The Early Ordovician "*Ceratopyge* Regressive Event" (CRE): Its Correlation and Biotic Dynamic Across the East European Platform

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A b s t r a c t. The late Tremadoc (Early Ordovician) "Ceratopygekalk" (*Ceratopyge* Limestone in Sweden or Bjørkåsholmen Fm. in Norway) of southern Norway, Sweden and probably of subsurface northern Poland represents a response to a globally effective multiple (*Ceratopyge*) regression event (acronymed CRE) that in other parts of the East European Platform (EEP) is alternatively reflected by a depositional hiatus or by submarine corrosion surfaces (central Sweden, Estonia, St. Petersburg, South Lithuania, central and northern Poland). Biostratigraphically the "Ceratopygekalk" defines the uppermost part of the **Paltodus deltifer** conodont **Zone**, the **Kiaerograptus supremus** graptolite **Zone**, the top of the **Apatokephalus serratus** trilobite **Zone** of Scandinavia or the top of the **Athabascaella playfordii** acritarch association, but also in other parts of the world a coeval event horizon is marked by the extinction of cordylodan conodonts, of bithecate (except a single sicular bitheca) graptolites and of nearly all olenid trilobites. Subsequent to the CRE "dichograptid" graptoloids, paroistodan conodonts, asaphid trilobites and chitinozoans make their debut appearance virtually simultaneously across the EEP. Relations of lithofacies developments in pre- and post-CRE sediments indicate a major shift from clastic to initial carbonate regimes migrating together with glauconite formation from the pre-*Ceratopyge* Limestone introduction of glauconite autigenesis in the outer shelf areas at the paleo-northern (now western) outer shelf to a late Hunnebergian glauconite introduction in the Moscow Interior Basin. It is proposed that the reason for the multiple global regressive event (CRE) is connected with a short-term major polar expansion of inland glaciers on the Ordovician Gondwana supercontinent, or alternatively with a major impact or with the slightly earlier (mid-Tremadoc) Finnmarkian or Sandomierz orogenic pulse which involved the northernmost part of the active lapetus and the Tornquist-Teisseyre margins of the East European Platform. The paleotopography and basin dynamics of the EEP during the Early Ordovician apparently reflected pre-Phanerozoic basement structures and response movements of Late Proterozoic granitic blocks and intervening aulacogens. Palynological and lithofacies data support a possible juxtaposition of the Urals margin and the Moscow Basin with respect to peri-Gondwanan terranes of central Europe.

INTRODUCTION

The "*Ceratopyge* Regressive Event", acronymed "CRE", [20] defines a "swarm" of globally effective marine lowstands near to but distinctly below the top of the Tremadoc Series as defined by the IUGS Working Group on Ordovician Chronostratigraphy [4: see Fig. 2]. This multiple regression event is documented lithologically and faunally virtually throughout all hitherto known Lower Ordovician platform shelf sections. It is here suggested that the distinctive turn-over of major fossil groups seen globally between the top of the Tremadoc and the base of Arenig is directly related to this prominent regressive event as was already proposed by Fortey [32] and Erdtmann [20].

Among the many more or less coeval heterofacial discontinuity contacts around the world, however, most "classic" appears to be a distinct disconformity or at least a massive sandstone interbed below a dolerite sill between the upper Tremadoc Afon Gam Fm. and the Garth Grit Mbr. of the "mid"-Arenig Carnedd lago Fm. at the historic Tremadoc and Arenig sections (e.g. at Ceunant-y-garreg-ddu) on the east side of Harlech Dome in northern Wales [57, 29, 66, 43, 139]. This break was originally proposed by Charles Lapworth [57] to form the diastem between the Cambrian and Ordovician Systems in Great Britain and elsewhere. In Scandinavia, however, the Cambro-Ordovician boundary was originally drawn

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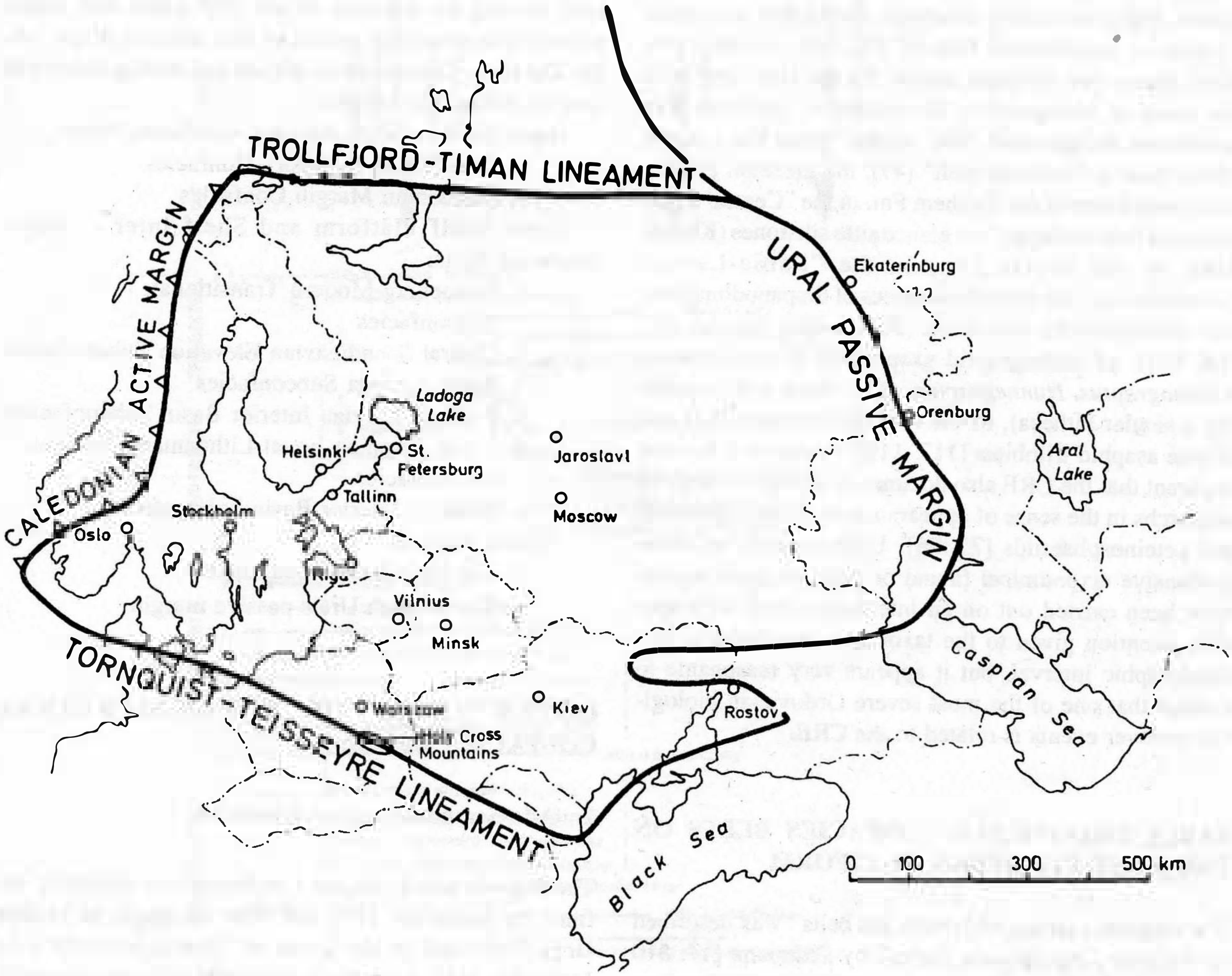

Fig. 1.

at the base of the *Dictyonema* Shales (i.e. first appearance horizon of *Rhabdinopora praeparabola,* Erdtmann [19]) by Moberg [76], although Moberg [74, 75] strongly originally favoured a Cambro-Ordovician boundary at the base of the *Ceratopyge* Limestone. Already Groom [38] favoured the first appearance beds of "*Dictyonema*" *sociale* to form the base of an Ordovician Tremadoc Series also for the British succession. Nevertheless, the importance of the *Ceratopyge* Limestone as a significant marker bed in Scandinavia was recognized already by Moberg (1882) and Brögger [7] and in its modern concept as a biological, sedimentological and geochemical "event" by Erdtmann [16, 17], Henningsmoen [43], Fortey [32], Erdtmann [19, 20, 21, 22, 23], Lindholm [60] and Löfgren [65]. In most of the inner shelf facies type sequences of east-central Poland ("Podlasie Basin") and in the Moscow Syneclise a single or a narrow series of distinct sedimentological breaks or lithological contacts appears to mark probably the same event which is here referred to as the "*Ceratopyge* Regressive Event" (CRE) of Erdtmann [20]. It is important to note that, although hematitic, phosphoritic and/or glauconitic lag horizons may indicate subaquatic erosion in certain sections, there is little, if any, evidence for subaerial erosion halos of transported clasts, or of subaerially weathered corrosion horizons anywhere to be observed on the East European Platform. At several locations of the transitional outer to inner (e.g. Hunneberg Mountain, SW Sweden) and inner shelf regions (e.g. in Västergötland, Östergötland and Öland, Sweden, central Estonian, south Lithuanian and NE Polish uplifts, etc.) there apparently existed long-term topographic rises which either lack Tremadoc sediments altogether or document their extremely condensed presence only. Almost uniformly, however, the "latest Tremadoc" (= pre-**T. approximatus Zone**) Hunneberg or Leetse siltshales or glauconitites transgress both the *Ceratopyge* Limestone or Varangu Claystones, or even directly overlie Middle to Upper Cambrian strata. The Hunnebergian transgression was probably one of the most extensive transgressions during the Ordovician on an interregional scale.

Paleobiologically the "*Ceratopyge* Regressive Event" appears to signify a quite sharp evolutionary incision. Cordylodan conodonts, such as *Paltodus deltifer* and many others ([64, 50]) became extinct during the CRE as well as bithecae-bearing graptolites [22, 23, 136, 60] and the latest epigones of olenid trilobites (Ebbestad, pers. comm. 1994) also nearly disappear during the *Ceratopyge* Limestone depositional interval [35, 36]. On the other hand, many new lineages appear for the first time wirh the onset of transgressive Hunnebergian greenish-gray mudstones (Hagastrand Mbr. of the Töyen Fm.) in the "Oslo-Scania Confacies Belt" [47], the greenish glauconitic limestones of the Tunhem Fm. in the "Central Scandinavian Subconfacies", or glauconitic siltstones (Klooga Mbr. of the Leetse Fm.) in the "Baltic-Ladoga Subconfacies": the first appearances of drepanodontiform and oistodontiform conodonts *(Paroistodus proteus,* etc. [64, 65]), of dichograptid graptolites (*Clonograptus, Araneograptus, Hunnegraptus,* etc. - some still possessing a sicular bitheca), of the first chitinozoans [83] and of true asaphid trilobites [117, 119]. Recently it became apparent that the CRE also documents a major change of acritarchs in the sense of appearance of rhopaliophodiids and peteinosphaeriids [73, 86]. Unfortunately no comprehensive taxonomical faunal or palynological studies have been carried out on an interfacies level with specific attention given to the taxonomic turnovers at this stratigraphic interval, but it appears very reasonable to assume that one of the most severe Ordovician biological turnover events is related to the CRE.

