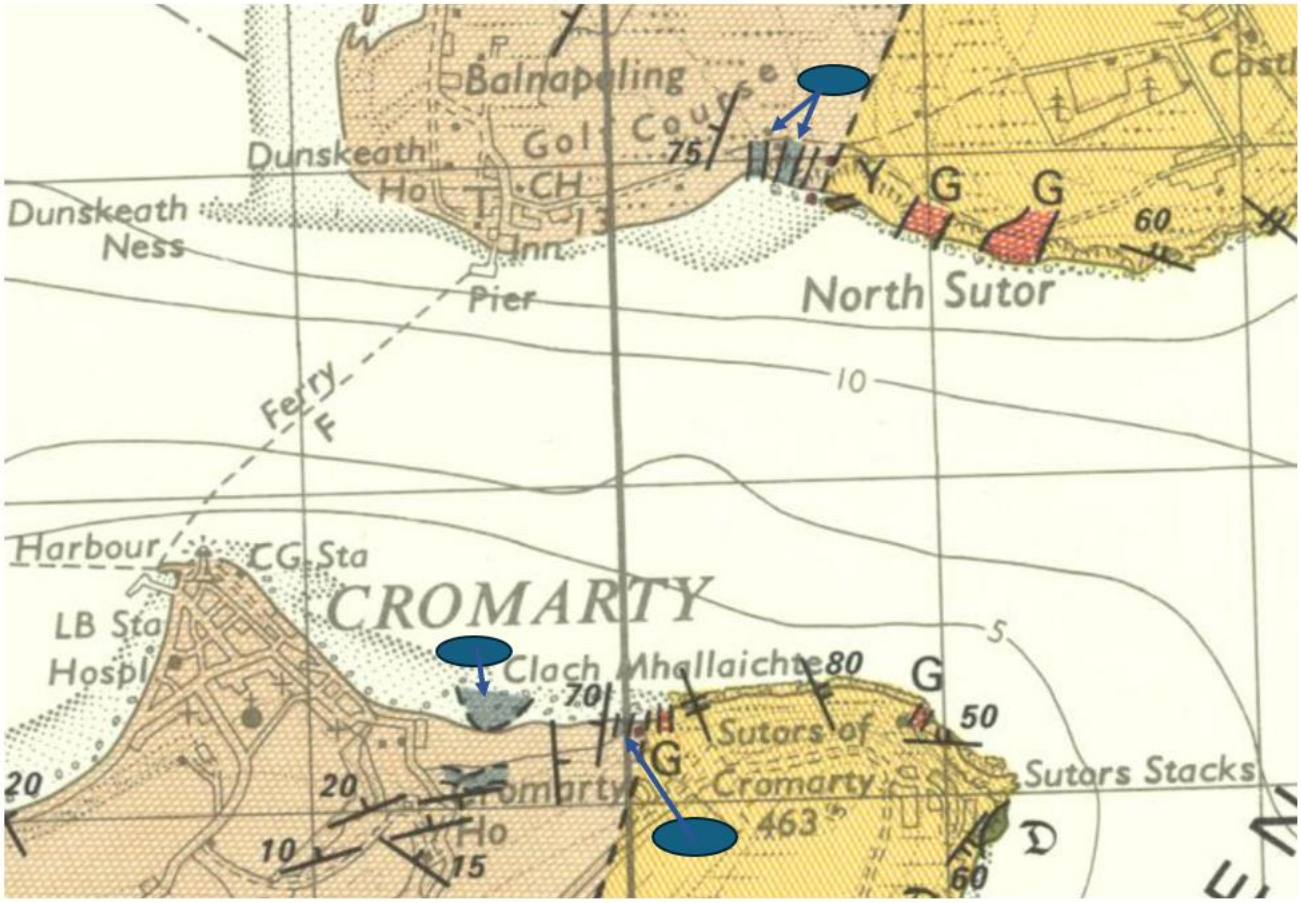
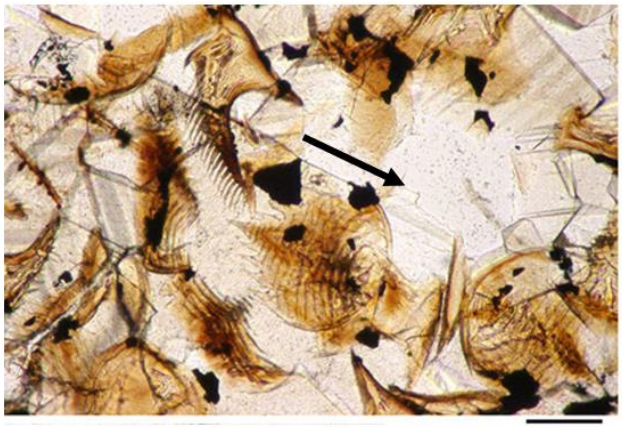
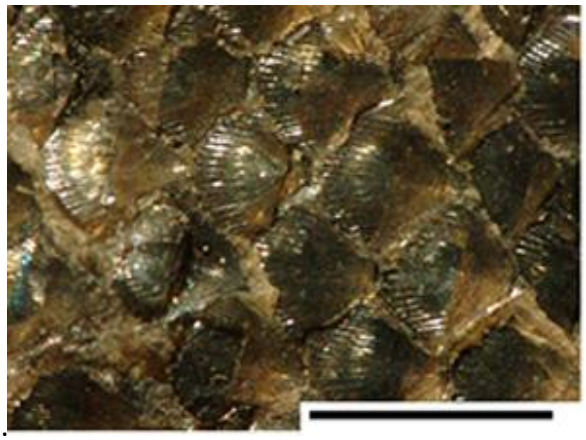


