THE TREMADOC IN EXTRA-CALEDONIAN SCANDINAVIA: ITS STRATIGRAPHIC RANGE AND ITS DEPOSITIONAL HISTORY

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Henningsmoen (1973, pp. 430-432), representing the Scandinavian point of view, provided an authoritative summary of the history of discussion of the Cambrian-Ordovician boundary. Certain salient points may usefully be re-emphasized here. Brøgger (1882) first emphasized the concept of a Tremadoc Stage (or a Tremadocian fauna) in discussions of Scandinavian stratigraphy. He took it to include the range of the Ceratopyge Series ('Etage 3a': a combination of the 'Ceratopyge Shale', 3aα and 3aβ, and the 'Ceratopyge Limestone', 3aγ) known in the Oslo Region in extra-Caledonian Sweden and on the Danish island of Bornholm. There is no detectable break, lithological or faunal, separating the Ceratopyge Series from the underlying "Dictyonema Shales", termed 2e and regarded by Brøgger (1882) as belonging in the Upper Cambrian Olenid Series (his "Etage 2"). Moberg (1890) took the base of the Ceratopyge Limestone as marking the Cambrian-Ordovician boundary. Later, discovery of the ceratopygid trilobite Hysterolenus within the Dictyonema Shales (Moberg 1898) caused him to change his opinion and to propose that the system boundary be taken at the base of the Dictyonema Shales. He advanced this opinion again (Moberg 1900) when, impressed by (among other evidence) the lithological continuity of the sequence from the Dictyonema Shale into the Ceratopyge Series, he referred the Dictyonema Shale to the Ordovician.

Since these times there has been general agreement within Scandinavia that the system boundary should be taken at the base of the Dictyonema Shales. Further, with regard to the Upper Cambrian it subsequently came to be accepted that beds containing nodules with the olenid trilobites Westergaardia scanica, Parabolina acanthura and Acerocare ecorne should be included with the Cambrian (on the Swedish platform the Upper Cambrian sequence ends slightly earlier, in the Peltura scarabaeoides Zone,