EARLY ORDOVICIAN CONFACIES BELTS ON THE EAST EUROPEAN PLATFORM

The original concept of "confacies belts" was described by the term "stratigenetic facies" by Erdtmann [17: 510 sequitur] as follows: "...the term 'stratigenetic development' is used for regionally distributed stratigraphical sequences similar in age, lithology, and fauna, and thus in depositional history". The term "confacies belt" was later defined by Jaanusson [47: 308] as being "...characterized by common biofacies trends and certain recurrent lithofacial features", i.e. Jaanusson expressed the same concept in a much more convincing and elegant way than ever attempted before. The configuration of paleogeographically defined "belts" proposed by Jaanusson, however, were meant to represent the Baltic-Scandinavian parts of the East European Platform (EEP) during Middle Ordovician times, whereas Erdtmann's "stratigenetic facies regions" were originally limited to Norway and Sweden and applicable to the Early Ordovician times. It is here proposed to use Jaanusson's term "confacies" and extend it regionally to all Baltic states and to Poland and Russia, where possible, and to establish certain "subconfacies", where logical and necessary. To avoid confusion with the (rather similar) Middle Ordovician paleogeographic confacies belts of Jaanusson [47 sequitur] new geographic terms are introduced here.

The extent of the pre- and post-CRE depositional environments and associated fauna and palynoflora across the East European Platform (Fig. 1) will be briefly outlined and discussed (Fig. 2). This will be done within the regional confacies or subconfacies units of those countries sharing the territory of the EEP today and which present a sedimentary record of this interval (Figs. 3A-D). The Early Ordovician confacies and subconfacies will here be defined as follows:

Outer Shelf or Shelf-marginal Confacies Belts:
1. Oslo-Scania-Lysogory Confacies
2. Caledonian Margin Confacies

Inner Shelf Platform and Shelf Interior Basin Confacies Belts:
1. Hunneberg-Modum Transitional Subconfacies
2. Central Scandinavian Elevation Subconfacies
3. Baltic-Ladoga Subconfacies
4. Podlasie-Latvian Interior Basin Subconfacies
5. South Estonian-Lovat-Lithuanian Elevation Subconfacies
6. Moscow Interior Basin Subconfacies

Special Regions:
1. The Holy Cross Mountains
2. The western Urals passive margin

OUTER SHELF OR SHELF-MARGINAL CONFACIES BELTS:

1. Oslo-Scania-Lysogore Confacies

The Oslo-Scania-Lysogore Confacies was originally defined by Erdtmann [17] and later (to apply to Middle Ordovician and in the sense of "confacies belts") by Jaanusson [47]. By today's standards of biostratigraphic resolution this confacies belt, when fully developed, represents the most complete record of Upper Cambrian to Lower Ordovician depositional continuity in the Scandinavian part of the EEP. At selected localities there may be ultra-condensed intervals or short breaks located at the top Cambrian *("Acerocare* **Regressive Event":** Erdtmann [20]), between the middle Tremadoc **Adelograptus tenellus Zone** and the **Bryograptus broeggeri Zone** (**"*Peltocare* Regressive Event":** Erdtmann [20]), and at the top of the *Ceratopyge* Limestone (CRE: Erdtmann [20]). In this confacies belt the Hunnebergian transgression is developed as a greenish-grey clay- or siltstone with rhythmically intercalated mm-thin black shale horizons (e.g. at Slemmestad, SW of Oslo and within the city of Oslo), whereas at the Hunneberg Mountain localities and W of Slemmestad (Vestfossen, Modum) a condensed dark glauconitic limestone *("armata*-Limestone") may be developed, instead. This transitional lithology is here referred to as "Hunneberg-Modum Subconfacies" (Fig. 3B and below).

There are more than 20 sections in published records which embrace the CRE in the Oslo Depression (Fig. 2). The northernmost sections are just within the Caledonide Åsen-Röa Nappe in Snertingdalen, NW of Gjövik ([30], personal observations 1993) and the southernmost out-

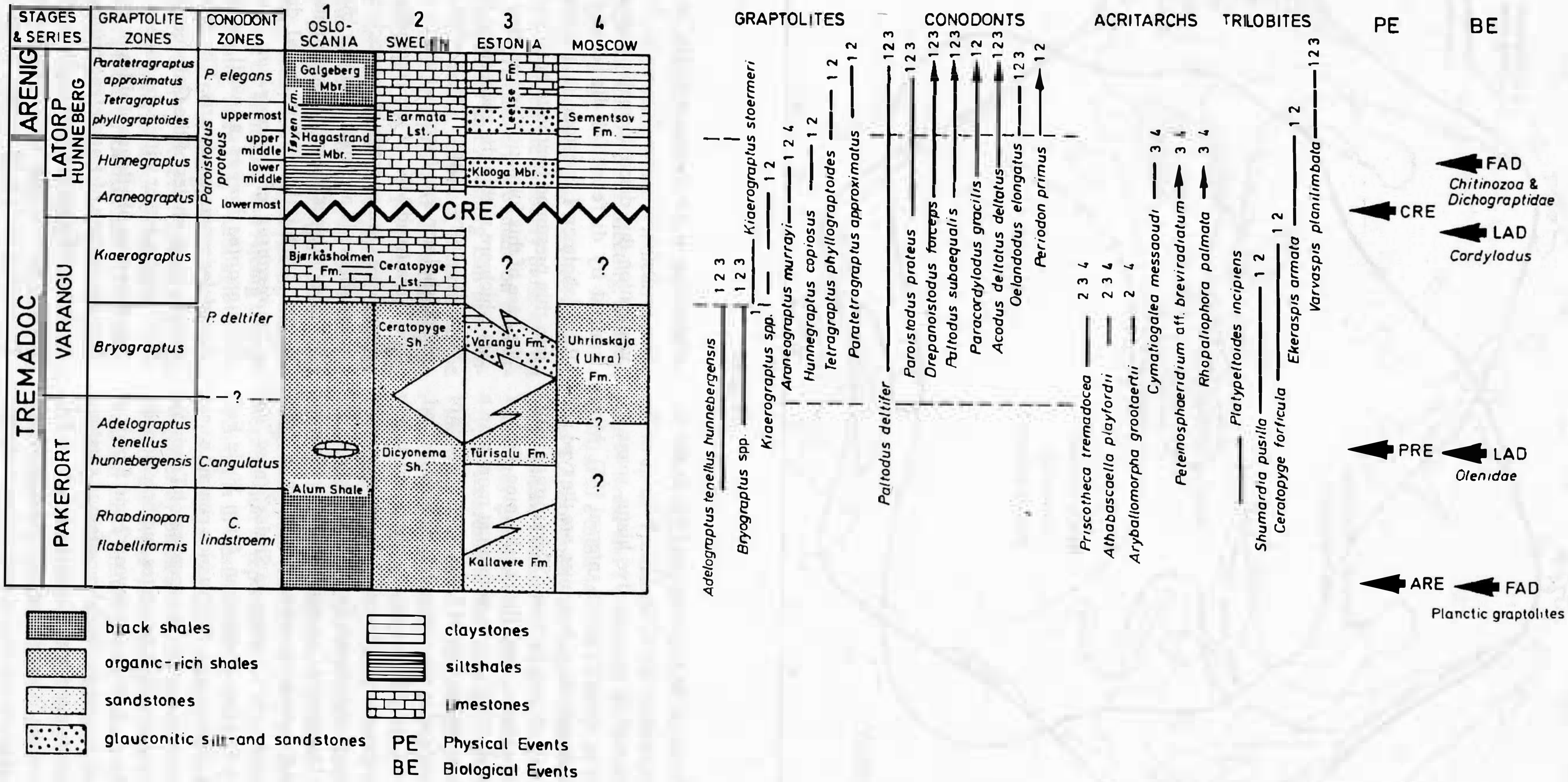
STAGES & SERIES
GRAPTOLITE ZONES
CONODONT ZONES
1 OSLO-SCANIA
2 SWEDEN
3 ESTONIA
4 MOSCOW
ARENIG
LATORP
HUNNEBERG
TREMADOC
VARANGU
PAKERORT
Paratetragraptus approximatus
Tetragraptus phyllograptoides
Hunnegraptus
Araneograptus
Kiaerograptus
Bryograptus
Adelograptus tenellus hunnebergensis
Rhabdinopora flabelliformis
P. elegans
Paroistodus proteus
uppermost
upper middle
lower middle
lowermost
P. deltifer
C. angulatus
C. lindstroemi
Galgeberg Mbr.
Tøyen Fm.
Hagastrand Mbr.
Bjørkåsholmen Fm.
Alum Shale
E. armata Lst.
Ceratopyge Lst.
Ceratopyge Sh.
Dicyonema Sh.
Leetse Fm.
Klooga Mbr.
Varangu Fm.
Türisalu Fm.
Kallavere Fm
Sementsov Fm.
Uhrinskaja (Uhra) Fm.
CRE
black shales
organic-rich shales
sandstones
glauconitic silt-and sandstones
claystones
siltshales
limestones
PE Physical Events
BE Biological Events
GRAPTOLITES
Adelograptus tenellus hunnebergensis
Bryograptus spp.
Kiaerograptus spp.
Kiaerograptus stoermeri
Araneograptus murrayi
Hunnegraptus copiosus
Tetragraptus phyllograptoides
Paratetragraptus approximatus
CONODONTS
Paltodus deltifer
Paroistodus proteus
Drepanoistodus forceps
Paltodus subaequalis
Paracordylodus gracilis
Acodus deltatus deltatus
Oelandodus elongatus
Periodon primus
ACRITARCHS
Priscotheca tremadocea
Athabascaella playfordii
Aryballomorpha grootaertii
Cymatiogalea messaoudi
Peteinosphaeridium aff. breviradiatum
Rhopaliophora palmata
TRILOBITES
Platypeltoides incipiens
Shumardia pusilla
Ceratopyge forficula
Ekeraspis armata
Varvaspis planilimbata
PE
BE
CRE
PRE
ARE
FAD Chitinozoa & Dichograptidae
LAD Cordylodus
LAD Olenidae
FAD Planctic graptolites

Fig. 2.