Fig. 8

a. 

b. 

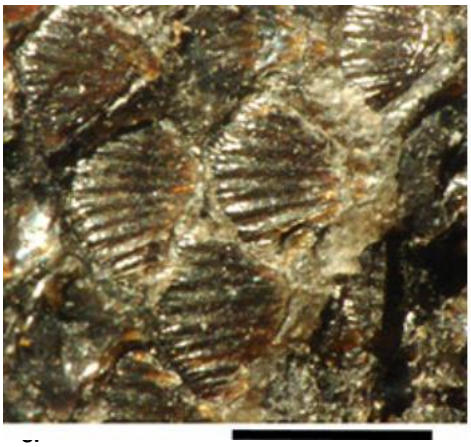


Fig. 9.

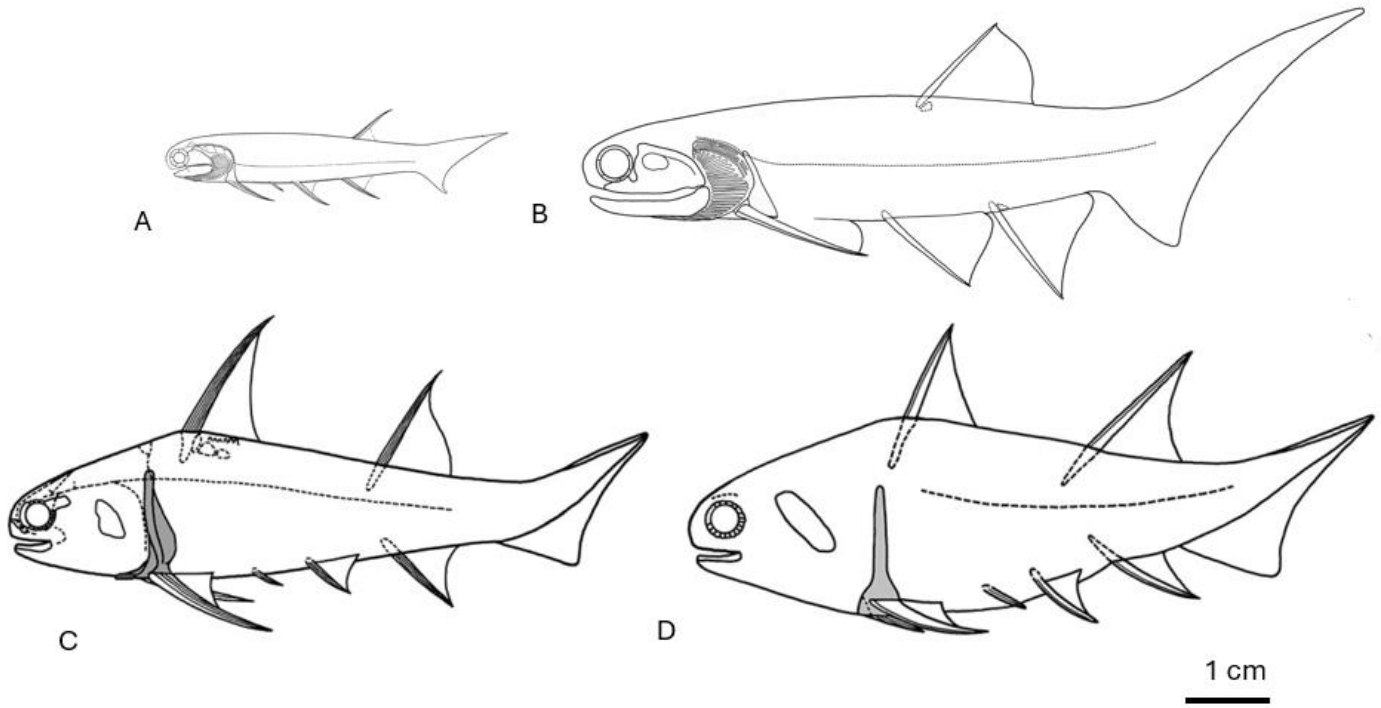


Fig. 10.