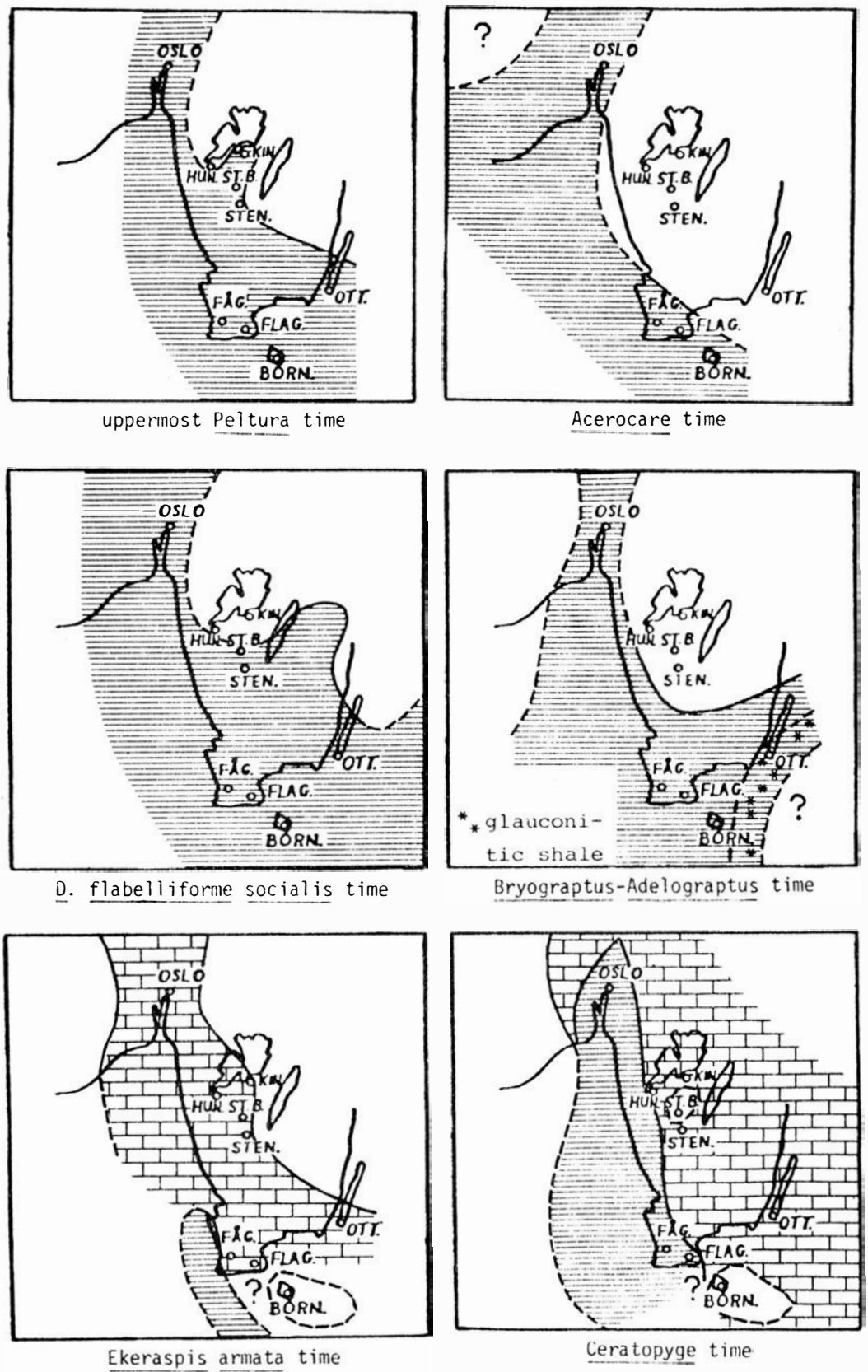

Figure 1. Paleogeography and facies of **southern** Scandinavia during the Upper Cambrian and Tremadoc (after Erdtmann in Bruton & Erdtmann 1980).

(Henningsmoen 1957). Considerable interest therefore attaches to the road section south of Nærsnes Church (SW of Oslo), which exposes the complete sequence from beds containing nodules with Acerocare ecorne, through an occurrence of Boekaspis hirsuta into the range of Jujuyaspis keideli (see Fig. 4 , p. 111). All of these occur only in limestone nodules separated by a few decimetres of black shales. In the shales in which the nodules are set the first graptolites occur at a horizon 45 cm above the Boekaspis-bearing nodule and approximately 35 cm below the anthraconite rim of a large nodule with Jujuyaspis. The graptolites are found in a 5 cm thick black shale unit which is crowded with excellent specimens of Dictyonema flabelliforme parabola and, less abundantly, D. flab. sociale. This part of the section is not tectonically disturbed. Lower, below the Boekaspis nodule, stratigraphic control is poorer because of strong folding and thrusting.

The Upper Cambrian--Mid-Ordovician black shales seem to represent a continuously developed, stable environment, with the limestone nodules (Bjørlykke 1973, 1974) or concretions (Henningsmoen 1974) allowing intermittent glimpses of the sequence of (probably non-benthic) trilobite faunas. The sudden appearance of planctic D. flab. parabola and related forms may be taken to indicated a special happening within this otherwise stable environment. Questions concerning the depositional history, and of the likelihood of stratigraphic continuity, are of immediate consequence. Considerations to be borne in mind are:

1 Black shale sequences of this character are widespread in the Oslo-Scania region from mid-Cambrian to Llandeilo.
2 Within these sequences there are occurrences of limestone concretions or nodules or nodular limestones, such as the Ceratopyge Limestone, Limbata Limestone, Endoceras Limestone, etc. These represent primary accumulations of biogenic material with varying degrees of superimposed diagenetic carbonate overgrowth (see Bjørlykke 1973, 1974 and Henningsmoen 1974 for two different views of the history of development of the carbonates in the Nærsnes section).
3 It is probably useful to think of these sporadic occurrences of shell material within the black shales in terms of variations in the position of a chemocline within the waters covering the broad, stable platform on which these sediments accumulated.

4 The faunas preserved in the nodules (and also the dictyonemids) are not benthic. The lack of trace fossils in the black shale sequences is a further indication of the exclusion of benthic communities. In contemporaneous carbonate bank or shelf deposits faunal control would involve a different range of factors.