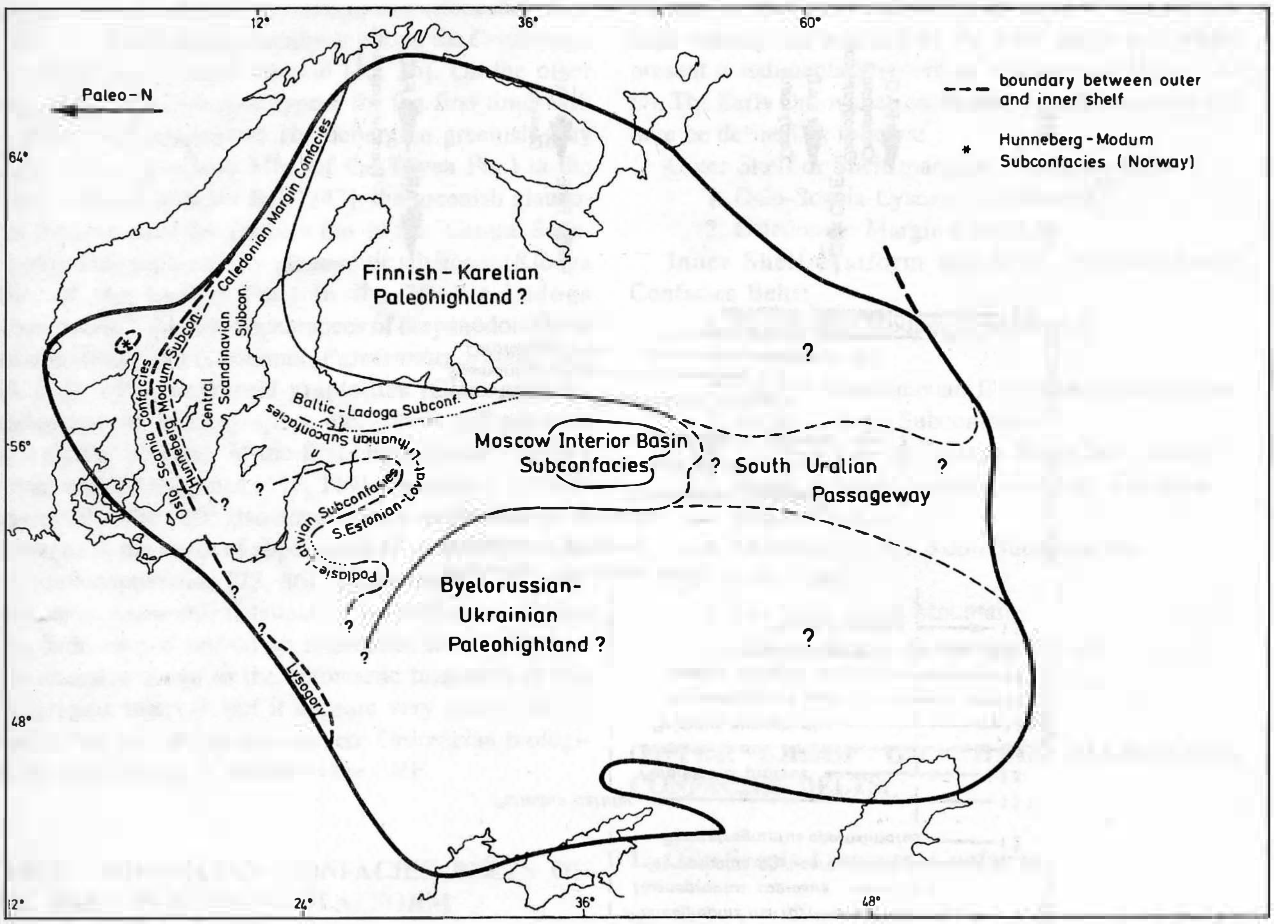

Fig. 3A

crops are at Vestfossen, W of Drammen [30]. In the actually southernmost outcrops of the Oslo Region, in the Skien-Langesund region, an extensive hiatus spans the Upper Cambrian to lower Llanvirn interval [85]. Most important to this investigation, however, are the type and paratype sections of the former "Ceratopygekalk" (*Ceratopyge* Limestone, now Björkåsholmen Fm. of Owen, Bruton et al. [85]) whitch outcrop at more than a dozen localities within the City of Oslo, on the islands of the Inner Oslofjord and in the community of Slemmestad, ca. 45 km SW of Oslo. These sections characteristically reflect the "Oslo-Scania Confacies" with an apparently complete stratigraphical record from the Middle Cambrian, across the Uppermost Cambrian *Acerocare* to basal Tremadoc ***Rhabdinopora praeparabola*** **beds**, encompassing ca. 10 meters of "*Ceratopyge* Shales" (now "upper beds" of the Cambro-Ordovician Alum Shale Formation of Owen, Bruton et al. [85]) which contain a condensed but presumably complete sequence of Tremadoc black shale facies graptolites, trilobites and brachiopods, to be followed by ca. 1.00 m of between 2 and 5 beds of dense accretional limestones with gypsiferous siltstone, shale, and glauconite interbeds of the Björkåsholmen Fm. The top 10 cm of the "Ceratopygekalk" usually consist of a very dense glauconitite which may appear to have a disconformable contact with the overlying green-grey silty shales of the Hagastrand Mbr. (e.g. at the type section on Björkåsholmen Peninsula), but upon closer investigation this disconformable contact may have been caused by differential diagenetic processes. The Björkåsholmen Limestone is accompanied by several mm-thin presumed bentonite beds: one ca. 60 cm below the base of this formation and another two bentonite layers which are within the succeeding Hagastrand Mbr. at slightly more than 1 m above the top of the Björkåsholmen Fm. (personal observations 1992, 1993). The Hagastrand Mbr. of the Töyen Shale Fm. consists of several tens to hundreds of microcycles of thicker grey-green siltbands and much thinner black shale laminae. Some of the black shales contain abundant graptolite fragments, especially of horizontal dichograptids, e.g. *Clonograptus* cf. *norvegicus, Hunnegraptus* and *Tetragraptus longus* as well as rare specimens of *Paradelograptus onubensis*. The transition to the continuous black shales of the Galgeberg Mbr. of the Töyen Shale occurs either within the zone of first occurrence of **Tetragraptus phyllograptoides** or slightly higher, at the first appearance of **Paratetragraptus approximatus** - the latter defining the base of the Arenig. The interval of the Hagastrand Mbr. measures between 6.50 m (Oslo-Töyen) and 9.70 m (Rortunet, Slemmestad) in thickness and until now represents an "interegnum" between the

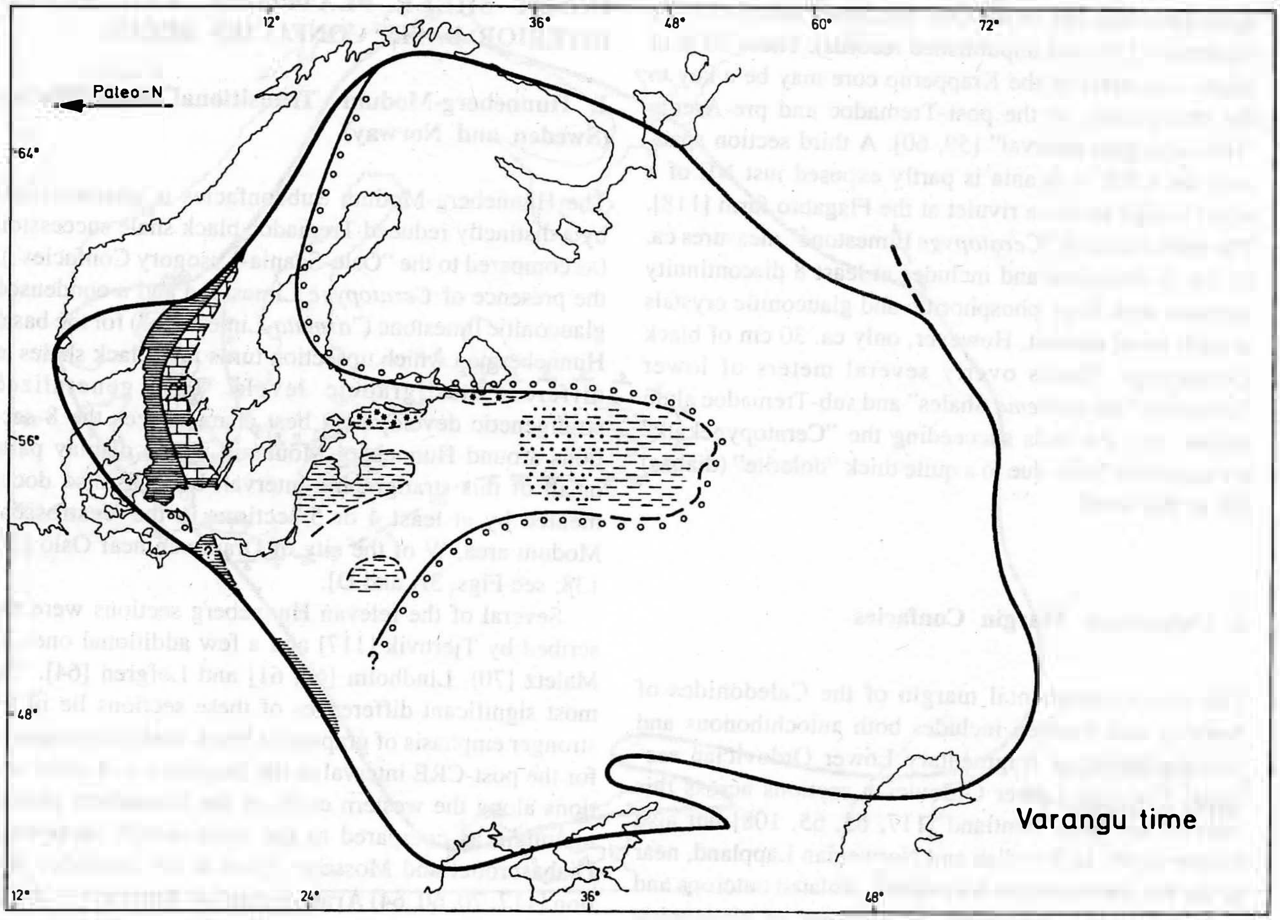

Fig. 3B

top Tremadoc Björkåsholmen Fm. and the FAD of *Paratetragraptus approximatus* which is indicative of the base of Arenig (Subcom. Ordov. Strat. Meeting, Sydney, Australia, 1991; see below).

With regard to the representation of the CRE the most complete sections in Sweden are probably those known from Scania and from Hunneberg Mountain on the border between Västergötland and Älvsborg Län in southern and west-central Sweden. However, sections on the Danish Island of Bornholm [93] and the stratigraphic record of the "Petrobaltic Core No. G14-1/86" ca. 15 km to the east of the German Island of Rügen [91] display an extensive hiatus covering the interval between the lower Tremadoc *"Dictyonema* Shale" (***Rhabdinopora fabelliformis***-bearing **beds**) and the upper Arenig Skelbro Limestone. Thus, most of Tremadoc and Arenig depositional records are missing there [93] - although this region belongs to the platform marginal "Oslo-Scania-Lysogory Confacies" [17]. Recent studies of the palynomorphs from the lowermost cored beds of the borehole "Rügen-5" has produced transitional "Tremadoc-lower Arenig" acritarchs ("*trifidum*-flora") which clearly document a peri-Gondwanan or Avalonian palynofacies for the subsurface Ordovician of Rügen "...showing no similarities to the Baltic palaeoprovince" [102].

The Fågelsång core section [41] in SW Scania records 5.80 m of Tremadoc black shales (equivalents of the *Dictyonema* and *Ceratopyge* Shales of the Oslo region), 0.70 m of a multi-layered *Ceratopyge* Limestone (including 5 discontinuity surfaces!) followed by ca. 10 cm of an "*armata*-Limestone" equivalent and 30 cm of glauconitic grey-greenish siltshales probably of Hagastrand Mbr. type. According to the fossil list of Hede ([41]: Table 2) the lower record of his **"Didymograptus balticus Zone"** contains *Clonograptus* aff. *norvegicus, Herrmannograptus* (= *Clonograptus* Monsen, 1937: [61]) and "*Didymograptus filiformis*" (= ?*Kiaerograptus* cf. *supremus* [60]). These first black shales definitely indicate a pre-**P. approximatus** position at that level in the Fågelsång core (Lindholm [60]: 292). Another relevant core section is reported from Krapperup at the Hoganäs Peninsula in westernmost Scania [59, 61] which may either substitute the CRE-induced "Ceratopyge-kalk" altogether by black shales or, alternatively, this core ends within the lower Hunnebergian shales prior to having reached the "Ceratopygekalk". More than 50 m of pre-**T. phyllograptoides Zone** black and grey shales include **Araneograptus murrayi** and, at its base, **Kiaerograptus supremus** a graptolite that is known to occur in black shale laminae within the "Ceratopygekalk" or

Björkåsholmen Fm. of the Oslo and Slemmestad sections (Erdtmann [16] and unpublished records). These 50 m of graptolitic strata of the Krapperup core may be a key to the stratigraphy of the post-Tremadoc and pre-Arenig "Hunnebergian interval" [59, 60]. A third section spanning the CRE in Scania is partly exposed just NE of a small bridge across a rivulet at the Flagabro farm [118]. The quite massive "*Ceratopyge* Limestone" measures ca. 90 cm in thickness and includes at least 8 discontinuity surfaces with large phosphoritic and glauconitic crystals at each basal contact. However, only ca. 30 cm of black *Ceratopyge* Shales overly several meters of lower Tremadoc "*Dictyonema* Shales" and sub-Tremadoc alum shales, and the beds succeeding the "Ceratopygekalk" are unknown there due to a quite thick "dolerite" (diabas) sill at this level.

