Note

The Scandinavian alum shales – Mid Cambrian to Tremadoc deposition in response to early Caledonian subduction

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Early Caledonian deformation and metamorphism apparently influenced the entire Baltoscandian margin, involving Early Ordovician assembly of thrust sheets and a related uplift history, extending into the Mid Ordovician. Metamorphism during this orogenic episode at temperatures of over 700°C and depths of at least 50 km suggest that subduction started in the Cambrian. Thus, early tectonothermal activity along the Baltoscandian margin probably occurred simultaneously with deposition of the Alum Shale Formation on the Baltoscandian platform. This correlation implies a genetic relationship and favours the hypothesis that the change to anoxic facies in the Mid Cambrian occurred in response to the start of subduction along the outer margin of Baltica.

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Kerogen-rich shales of Mid Cambrian to earliest Ordovician age occur extensively in Scandinavia (Westergård 1922; Henningsmoen 1957; Andersson et al. 1985). Their deposition on the Baltoscandian platform extended from Finnmark in northernmost Norway to Skåne in southern Sweden and beneath Denmark. The youngest members of this, the so-called Alum Shale Formation, are of Tremadoc age and extend eastwards to the Baltic states and southwards into Poland. The formation can be traced beneath and within the lower Caledonian nappes of the Scandes as far west as the present Norwegian coast (Gee 1980).

The transition upwards in the Mid Cambrian from shallow marine successions of shales and sandstones into deeper (100 m +), anoxic environments has been generally interpreted to reflect small changes in the passive margin evolution of this western part of continent Baltica. An alternative hypothesis is entertained here – that the deepening of the basin in the Mid Cambrian was related to early Caledonian (Finnmarkian) subduction along the outer Baltoscandian margin and initial loading of the latter by some of the rock units now preserved in the Upper (and Middle?) Allochthon(s) of the Scandes.

Development of the Baltoscandian passive margin (Gee 1975), as recorded in the Seve Nappes and the underlying Middle and Lower Allochthons, involved late Proterozoic rifting (Kumpulainen & Nystuen 1985) and extensive dolerite intrusion of the outer margin (Solyom et al. 1979; Andreasson 1986) in the Vendian (Claesson & Roddick 1983). Evidence for early Caledonian deformation of this margin has been based, until recently, on isotopic age-determination studies in the Finnmark area of northern Norway. Pre- and syntectonic intrusions of the Seiland Igneous Province occurring in the Sørøy Nappe of the Kalak Nappe Complex have yielded whole rock Rb/Sr ages of c. 600 Ma (Brueckner 1973, 1975; Pringle 1975) and 540–490 Ma (Sturt et al. 1978). On the basis of some doubtful (Debrenne 1984) archaeocyathids (Holland & Sturt 1970) in the country rocks, the early ages have been rejected by most authors and the younger group have been interpreted to be related to syn-tectonic, early Caledonian (Finnmarkian) orogenesis (Sturt et al. 1978; Ramsay et al. 1985; Roberts et al. 1985). Some support for this early episode of deformation was provided by Rb/Sr whole rock isochron studies of shales and slates in the underlying tectonic units in Finnmark (Pringle 1973). However, an alternative hypothesis ascribes the alkaline-dominated Seiland Igneous

Province to the passive margin evolution of Baltoscandia (Krill & Zwaan 1987), perhaps localized in northern Norway by 'deep transform penetration of the continental margin during opening of Iapetus, the intrusions occurring into metasediments of the Sørøy Nappes prior to Early Ordovician thrust assembly of the Kalak Nappe Complex' (Bergström & Gee 1985, p. 267). This interpretation is supported by the c. 600 Ma ages (Brueckner 1976) and suggests that the 540–490 Ma ages may reflect early Caledonian subduction, but are younger than the time of intrusion.

Independent of these alternatives in Finnmark, there has accumulated a large body of isotopic age-determination evidence elsewhere in the mountain belt, favouring early Caledonian subduction (W-dipping) and medium to high grade metamorphism of the outer margin of Baltoscandia, followed by Early Ordovician uplift and cooling. Much of this uplift history is documented by $^{40}Ar/^{39}Ar$ hornblende ages of c. 460–510 Ma (Dallmeyer et al. 1985; Dallmeyer & Gee 1986) which clearly reach back into the Tremadoc (Harland et al. 1982). The overlap of these uplift ages with the time of deposition of the alum shales suggests a causal relationship between the early Caledonian subduction and the development of the anoxic environments in a foreland basin (Beaumont 1981). If this is the case, then the initiation of alum shale deposition probably reflects the onset of this early Caledonian tectonothermal activity in the Mid Cambrian.

The alum shale successions on the platform are interrupted in some areas by a hiatus in the latest Cambrian and/or early Tremadoc (Andersson et al. 1985). However, except in Finnmark, where the Tremadoc shales on Digermulhalvøya contain thick sandstone intercalations (Reading 1965), there is very little evidence on the platform of Finnmarkian orogenic activity along the outer margin of Baltica. Late Cambrian to Tremadoc facies changes towards the margin might be expected to be comparable to those recorded along the western edge of the Appalachian basin in the Late Devonian to earliest Carboniferous Chattanooga and related shales (Conant & Swanson 1961; Woodrow & Sevon 1985). The apparent absence of these facies changes may reflect distances of thrust emplacement onto the platform, the movement in the Scandes being substantially greater than that in the Appalachians.

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