The nature of these Scandinavian sections - their consistently fine-grained lithological character maintained over a wide areal extent and through a long span of time, their consistent, if intermittent occurrences of pelagic faunas (probably controlled by chemocline variations), should be emphasized when attempting comparisons with the original Tremadoc in North Wales. Henningsmoen (1973, table 1) has already pointed to the less stable environments and the greater likelihood of syndepositional tectonic effects that are characteristic of the British case and has suggested that almost everywhere in Great Britain, the Tremadoc Series is likely to be bounded above and below by depositional breaks. Recent assessment of new information (A.W.A. Rushton, 1980, written comm.) indicated that the gap at the lower limit might be closed in certain sections in North Wales (Ogof-ddu and Bryn-llyn-Fawr). Parabolina acanthura (contemporary of Acerocare ecorne) and Parabolina heres (contemporary of the other underlying 'missing' trilobite zones) have now been found at those sections mentioned above in North Wales. It therefore appears that, in terms of the Acado-Baltic facies development, a continuous sequence may also exist in Britain across the interval between the Upper Cambrian Merioneth and Tremadoc Series.

A continuous and conformable section across the Tremadoc-Arenig interval, documented by overlapping fossil ranges, has not yet been demonstrated from Britain. This author has read reports submitted by P.M. Allen (Rushton, 1980, written comm.) which suggest existence of a continuous transition from the Amnodd Shales (Upper Tremadoc of Fearnsides 1905) and the Erwent Limestone (Arenig according to Fearnsides 1905) in a stream section at Caunant-y-gareg ddu on the western slope of Arenig Mountain in North Wales. Similar sections are available at the Croes-y-ddwy afon and Bryn Glas quarries along the northern flanks of Harlech Dome. However, the stratigraphical short-comings of all these sections, (i.e. in the Ceunant-y-gareg ddu-"Black Rock Gorge", where 38 m of section between the Amnodd Shales and Erwent Limestone are unfossiliferous

where a several metres thick dolerite sill intervenes, and where the lowermost Arenig - in Fearnsides' view - Llyfnant Flags are entirely missing), and the numerous faults , make it difficult to achieve a good resolution of depositional history in this area. Further, the earliest known Arenig graptolite in the type area around Arenig Fawr is Didymograptus cf. D. simulans (a rather 'non-descript' form related to D. extensus and D. nitidus), reported from the Llyfnant Flags, indicated a rather high post-T. approximatus position in terms of the Lake District (northern England) and Scandinavian graptolite sequences. With only one somewhat questionable occurrence of T. approximatus from the Skiddaw Slates of the Lake District (Jackson 1964, p. 530; Erdtmann 1965, p. 532) and the absence, so far, of any finely-tuned graptolite zonation for the Arenig of Britain (Jackson 1962) there is practically no detailed evidence on graptolites in Britain between the Clonograptus tenellus - Adelograptus hunnebergensis zones (Stubblefield & Bulman 1927; Cope, Fortey & Owens 1978) and Tetragraptus approximatus. This range spans at least 3 recognizable graptolite zones (Henningsmoen 1973, table 1) or 15 m (out of 20 m for the Ceratopyge Series plus Hagastrand Member) of the post-Dictyonema flabelliforme/pre-T. approximatus sequence in the Oslo—Skåne region (see Fig. 2).

If one accepts Tetragraptus approximatus, with its short range and cosmopolitan occurrence, as indicating the base of the Arenig Series, the entire Scandinavian sequence between the Kiaerograptus kiaeri (and the enclosed Ceratopyge Limestone, Erdtmann 1965a) and Temnograptus to Tetragraptus phyllograptoides beds (lower part of Tjernvik's 1956 Hunneberg Substage) has no firm representation anywhere in Great Britain (Skevington 1966, p. 115). Only the lower half (approximately) of the British Tremadoc Series can be correlated to the Scandinavian sequences (see Fig. 2). This gap is neither closed nor cancelled by Tjernvik's (1956, 1960), Erdtmann's (1965a, 1965b - tentative!) and Jaanusson's (1979) inclusion of all post-Ceratopyge beds in the Arenig Series. Such procedure demonstrates instead the great uncertainty of the above authors as to the means of applying this British term (in a chrono- or biostratigraphical sense!) to the Scandinavian case (Fig. 2).