2. Caledonian Margin Confacies

The active continental margin of the Caledonides of Norway and Sweden includes both autochthonous and parautochthonous fragmentary Lower Ordovician sections. The best Lower Ordovician sections across this interval are from Jämtland [117, 63, 65, 108] but also further north, in Swedish and Norwegian Lappland, near to the Finnish border at Kilpisjärvi, isolated outcrops and erratic boulders document the presence of glauconitic limestones that may be either related to the "Ceratopygekalk" or to the "*armata*-Limestone", but these lack the diagnostic trilobites. In general, this confacies belt seems to represent only discontinuous successions across the Upper Cambrian to Arenig interval. However, the discontinuities are probably more of structural than of depositional nature caused by the beginning "unrest" of the Grampian and Finnmarkian orogenic pulses.

Within the parautochthonous region of Cambro-Ordovician rocks in Jämtland only a small roadside pit to the east of Brunfloviken, ca. 15 km SE of Östersund has yielded ca. 8 cm of pebbly phosphoritic and glauconitic dark limestone containing a mixed redeposited and autochthonous conodont assemblage which is ascribed to the **Paltodus deltifer Zone** containing *Paltodus varanguensis* in its lower part and *Paroistodus numarcuatus, Distacodus peracutus* and *Acodus tetrahedron* in the upper part [108]. An island lakeshore section on the Island of Andersön in the Storsjö Lake of Jämtland exposes an allochthonous sequence which demonstrates the presence of the "*armata* Limestone", but this overlies the lower Tremadoc "*Dictyonema* Shales" with an apparent disconformity [113, 117], thus proving a possible later development of pertinent chemocline conditions along the Iapetus margin of the EEP resulting from westward step-by-step uplifting due to an approaching island arc chain.

INNER SHELF PLATFORM AND SHELF INTERIOR BASIN CONFACIES BELTS:

1. Hunneberg-Modum Transitional Subconfacies (Sweden and Norway)

The Hunneberg-Modum Subconfacies is characterized by a distinctly reduced Tremadoc black shale succession (as compared to the "Oslo-Scania-Lysogory Confacies"), the presence of *Ceratopyge* Limestone and a condensed glauconitic limestone ("*armata*-Limestone") for the basal Hunnebergian which upsection turns into black shales at different stratigraphic levels. This generalized stratigenetic development best characterizes the 8 sections around Hunneberg Mountain which display parts or all of this stratigraphic interval, but it is also documented by at least 4 or 5 sections in the Vestfossen-Modum area, W of the city of Drammen near Oslo [30, 138: see Figs. 3A and D].

Several of the relevan Hunneberg sections were described by Tjernvik [117] and a few additional ones by Maletz [70], Lindholm [60, 61] and Löfgren [64]. The most significant differences of these sections lie in the stronger emphasis of graptolitic black shale development for the post-CRE interval at the Storeklev and other sections along the western cliffs of the Hunneberg plateau mountain as compared to the northeastern sections at Diabasbrottet and Mossebo. Even at the Storeklev section [117, 70, 60, 64] **Araneograptus murrayi** is absent and this zone is substituted by thin "*armata*"-Limestone, but the **Hunnegraptus copiosus Zone** is in its distinctive dark graptolitic shale development at Storeklev and also evidently placed below the first appearances of *Tetragraptus phyllograptoides* and *Paratetragraptus approximatus* [70]. *Hunnegraptus copiosus* also occurs at Holsbrottet [70: 22], but at all other Hunneberg sections the graptolitic shale development starts higher upsection. The *Ceratopyge* Limestone (called "Tunhem Fm." by van Wamel [130]) is present at all the historic alum shale pits and caverns which now form the most significant - but progressively collapsing sections around Hunneberg Mountain.

The Norwegian sections on the western flank of the Oslo-Depression (striking NNE-SSW) are also transitional in lithofacies between the "Oslo-Scania-Lysogory Confacies" and the "Central Scandinavian Confacies" because the Tremadoc beds are restricted to only a few cm of "*Dictyonema*" and "*Ceratopyge* Shales", ca. 60 cm of *Ceratopyge* Limestone and less than 1 m of glauconitic "*armata*-Limestone" [30, 138]. As stated above, this development fully resembles the "stratigenetic facies" [17] of the Hunneberg Mountain sections [117, 64] in west-central Sweden. The biostratigraphic inventory of this "Modum-Vestfossen" development is limited, but trilobites of the *Ceratopyge* and "*armata*-Limestone" predominate [30]. Much less is known about the fauna of the underlying and overlying beds with respect to the CRE.

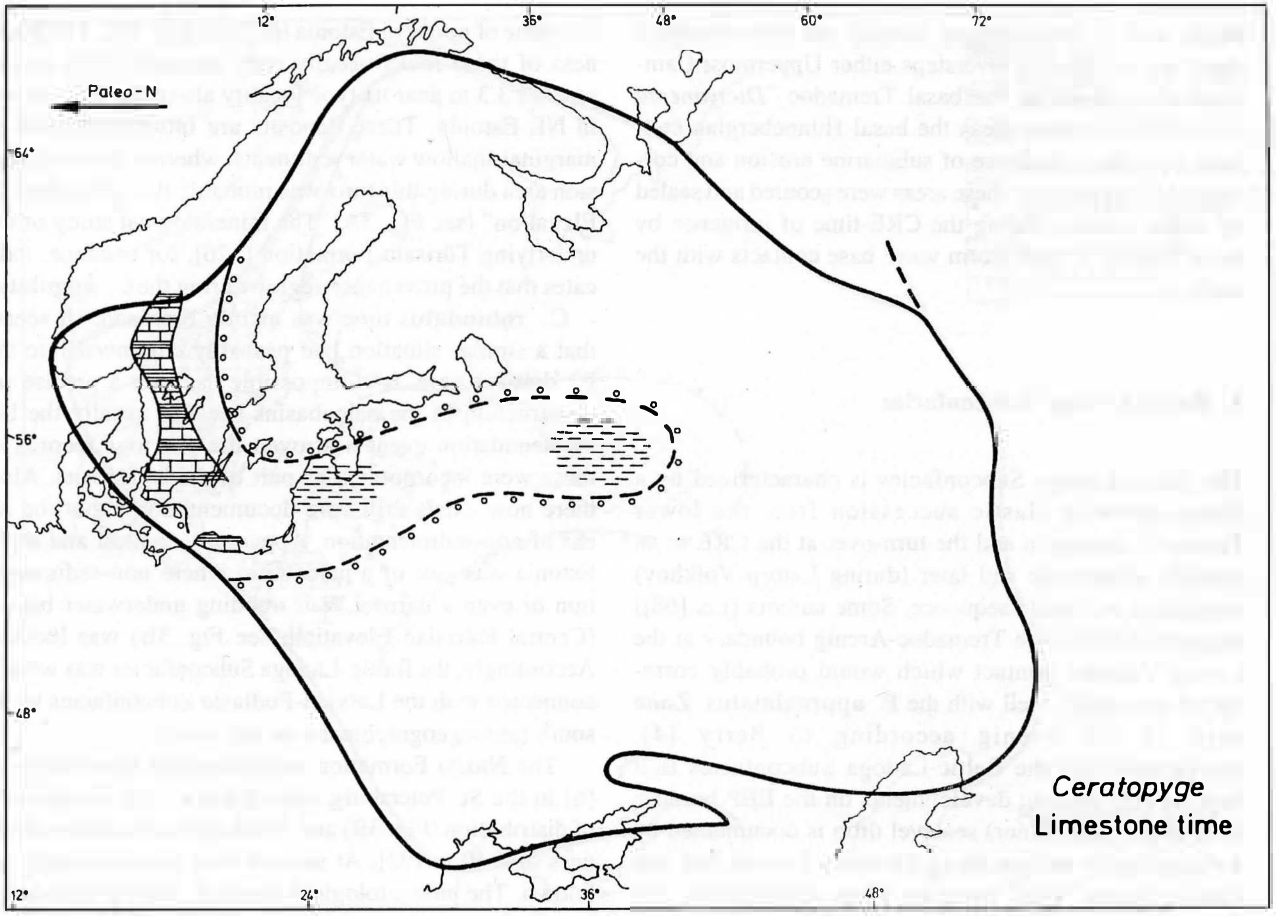

Fig. 3C

2. Central Scandinavian Elevation Subconfacies

The "Central Scandinavian Confacies" characteristically displays a strongly reduced stratigraphic spectrum near the CRE. The Tremadoc consists of very thin discontinuous segments of "*Dictyonema* Shales", very thin middle or upper Tremadoc *Ceratopyge* Shales, glauconitiferous *Ceratopyge* and "*armata*-Limestone" and thin limestone bands belonging to the Hunneberg Stage. In centrally located areas of parts of Billingen, Närke, Östergötland, northern Öland and Dalarna the Hunnebergian transgression usually starts with a thin glauconitic "*armata*-Limestone" directly overlying either cm-thin "*Dictyonema* Shale" or even the Upper Cambrian Alum Shales containing *Peltura scarabaeoides* at the top. Here the topmost Cambrian (*Acerocare* beds) and the entire Tremadoc is usually absent. Nevertheless, at least 10 sections are known to include the *Ceratopyge* Limestone from southern Öland and parts of Västergötland in central Sweden. In the subsurface borings from the Island Gotska Sandön N of Gotland and from File Haidar on Gotland [116, 114, 1] a transition to the "Baltic-Ladoga Subconfacies" may be encountered in the presence of Tremadocian (?) sandy mudstones (Estonian-type upper "Kallavere" equivalents?) **below an extensive Tremadoc hiatus spanning the interval of these "Kallavere-type" sandstones and Llanvirnian "platyurus"-Limestones.**

Due to the extensive Tremadoc hiatus the CRE is rather poorly preserved in the region of the "Central Scandinavian Confacies", although the *Ceratopyge* Limestone is present at several localities, e.g. at the Brattefors "outgassing" crater at Kinnekulle Mtn. [115, 112] in the Stenbrottet quarry, E of Mösseberg Mtn., at Stora Backor, W of Mösseberg Mtn. [117], and at several localities on southern and central Öland, east-central Sweden [117]. At all these localities Tremadoc beds, except the basal *Dictyonema* Shales, are notably condensed to a few cm or dm of glauconitic and phosphatic shales ("Djupvik Fm." [130]) or absent. The overlying Hunnebergian is usually also restricted to a few cm of richly glauconitic beds of the "*armata*-Limestone" (called "Köpingsklint Fm." by van Wamel [130]). South of Ottenby on the southern tip of Öland there appears to exist a gradual transition between the typical developments of the "Oslo-Scania-Lysogory" and the "Central Scandinavian Confacies" [1]. On the other hand, at the Kinnekulle and Billingen Mountains in Västergötland the *Ceratopyge* Limestone is absent, but the Hunnebergian transgression begins with a very thin and richly glauconitic limestone belonging to the "*armata*-Limestone", and also a little further to the northeast and east, in the regions of Dalarna, Närke and in Östergötland usually the Hunnebergian transgression directly oversteps either Uppermost Cambrian alum shales or the basal Tremadoc "*Dictyonema* Shales". In all these areas the basal Hunnebergian contacts may show evidence of submarine erosion and corrosion [1]. Apparently these areas were scoured and sealed by oxide staining during the CRE-time of influence by wave base or at least storm wave base contacts with the seafloor.

3. Baltic-Ladoga Subconfacies

The Baltic-Ladoga Subconfacies is characterized by a fining-upwards clastic succession from the lower Tremadoc upsection and the turn-over at the CRE to an initially glauconitic and later (during Latorp-Volkhov) condensed carbonate sequence. Some authors (f.e. [68]) suggest to define the Tremadoc-Arenig boundary at the Latorp-Volkhov contact which would probably correspond reasonably well with the **P. approximatus Zone** base of the Arenig according to Berry [4]. Stratigraphically the Baltic-Ladoga Subconfacies Belt best reflects eustatic developments on the EEP because each major (and minor) sealevel drop is documented by a discontinuity surface along the many Finnish Bay and Ladoga coastal "klint" outcrops. These discontinuity surfaces usually are not caused by subaerial or even submarine erosion but more likely by non-sedimentation or possibly sediment omission. In contrast to this subconfacies belt in basinal settings, e.g. in the Podlasie-Latvian and Moscow Interior Basin Subconfacies a more extensive fineclastic succession accumulated which becomes glauconitic and "marly" at the onset of the Hunnebergian transgression, but which is characterized by a relatively thick (up to 100 m in the core of the Moscow Basin) partly bituminous virtually continuous claystone succession for the Tremadoc-Hunnebergian interval. The shoals of the South Estonian-Lovat-Lithuanian Elevation Subconfacies are defined by strongly reduced to lacking Tremadoc deposits and often show onlaps of Hunnebergian beds directly on top of Upper Cambrian to lower Tremadoc "Kallavere" Sandstones, thus displaying strong confacies similarity with the Central Scandinavian Confacies of Sweden and Poland (see Fig. 3D). In this subconfacies a reasonably precise stratigraphic definition of the CRE is also more difficult, similar to Central Sweden.

The analogues of the upper *Ceratopyge* Shales in the Baltic-Ladoga Subconfacies are represented by the Varangu and Nazija Formations ([69]; authors' comment: Table 1 in Männil [69] is unfortunately wrong by correlating "Varangu" with a "Tremadoc **approximatus Zone**"). The lithology of both units is similar and represented by glauconitic siltstones and claystones. The distribution area of the Varangu Formation is limited to a W-E trending kidney-shaped region parallel with the coastline of northern Estonia ([42; see Fig. 3B). The thickness of these rocks usually only measures 0.15 m and reaches 3.3 m near its type locality along the Selja-River in NE Estonia. These deposits are interpreted here as marginal shallow water sediments, whereas the main erosion area during this time was probably the "Paleofinnish Elevation" (see Fig. 3A). The mineralogical study of the underlying Türisalu Formation [126], for instance, indicates that the provenance region during the **C. angulatus - C. rotundatus** time was mainly Finnland. It seems that a similar situation had probably continued into the **P. deltifer** time. It is impossible to make a precise reconstruction of the paleobasins because usually the latest denudation event destroyed the previous records or these were incorporated as part of those deposits. Also, there now exists drill core documentation about the areas of non-sedimentation. Apparently, central and south Estonia was part of a paleobasin where non-sedimentation or even a narrow W-E trending underwater barrier (Central Estonian Elevation; see Fig. 3B) was located. Accordingly, the Baltic-Ladoga Subconfacies was weakly connected with the Latvian-Podlasie Subconfacies to the south (paleogeographically to the west).

The Nazija Formation established by Borovko et al. [6] in the St. Petersburg district has a very limited area of distribution (Fig. 3B) and developed a maximum thickness of 0.40 m [92]. At present only five outcroups are known. The paleontological material, mainly conodonts, inarticulate brachiopods and acritarchs allows to correlate the Varangu as well as the Nazija formations with the upper Tremadoc graptolite **Kiaerograptus cf. primigenius Zone** [51], the conodont **P. deltifer Zone** [131, 132] with the acritarch **"Priscotheca tremadocea-Athabascaella playfordii"** association [133, 87] and with inarticulate brachiopods [67, 6, 92]. The question is: Are the *Ceratopyge* Limestone analogues represented in the Baltic-Ladoga Subconfacies? Probably, this time interval is only represented by a hiatus (see Fig. 2). However, calcareous glauconitic siltstones recorded from the boring F-366 in Hiiumaa Island [87] are characterized by an acritarch assemblage that may be slightly younger than the "typical" Varangu assemblage of mainland Estonia. The maximum regression phase (= ?*Ceratopyge* Limestone development of the Oslo-Scania-Lysogory Confacies) is probably not represented by any time-equivalent deposit in the Baltic-Ladoga Subconfacies but possibly in the Latvian and Moscow Interior Basins (see below).

The base of Leetse Formation, being characterized by the Klooga Member (Fig. 2), which consists of glauconitic more or less argillaceous and calcareous siltstones best indicates the onset of the Hunnebergian transgression. The distribution area of Klooga Member is nearly the same as that of the Varangu Formation. The lower boundary of Klooga Member is usually sharp and is commonly represented with shell-debris of the brachiopod *Obolus* and small (?phospatic) pebbles. Therefore, it is possible that the Baltic-Ladoga Subconfacies was a cor-

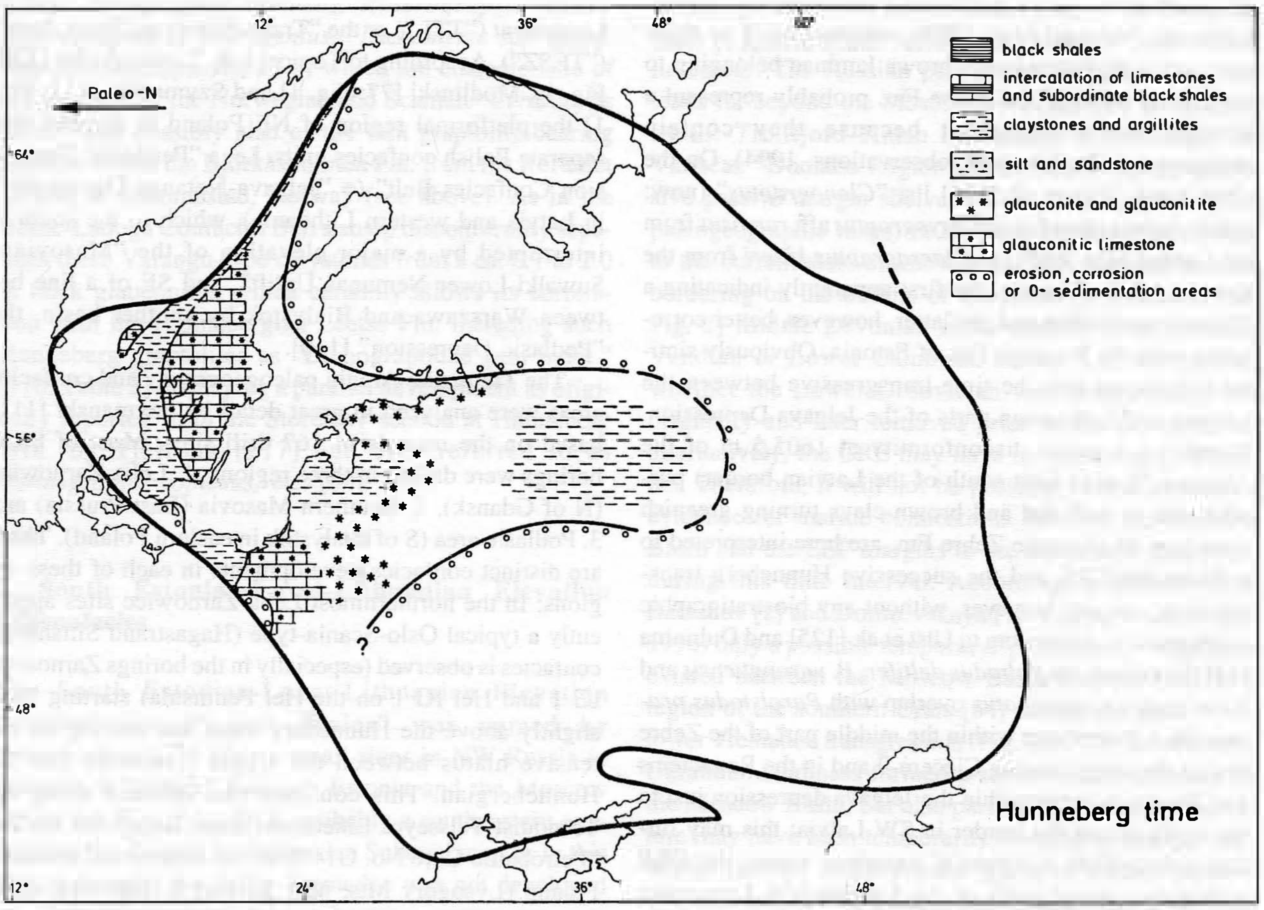

Fig. 3D

rosion or non-sedimentation area at the time of the maximum regression (CRE).

4. Podlasie-Latvian Interior Basin Subconfacies (incl. Kaliningrad District)

Except for the coastal klint exposures along the Finnish Bay and the southern shores of Ladoga Lake there are no further outcrops of Lower Ordovician beds in Estonia nor in the neighbouring Baltic countries Latvia, Lithuania, the Kaliningrad District of Russia and in epicratonic Poland. Instead, the depth of the pertinent beds gradually dips southward to reach 2650 m below today's surface in northernmost Poland. In the South Estonian-Lovat-Lithuanian Elevation Subconfacies (Figs. 3A, B, D) an extensive disconformity separates top Cambrian to Tremadoc Kallavere Sandstone from the characteristic Leetse glauconitite indicative of the Hunneberg transgression, but within the Podlasie-Latvian Confacies of Latvia and NW Lithuania a similar hiatus above Kallavere Sandstones is believed to be transgressed by the grey-purplish claystones of the Zebre Fm. [107] which are correlated with the middle Tremadoc Türisalu Fm. of NW Estonia as well as with Varangu equivalents in SE Latvia [44: Table 4]. However, no recent information on the biostratigraphic range of the Zebre Fm. exists at present which may indicate that the Zebre Claystones in the "Podlasie-Latvian Subconfacies" possibly encompass both the Türisalu, Varangu, Klooga and Leetse Fms., altogether in their characteristic deepest basinal lithology, as claystones (see below).

As stated above, all information about the extent of Lower Ordovician rocks and their biostratigraphy as well as their diastems south of the Finnish Bay klints can only be obtained through investigations of hundreds of basement penetrating cores which had been drilled in the Baltic republics during the Soviet times. However, the available information about detailed stratigraphy of these cores at the specific CRE level from recent literature [44, 90] is rather general. According to Ulst et al. [125] and Paškevičius [90] SW Latvia and adjacent NW Lithuania belong to the "Jelgava Depression" and to the axial central Latvian-Lithuanian "Notanga Depression" which is bordered to the SE by the eastern Latvian to central Lithuanian "Lower Nemunas" (Memel) Elevation" which, in turn, belongs to the "South Estonian-Lovat-Lithuanian Subconfacies Belt". Of these regions only in the "Jelgava Depression" the brown organic claystones of the Palukne Mbr. may correspond to the Türisalu Fm. of Estonia (Erdtmann and Paalits, pers. observ. of the Akmenė-71 core kindly made available by Dr. J.

Laškovas, Vilnius, May 1993), whereas ca. 1 m thick grey-green claystones with brown laminae belonging to the Lutrini Mbr. of the Zebre Fm. probably represent a Klooga Mbr. equivalent because they contain chitinozoans (Paalits, pers. observations, 1994). On the other hand, Ulst et al. [125] list "*Clonograptus*" (now: *Adelograptus) tenellus* and *Bryograptus* aff. *ramosus* from the Lutrini Mbr. and i. al *Kiaerograptus kiaeri* from the Kumbri Mbr. of Latvia, the first apparently indicating a Türisalu equivalent and the latter, however, better correlating with the Varangu Fm. of Estonia. Obviously similar lithologies may be time-transgressive between the Latvian and Lithuanian parts of the Jelgava Depression. Overlying a minor disconformity at 1605,5 m of the Akmenė-71 core (just south of the Latvian border) purplish red to dark red and brown clays turning greenish upsection of the same Zebre Fm. are here interpreted to indicate the CRE and the successive Hunneberg transgression - as yet, however, without any biostratigraphic confirmation. According to Ulst et al. [125] and Dubinina [14] the conodonts *Paltodus deltifer, P. varanguensis* and *Paroistodus numarcuatus* overlap with *Paroistodus proteus* for a short range within the middle part of the Zebre Fm. at the neighbouring Ciecere-9 and in the Ragaciems and Ventspils cores within the Jelgava depression just to the north across the border in SW Latvia; this may further substantiate a potential transition across the CRE within the central parts of the Latvian-NW Lithuanian Jelgava Depression.