Skevington (1966, p. 115) and Henningsmoen (1973, p. 430) have pointed

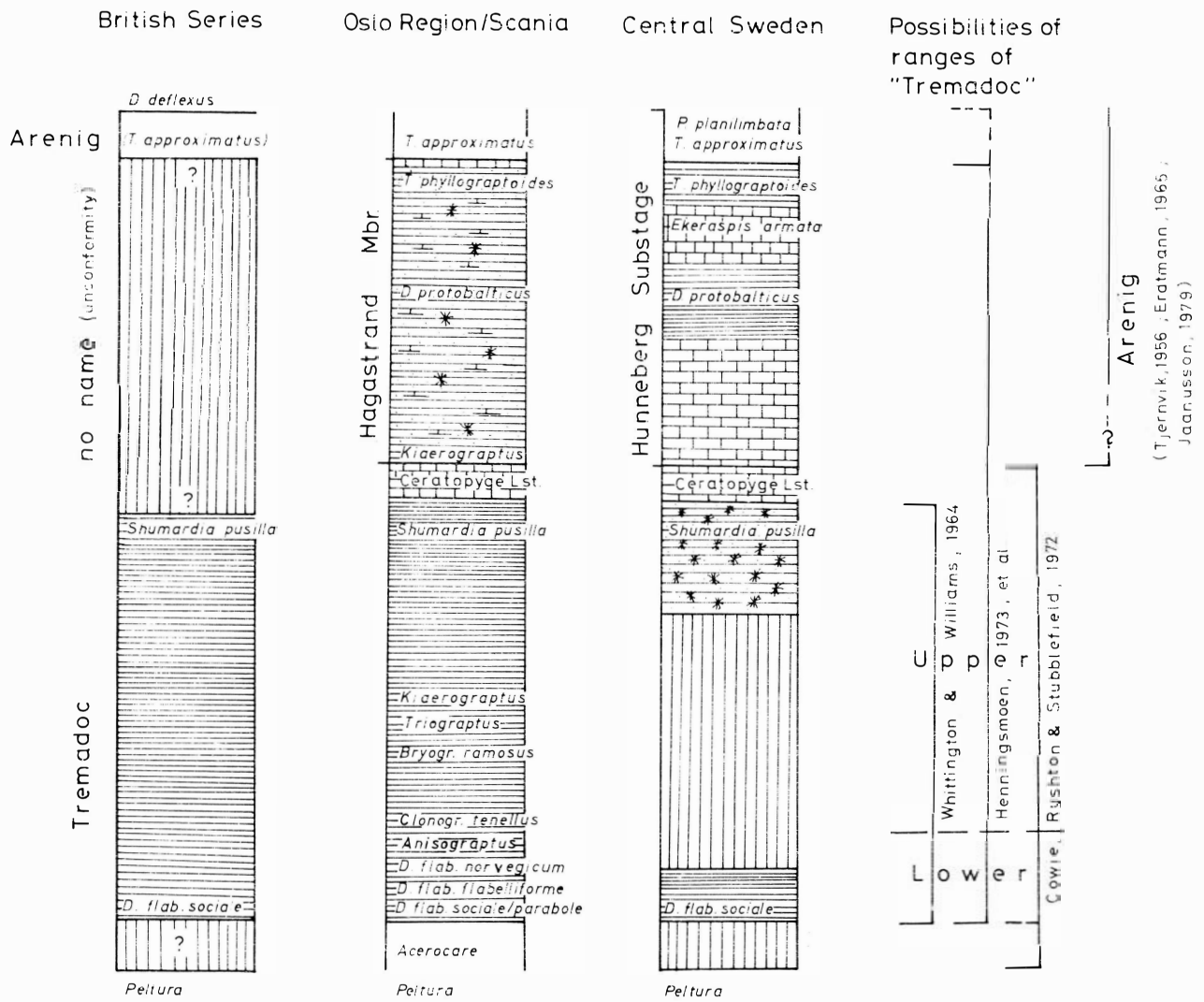

Figure 2. Correlation of Tremadoc rocks in Britain and Scandinavia. The right column shows the various definitions of the Tremadoc and Arenig Series (after Erdtmann in Bruton & Erdtmann 1980).

this out as an argument against taking the intersystem boundary between the Tremadoc and Arenig Series.

In addition to the poor correlation of horizons in the Tremadoc-Arenig range between Great Britain and Scandinavia, there is the evidence from most extra-European areas, which again supports the observation that a large fraction of depositional time represented elsewhere is missing in all British sections. The 'Pacific' trilobites and graptolite zones of North America, Siberia, Northern China, and Australia do not conform with the British concepts of Tremadoc and Arenig.

Article first appeared in Bruton & Erdtmann (1980)