In the Russian Kaliningrad District (former northern East Prussia) there are three cores from the western parts which reached into the Lower Ordovician. According to Laškovas (pers. comm. 1993) boulder-size volcaniclastic conglomerates have been observed at the base of Leetse glauconitites in the drilling core "Vladimirovo-1" south of Kaliningrad. The source of these volcaniclastics is unknown, but possibly they may be related to volcanic pipes near the Tornquist-Teisseyre Line, to intraplate rifting or to a contemporary as yet undetected local impact event (see above: bentonites near the *Ceratopyge* Limestone at Slemmestad in the Oslo Region).

Approximately one third of the northeastern territory of Poland belongs to the pre-Vendian consolidated epicratonic East European Platform. Except for very few outcrops in the southern parts of the Swietokrzyskie (Holy Cross) Mts., which may be considered as a separate terrane (see below), there are no Lower Ordovician outcrops in epicratonal Poland, instead more than 160 deep borings have penetrated Ordovician rocks at depths between 2650 m in the north and only a few hundred meters in the SE [77, 111]. To the SW the platformal margin is defined by an abrupt system of parallel fault lineaments striking from the Pommeranian Baltic Sea coast near Slupsk following the Vistula River along a line N of Bydgoszcz, Torún and Warszawa to continue on to Lublin and eventually adjoining the Alpine-Carpathian front near the northern Slovak border with Poland. This lineament belongs to the central part of the Tornquist-Teisseyre Lineament ("TTL") or the "Trans-European Shear Zone" ("TESZ"). According to Tomczyk & Tomczykowa [120: Fig. 1], Modlinski [77: Fig. 1] and Szymanski [111: Fig. 1] the platformal region of NE Poland is divided into separate Polish confacies units, i.e. a "Peribaltic Depression Confacies Belt" (= "Jelgava-Notanga Depression" in Latvia and western Lithuania), which to the south is interrupted by a major elevation of the "Masovian-Suwalki-Lower Nemunas Uplift", and SE of a line between Warszawa and Bialystok by another basin, the "Podlasie Depression" [110].

The Tremadoc-Arenig paleogeography and confacies areas were analyzed in great detail by Szymanski [111] based on the records of 167 drill sites. Most of these borings were drilled in three regions: 1. Leba-Zarnowiec (N of Gdansk), 2. Southern Masovia (East Prussia) and 3. Podlasie area (S of Bialystok in eastern Poland). There are distinct confacies developments in each of these regions: In the northernmost Leba-Zarnowiec sites apparently a typical Oslo-Scania-type (Hagastrand Siltshales) confacies is observed (especially in the borings Zarnowiec IG 1 and Hel IG 1 on the Hel Peninsula) starting from slightly above the Hunneberg base, but leaving an extensive hiatus between the Upper Cambrian and the Hunnebergian. This confirms that inboard along the Tornquist-Teisseyre Lineament from Bornholm via the "Petrobaltic Core No. G14-1/86" to central and southern Poland (Lysogory Mts. near Kielce) a ridge-like uplift developed and spread eastward into Lithuania during most of the Tremadoc starting from the end of the "*Dictyonema*" Shale transgression. During the Hunneberg transgression and upsection into the Arenig (Töyen Shale facies; see Fig. 3D) this uplift was once again incorporated into an outer shelf-type black shale facies belt [121, 111]. A similar claystone-dominated Hunnebergian lithofacies also extended slightly eastward as a "North Pommeranian Tongue", where it was encountered in the "Leba" and "Zarnowiec IG 1" borings ([137], Erdtmann, pers. observ. 1977). This confacies belt may have been temporarily connected with the "Jelgava and Notanga Depressions" of the Kaliningrad District, western Lithuania and Latvia. According to personal information by Dr. W. Bednarzcyk (1993) at several borings in the Gdansk area (especially at "Bialogora 1" and "Gdansk IG 1") thin nodular limestone beds (*Ceratopyge* Lst. equivalents?) containing *Paltodus deltifer* have been encountered below glauconitic grey shales containing *Paroistodus proteus,* thus correlating directly with the Hagastrand lithology and conodonts of the "Oslo-Scania-Lysogory Confacies Belt" for the post-CRE transgressive development as described above (Fig. 3D).

A second basinal confacies "tongue" is developed from a pre-Vendian rift-graben in the eastern Polish "Podlasie Depression" [110] extending from S of Bialystok eastward into Belarus N of Brest. From several dozens of borings complete records of ca. 4 m thick Tremadoc organic shales are described by Szymanski [110: Table 2], which in the top 1.50 m contain the graptolites *Bryograptus ramosus, Kiaerograptus kiaeri, Kiaerograptus* cf. *primigenius, "Dictyonema* sp." (probably *Araneograptus*?), all of which are characteristic of the top beds of the Norwegian and Scanian *"Ceratopyge* Shale" and possibly also of the thin graptolite-bearing horizon within the Björkåsholmen Fm. from the Rortunet section at Slemmestad, Norway (see above). As in the Baltic-Ladoga Confacies Belt a sharp disconformity separates these Varangu-type claystones from a ca. 0.7 to 2.0 m thick glauconitite which certainly allows its correlation with the Hunnebergian Leetse Fm. including such Hunneberg graptolites as "Dichograptidae gen. indet." [110: Table 2] displaying a parallel development as originally reported from the Storeklev section at Hunneberg Mtn. by Tjernvik [117] and now referred to as *Hunnegraptus copiosus,* etc. [60].

5. South Estonian-Lovat-Lithuanian Elevation Subconfacies

The South Estonian-Lovat-Lithuanian Elevation Subconfacies ("Lovat Facies" was named by Dmitrovskaja [11] after a small river in NW Russia to describe a "barrier" between Estonia and the Moscow Basin; see Figs. 3A - D) is probably a southeastern analogue to the Central Scandinavian Subconfacies as in this area apparently the entire Tremadoc was not developed or, alternatively, eroded by submarine current scouring during the CRE. This corresponds to the Östergötland-Närke and Dalarna districts of Sweden and to NE Poland (see above). Within certain shallow depressions, such as the "Notanga Belt" [90] at least remnants of the top Cambrian/Lower Tremadoc Salantai Sandstones may show that a more complete sequence may have been developed prior to the CRE, however, the glauconitic Hunnebergian Leetse Fm. follows everywhere in central and southeastern Lithuania above a distinct disconformity at ca. 760 m depth. According to the "Ordovician Stratigraphic Scheme" published by Paškevičius [90] virtually everywhere in Lithuania except in the "Jelgava Depression" there is such an extensive hiatus developed between the Salantai Mbr. and the richly glauconitiferous Leetse Fm. Investigations of the Salantai/Leetse contacts may produce erosional pockets and scouring surfaces which may be related to the winnowing effects of CRE-induced wave or storm-wave contacts with the seafloor. In southeasterly direction this hiatus widens toward the "Belarussian-Ukrainian Paleohighlands" (Fig. 3A).

6. The Moscow Interior Basin Subconfacies

By far the largest complex of platformal Lower Ordovician sediments relevant to the CRE probably occurs in the subsurface of Russia. Many hundred cored well borings penetrate the Lower Ordovician of the European parts of Russia which includes the Moscow Syneclise in its center. The Russian part of the EEP, however, extends far beyond the Moscow Syneclise and is bordered by the Trollfjord-Timan Lineament in the north, the Variscan "Donbass Region" in the south and the extensive passive margin shelves of the Ural basins (see all paleogeographic maps) in the east. However, according to the current state of knowledge from the core records bordering on the outline of the Moscow Syneclise [10: Fig. 2] Middle Devonian rocks usually directly overly Vendian or Lower Cambrian strata. It is not known, whether the Lower Ordovician was more widespread originally and later removed prior to the Devonian or, alternatively, the CRE may have initiated this great hiatus. Therefore, it will not be possible to find any direct evidence for marine connections between the Moscow Basin and the EEP margins to the north, east, and south during this time interval. According to Balashova & Balashov [2] and Dmitrovskaya [10-12], personal comm. 1990) only a possible temporary "passageway" may have existed between the Moscow Basin and the Orenburg region of the southern Urals [84] during the peak of the lower Tremadoc transgression (Fig. 3A). The Belarussian-Ukrainian landmass formed a southwestern treshold for the Moscow Basin, but also parts of this emergent structure may have been temporarily covered by marine conditions (similar to the Finnish-Karelian region) because they did not provide a major provenance region for clastic aprons during regressional events such as the CRE. The deep subsurface paleogeographic configuration of basins and rises both on the Russian and Scandinavian parts of the EEP probably reflects late intraplate epeirogenic response movements to the pre-Vendian aulacogens which were developed all across the Russian-Ukrainian parts of the EEP [5, 31].

As far as the available literature reveals [11: Fig. 2], a "western Moscow Basin confacies" may be distinguished from an "eastern" deeper-water basin with its approximate center near the town of Jaroslavl during the Early Ordovician. The shallower western "facies" is characterized by sandstones for the Tremadoc and siltstones for the lower Arenig interval probably separated by a disconformable contact, whereas the central basin N of Moscow consists of grey argillites belonging to the Tremadoc Uhrinskaja Fm. which apparently succeed, without noticeable discontinuities, into the Hunnebergian Sementsov Fm. consisting of up to 30 m of gray and greenish slightly carbonaceous argillites at the type locality, the boring Leshkaja 1. The upper Tremadoc Uhrinskaja Fm. is defined at the boring "Danilovo-8" located directly at the presumed contemporary center of the Moscow Basin [11: Fig. 2], where its thickness is at a maximum of 35 m. Lithologically the Uhrinskaja Fm. does not resemble the Estonian Türisalu and Varangu claystones, whereas the Sementsov Fm. is lithologically similar to the Hagastrand Mbr. (Hunnebergian part of the Töyen Shale Fm. of the Oslo-Scania-Lysogory Confacies Belt). The graptolites listed by Dmitrovskaja [12: p. 24] for the Uhrinskaja Fm. are somewhat inconclusive for the precision dating needed, but "*Bryograptus ramosus*" and "*B. kjerulfi*" as well as "*Kiaerograptus kiaeri*" point strongly to a "*Ceratopyge* Shale" or Varangu equivalence of the Uhrinskaja Fm., whereas "*Tetragraptus phyllograptoides*" and "*Paratetragraptus approximatus*" from the lower Sementsov Fm. [12: p. 25] clearly indicate an early Arenig date (see Fig. 2). On the other hand, Dmitrovskaja (1991: p. 24) also lists "*Dictyonema* aff. *uralense, D.* cf. *murrayi* (sensu Monsen 1937 = *Araneograptus* Erdtmann & VandenBerg 1985), *Clonograptus flexilis, Adelograptus* sp. and *Temnograptus* sp. from the basal beds of the Uhrinskaja Fm. - all these forms could be interpreted as being characteristic of the pre-Arenig Hunnebergian interval as seen at Storeklev, Hunneberg Mountain and in the Hagastrand Mbr. of Oslo and Slemmestad (see above and Lindholm [60, 61]). The junior author investigated acritarchs from a core of the drilling site "Orehovo-1" near the eastern margin of the Moscow Basin, where he observed a distinctly disconformable contact between the greyishbrown Uhrinskaja and the greenish Sementsov Fms. (Paalits, unpublished data). From the published records it may thus be ascertained that the locations of the borings "Danilovo-1 to -8" are likely to represent the core of the Moscow Basin and also possess the highest potential for an uninterrupted succession across the CRE interval. The observations from "Orehovo-1" show that the marginal areas of the Moscow Basin apparently documented a hiatus at the CRE level similar to all but the marginal and deeper-water confacies of the Baltic-Scandinavian parts of the EEP. According to Dmitrovskaja [10, 11] the western parts of the Moscow Basin show faunal links with the Baltic-Scandinavian confacies regions, whereas the eastern basin may have temporarily been connected with the southern Urals as may be indicated by typically Baltic Tremadocian trilobites, such as *Ceratopyge forficula, Euloma ornatum* and *Geragnostus sidhenbladi* [2] and graptolites ("*Dictyonema uralense*" and "*Didymograptus klotschichini*", the latter being possibly related to *Kiaerograptus primigenius*) described from the Orenburg region [84]. Unfortunately no additional data could be obtained confirming or disproving the potential presence of CRE-related beds in the vast regions of eastern European Russia and the Ukraine belonging to the EEP between the Moscow Basin and the Urals margin.

SPECIAL REGIONS:

1. The Holy Cross Mountains

In southern Poland Lower Ordovician rocks are best known from a few outcrops and many drill cores of the Gory Swietokrzyskie (Holy Cross Mts.; Fig. 1). The Ordovician lithofacies are divided into a northern flank, the Lysogory Hills, which are separated by a probable northward thrust from the southern flank, the "Klimontow Anticlinorium" [55]. In the Lysogory Hills Lower Ordovician rocks are limited to a relatively thick and uninterrupted succession of topmost Cambrian and basal Tremadoc mudstones with large calcareous concretions succeeded disconformably by Caradoc black shales, whereas in the strongly (Variscan) deformed southern flank, within the narrow Kielce Syncline, *Thysanotus siluricus*-bearing sandstones initiate a new depositional cycle which unconformably overlie Lower Cambrian sediments. The stratigenetic facies of a probable Hunneberg to Arenig fining upwards cycle in the Kielce Syncline is of "Bohemian", e.g. Milina/lower Klabava type (or Frauenbach/Phycodes transition in the Schwarzburg Anticlinorium of Thuringia, Germany: Erdtmann [24]) containing a characteristic cold-water "peri-Gondwana-type" or "Bohemian-type" graptolite, trilobite and brachiopod fauna. Very probably the Lower Ordovician transgressive cycle of the Bohemian type represents the same general event as the Hunneberg transgression on the EEP, but it is of a distinctly different cold-water facies which clearly relates the southern flank deposits of the Swietokrzyskie Mts. to a separate terrane ("wrench terrane" of Erdtmann [24]), which was closer related to peri-Gondwana than to the EEP [58]. The northern flank of the Lysogory Hills, on the other hand, shows close bio- and lithofacies ties with the Oslo-Scania Confacies Belt and even more so, as far as completeness of the C/O boundary record is concerned, with the coeval active platform-marginal succession on the Digermul-Peninsula in northernmost Norway [97, 82]. However, just as on the Digermul Peninsula, the entire thick Upper Cambrian to Lowermost Tremadoc sequence of Lysogory ends abruptly near the top of the "*Dictyonema*" Shale sequence ("Finnmarkian orogeny" of Sturt, Pringle & Roberts 1975; [121]). Although a direct juxtaposition of coeval beds is not possible because of the pre-CRE termination of the Lysogory sequence and a post-CRE inception of the southern Kielce Syncline sequence, there are undoubtedly very different depositional environments involved between the deeper active platform-marginal EEP-type sequence in the north and a rift-basinal type cold-water post-CRE succession in the south. This intra-Silurian "camouflaged" transcurrent "Lysogory Fault" [55; Fig. 2] or "Holy Cross Dislocation" [58] certainly represents an exposed segment of the multiple-activated Caledonian "Trans-European Shear Zone" (TESZ) and appears to have its exact northern extension in the "Römö-Mön-Rügen Fracture Zone" of Katzung et al. [52], where also thick Silurian marine deposits fully conceal the same final "docking" event of the EEP against the Middle European peri-Gondwana terranes [91, 24, 102].

2. The western Urals passive margin

Along the western margins of the Urals Lower Ordovician rocks are quite common, but in most part as yet badly biostratigraphically dated [45, 46, 94]. Here apparently rift basins developed [95] during the Tremadoc-Arenig interval which contained thick suites of polymict clastic deposits possibly also indicating a cooler paleoclimate and closer paleogeographic apposition of the Uralian passive shelf margins to the peri-Gondwana environments of central and western Europe ("peri-Gondwanan terranes" of Van der Voo [129], Torsvik & Trench [123: Fig.2], Smethurst [106]). Palynofacies and paleoenvironmental data further substantiate a paleoclimatic south-oriented constellation of the Uralian margin of the EEP with regard to the central European peri-Gondwana terranes and thus would support the counterclockwise rotational course of the EEP for the Early Ordovician time as originally proposed by Torsvik et al. [122].

INTRAPLATE HETEROTAXIAL FACIES CORRELATION OF THE CRE ON THE EEP

It is surmised that extensive parts (if not all) of the East European Platform were submerged below the interface of tidal influence during most of the Ordovician Period. Except for island arc chains beyond the active margin of the Caledonides [8] only the territories of Fenno-Karelia, the "Byelorussian-Ukrainian Paleo-Highlands" and probably the eastern parts of European Russia may have emerged above the sealevel at times of major regressions (Fig. 3A). In virtually all other confacies regions mentioned above regression-induced erosional or corrosional disconformities are believed to have resulted from bathymetrically stepwise lowering of chemocline interfaces and/or mechanical current scouring (at elevated rises) of the sea floor affecting the chemoclines down to the deepest epicratonic troughs during these regression events. The "*Ceratopyge* Regressive Event" may thus be seen as such a physico-chemical response to one of the most extensive global regression events during the Ordovician Period [32]. However, due to the regional differences in chemistry of the partially silled watermasses and due to the inferred variations of current regimes between late Tremadoc and early Hunneberg sealevel high-stands and the CRE low stand, and due other regional topographic variations the geological "signal", attributable to the CRE, and preserved until today, is greatly different between the distinct confacies regions across the EEP. Furthermore, there are marginal intraplate basins, especially those facing open oceans, which may not show a distinctive signal for the CRE and thus may remain, as yet, undetected across the CRE interval as far as fithofacies variations are concerned. However, as demonstrated in the regional survey above, virtually not only in elevated, but especially in basinal settings, the CRE is documentable, at least as a single but more frequently as "multiple" lithological signal.

A characteristic step-wise migration of glauconite autigenesis is observed from a late Tremadoc initial occurrence in the top *Ceratopyge* Shales of the Oslo-Scania outer shelf basin to a late Hunneberg introduction of glauconite in the eastern parts of the Moscow Basin. By comparing the paleogeographic lithofacies distribution along with biostratigraphic constraints it is possible to estimate the relative "speed" and overall significance of the transgressional advances on the EEP during the Tremadoc: According to such "ranking" of eustatic pulses the most "vigorous" transgression in the Lower Ordovician was the early Hunnebergian one, followed by the advance of the "*Dictyonema*" Shale transgression at the base of the Tremadoc (following the ARE), thirdly by the *Ceratopyge* Shale transgression (following the PRE - see Fig. 2). Ranking the "impacts" of EEP-wide regressions, apparently the CRE was the most significant eustatic retreat, followed by the ARE and then by the rather "mild" lowstand of the PRE. However, one question remains unanswered: Are all these regression- (ARE-, PRE-, and CRE-) related signals (discontinuity surfaces, chemical impregnations, lag horizons, phosphorites, etc.) isochronous or at least penecontemporaneous?

At present the best method to approach an answer to this question is through a detailed ecobiostratigraphic correlation analysis based on all available micro- and macrofossil records and their environmental implications. Of course, such an analysis may be potentially handicapped by low time-resolution or by high endemicities of most of these fossils. As shown in Fig. 2, however, a high-level taxonomic turnover signal (pre-event extinctions and post-event innovations) occurs at this particular level of the CRE all across the EEP - and virtually on a global scale as well. The extinction of i. al. bithecae-bearing graptolites, of cordylodan conodonts, of nearly all olenid trilobites and the replacement of these by post-CRE dichograptid graptoloids, paroistodontiform conodonts, a "burst" of asaphid trilobites and the first appearance of chitinozoans, makes the CRE one of the most precise bio-event markers during the Ordovician on a global scale [20: Fig. 2]. No doubt, the distinct four or more discontinuities or micro-disconformities observed within the *Ceratopyge* Limestone by Hede [41], Tjernvik [117, 118], Tjernvik & Johansson [119] and by others concisely indicate that multiple phase epicratonic eustatics may have been reflected in finer-tuned oscillations at basinal settings than seen in elevated areas of submarine current scouring and erosion. Furthermore, especially along the Baltic-Ladoga Subconfacies Belt, it becomes evident that a long phase (beginning with Vendian arkoses) of clastic sediment deposition is replaced by carbonates exactly at the CRE as a "hinge point". In many other confacies regions there appears to be a turnover point at the CRE between badly ventilated seafloors to better ventilated sediments as far as oxygen supply would be concerned. Even in the less well dated sedimentary suites of the Urals (along the West Uralian Megazone) a distinctive change from rift-basinal polymict sandstones to oceanfloor cherts and volcaniclastics is observed between the Tremadoc and Arenig (K. S. Ivanov, pers. comm. 1994) - although this may have regional tectonic causes which probably are irrelevant to the CRE.

BIOSTRATIGRAPHIC RESOLUTION OF THE CRE

At present the optimum biostratigraphic resolution of the CRE on the EEP may be that obtained by Cooper & Lindholm [9] based on graptolites, placing the CRE between the top of the **Kiaerograptus supremus** and the bottom of the **Araneograptus murrayi Zones**, or, based on conodonts, between the top of the **Paltodus deltifer** and bottom of the **Paroistodus proteus Zones** [108, 64], or respectively between the **Rossodus manitouensis** ("Fauna C") and **Polycostodus minutus** ("Fauna D") **Zones** of the North American conodont sequence [50]. At the Brunfloviken section in Jämtland Sturkell (1991) and at the Ciecere-10 boring in Latvia [125] a short (3 cm) overlap interval between **Paltodus deltifer** and **Paroistodus proteus** is reported, thus indicating a potential complete transition and cut-out of the CRE in this extremely condensed section. For most of the EEP the trilobite zonation is not yet standardized, but the CRE would best be placed between the top of the **Apatokephalus serratus** and the bottom of the **Ekeraspis armata Zones** ([119], Ebbestad, pers. comm. 1994). The acritarch record is as yet deficient with regard to the scale of resolution comparable with that of graptolites and conodonts, but it appears that a "**Priscotheca tremadocea-Athabascaella playfordii** association" is replaced by a "**Cymatiogalea messaoudi-Rhopaliophora palmata** association" at the CRE in all EEP sections [87] and, less distinctly, within the peri-Gondwana facies and elsewhere. In the type Tremadoc-Arenig boundary sections of northern Wales a "...typical Tremadoc (acritarch) assemblage evolved gradually ... and was abruptly terminated before the Arenig" [13]. Among other fossil groups only chitinozoans may yield promising indices at this level, however, despite a previous record from the "Tremadoc ?" [37: p. 34], it is now confirmed that *Lagenochitina esthonica,* appears for the first time in the basal Hunnebergian (or Latorpian) Klooga Mbr. of the Leetse Fm. which lithologically strongly resembles the immediately subjacent Varangu Claystone in northern Estonia [83: Fig. 2]. The possibly oldest chitinozoan, *Lagenochitina destombesi,* however, is recorded from lower to middle Tremadoc (?) of Morocco [15], but in several other peri-Gondwanan confacies locations, such as one in Bohemia near the base of the Klabava Fm. [28], and from coeval beds of Algeria and presumably from other regions (e.g. South America?), *Amphorachitina conifundus* defines Hunnebergian strata in association with *Araneograptus murrayi* and *Clonograptus* spp. [88], although a late Tremadoc first appearance of *A. conifundus* is possible.

GLOBAL CORRELATIONS OF THE CRE

Although the geological record of lithogenetic and biofacies regimes may be regarded as uniquely well documented on the EEP during the Lower Ordovician, especially with regard to sensible responses of watermass alterations and preservation of original signals and a "mixed record" of cold- and warm-water biota [32, 9], a correlation of the CRE with potential coeval transitions from low sealevel to transgressional first order cyclicity ("reversal system tracts") is made difficult by low-level resolution of the "generalistic" pandemic fossils of all open-ocean or cooler climate Gondwana and peri-Gondwana terranes as well as by the high diversity and endemicity of warm-water fossils inhabiting palinspastically low-latitude continental plates and microcontinents during the Ordovician. Nevertheless, the post-Tremadoc/infra-Hunnebergian CRE interval apparently was a time of a distinct global eustatic minimum.

In the Czech Republic a detailed account across the probably CRE-coeval boundary between the top Tremadoc Milina Fm. and the basal beds of the Arenig Klabava Fm. has been recorded from Bohemia (Prague Basin) based on brachiopods [72]. Here it is demonstrated that a sharp break in the brachiopod community composition occurs, although most of the genera such as *Jivinella, Leptembolon* and *Orbithele* cross this formation boundary; the distinction lies generally on the species level. On the other hand, distinction within trilobites across the Milina/Klabava boundary appears to be much greater, as all Tremadoc genera such as *Ceratopyge, Orometopus, Apatokephalus, Harpides* and *Niobella* (which are also common in the Scandinavian *Ceratopyge* Limestone) abruptly disappear ca. 3 m below the Milina/Klabava formational boundary [72: Table 5]. The lowermost beds of the Klabava Fm. are also characterised by "upper" Hunneberg to earliest Arenig graptolites, such as "*Clonograptus* sp. A" (= *?Hunnegraptus* sp.), "*Acrograptus* sp." (= *? Didymograptus* cf. *balticus)* and *Temnograptus* sp. [56], first chitinozoans *Lagenochitina esthonica* and *Amphorachitina conifundus* [89, 28] together with such Hunneberg-early Arenig acritarchs as *Cymatiogalea messaoudi, Rhopaliophora palmata* and *Caldariola glabra* and the late Tremadoc to early Arenig *Stelliferidium trifidum* [28].

The type sections and especially their bases for Tremadoc and Arenig in Great Britain are still much debated (see above, and [33, 35, 36]). There are three completely different biogeographic "provinces" or biofacies involved in Britain: the Anglo-Welsh, the Lake District and the Girvan provinces. The Girvan province (Ballantrae Complex) may eventually produce the "Pacific" index graptolite *Paratetragraptus approximatus* for the base of the Arenig [100], but the peri-Gondwanan-type litho- and biofacies sequences of the Lake District and Anglo-Welsh provinces are apparently deficient with regard to this index form. All attempts at a biostratigraphically fully documentable section across the Tremadoc/Arenig boundary have completely failed in the United Kingdom so far [33: p. 10], although beds equivalent to those below *P. approximatus* and above the *Ceratopyge* Limestone (CRE) at Hunneberg Mtn. in Sweden [117] and in the Oslo Region, Norway [16, 17, sequ.] are in evidence within structurally complex sections at Trusmadoor in the Lake District [99, 79, 33]. However, in the Lake District as well as in southern Wales there is no transition as yet proven to exist between the top Tremadoc and the newly created lower Arenig "Moridunian Stage" of Fortey & Owens [34]. It appears most reasonable to assume that the best chances for such a transition to be found would exist in the Lake District, where the immediate post-CRE graptolite zone of **Araneograptus murrayi** is in evidence. The distinctive sandstones, grits (below and above the top Afon Gam dolerite sill) and quartzites (e.g. "Stiperstones Quartzite": Whittard [135]) in the classic sections of northern Wales and in Shropshire [36] may represent those "regressive interbeds" which were either the result of or at least related to the CRE, although Fortey & Owens [36: Fig. 2] claim these to indicate an equivalent to the transgressive Hunneberg Stage ([36: Fig. 2] correctly refer these to "prograding sands" which would be characteristic of regression-induced seawards prograding littoral sands).

Due to their thorough discussion of the cyclic "overturn" nature of the Stiperstones Quartzite and its significance to the concept of the British Tremadoc/Arenig boundary a short discussion of the conclusions put forth by Fortey & Owens [36: p. 558-561] appear advisable at this point: Based on the concept of a globally synchronous nature of the CRE (regardless whether as single or multiple event) these authors believe that the Stiperstones Quartzite is coeval with the *Ceratopyge* Limestone (instead of a basin enclosure and anoxia hypothesis within the Habberley Shales of Fortey & Owens [36]) and thus evidently upper Tremadoc in age. The CRE may either be positioned within the Stiperstones Quartzite or at its contact with the superincumbent Mytton Flags. It is more convincing to see a parallel development in the *trifidum*- and *Araneograptus murrayi*-bearing Mytton Flags with the *A. murrayi*-bearing Lower Hunnebergian Hagastrand Siltshales of the Oslo region, especially since *Stelliferidium trifidum* has to be regarded as a relatively long-ranging taxon which Rasul [96: p. 57] reports to occur already in the **Shumardia (Conophrys) salopiensis Biozone** of the Shineton Shales and which may, indeed, range into the **P. approximatus Zone** or its presumed "coeval" beds in the Watch Hill Grits of the Lake District [78]. Thus, "*trifidum*-bearing beds" may be pre- and/or post-CRE in age.

In epicratonic North American sequences the CRE break corresponds to the end of the "Saukian III Megacycle" and the onlap of the "Tippecanoe I Megacycle" of Sloss [104, 105] which may have regionally different names and different biostratigraphic definitions according to the distinctive facies settings on the North American continent straddling the paleo-equator at that time. Along the active Iapetus marginal setting of the Cow Head Group in western Newfoundland [49] within the distal mudsupported "Green Point Lithofacies" there is an exemplary transition from regression-induced distal-turbiditic "ribbon" limestones within La 2-dominated graptolitic mudshales (top of Broom Point Mbr. of James & Stevens [49] and massive red shales (bottom beds nos. 42 and 43 of St. Paul's Mbr. of James & Stevens [49]). Coeval red mudstone beds, probable indicators of oxygen advection from deep waters during an incipient transgression, are not only seen at correlative homotaxial facies horizons in other Cow Head and in Quebec sections (distinctly below the first occurrence horizon of *Paratetragraptus approximatus*, sic!), but also in the coeval red Olešna-facies (Fm.) beds of the basal Klabava Fm. (Klouček [54], Havliček [40]): in the Barrandian of the Czech Republic [72], at the base of the Ningkuo Shales along the southern Jiangnan Slope Facies of the Jangtze Platform (Yinchupu Red Shale Fm.: Ni & Fang [81: 61, 64-65, 69-70]) and probably elsewhere in coeval homotaxial facies settings (e.g. Muxiantougou Red Shales at north-east slope of the Sino-Korean Platform near Hunjiang in Jilin Province, China [134, 71]). These characteristic red mudstones may, indeed, present the precise "turning point" between the CRE and the incipient transgression within depositionally continuous continental slope or outer shelf marginal settings.

In the classic Victorian sections of Australia [27, 127, 128] the Angry Hill Sandstone Fm. may have its base at the CRE level (the horizontal *Araneograptus macgillivrayi* of La 2 beds of the "Tremadocian" Bryo Gully Shales is probably a precursor of the Hunnebergian *A. murrayi*). However, the occurrences of the pendent *Araneograptus pulchellus,* of *Clonograptus rigidus-flexilis* and other "Hunnebergian-type" graptolites in higher La2-beds indicate that the Bryo Gully Shales probably encompass the CRE in this outer shelf-marginal setting of the Bendigo-Ballerat Belt of central Victoria [128].

In northern Argentina, especially along the flanks of the Cerro San Bernardo in the city of Salta, a distinct ca. 3 m thick *Cruziana*-bearing sandstone bed was observed by the senior author in 1993, which intervenes into the mud-dominated "Formacion de San Bernardo" [39], i.e. between beds containing the trilobite *Apatokephalus serratus* and the graptolite *Araneograptus murrayi* (=

"*Dictyonema yaconense*" of Turner [124]). This ca. 3 m thick sandstone bed may here represent the local intercalation of prograding near-shore into outer shelf environments. In adjacent southern Bolivia (Abra Negra section, Erdtmann et al. in press) a distinct disconformity has been observed between the Tremadoc Cieneguillas Fm. and the *A. murrayi* and *Hunnegraptus copiosus*-bearing basal Obispo Fm. [103; Erdtmann et al., in press]. Also this disconformity, which in nearby localities is substituted by a strong intercalation of massive turbidites, the "Formacion Filoma" [98], is here proposed to be directly related to the prograding of turbidite provenance environments caused by the same event which may represent the CRE on the EEP. In most of the deep water sequences, of the cool-climate peri-Gondwana terranes, however, biostratigraphic resolution is as yet rather low, although pandemic graptolites such as *Araneograptus macgillivrayi* to *A. murrayi* and transitions of acritarch associations as those mentioned above may assist in identifying this event - even if lithological breaks or disconformable contacts are not clearly developed. Further south, in the "Midcontinent North American" type confacies of the San Juan Precordillera of Argentina [53] the "drowning" of an algal sponge mound complex ca. 30-50 m above the boundary between the La Silla and San Juan Limestone Formations may mark a corresponding "interval" of the CRE because the last appearance of *Paroistodus numarcuatus* overlaps with the first appearances of *Acodus? deltatus* and *Paroistodus proteus* within a 20 m interval of sponge-algal mounds within the basal San Juan Formation at Cerro La Silla [53: Fig. 4].

POSSIBLE REASONS FOR THE "*CERATOPYGE* REGRESSIVE EVENT"

Except for the older, i.e. late early or mid-Tremadoc Finnmarkian [109] or Sandomierz orogeny [101] of the Holy Cross Mts. there are no contemporary tectonic activities affecting the active EEP margins and which could be related to the obvious global extent of the regression during the CRE. Unfortunately no indications of decreased hot spot or oceanic rifting (MORB) activities could be observed in sediments from the stratigraphic vicinity of the CRE, which many provide indication of a Pitman-type regression. Neither have investigations yielded increased iridium or microtectite contents from contemporary sediments potentially relating the CRE to a major impact. Therefore, the reason for this profound short-term but also presumably multiple oscillation eustatic event could be at best assumed to be caused by pulsations of expansions and retreats of continental glaciers with a southpolar center having been located near the NW African/NE South American parts of the Gondwana Supercontinent. However, upon intense searching, only rather controversial "diamictites" or "tilloids" could be found anywhere on Gondwana from the middle Tremadoc "Formacion de Saladillo" of the Quebrada del Toro, ca. 90 km NW of Salta in northern Argentina [39, 25] which may support a glacial maximum hypothesis [32] near to the CRE. The rather unsatisfactory geological evidence for a glacial maximum at this stratigraphical interval, however, may be caused by many factors, of which subsequent erosion by the more extensive later Ordovician and Hirnantian glaciations may be only one reason [32], but also insufficient biostratigraphic dating potentials for a lacking glaciomarine erratic apron of the distant inland ice sheet may be yet another. Nevertheless, the authors tend to agree with Jaanusson's [48] statement that "The entire Ordovician Period was ... characterized by an extreme biogeographical differentiation of marine faunas..." and this, apparently, was caused by climatically strong amplitudes very similar to those of the Pleistocene.

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Бэрнд-Дитрих Эрдтманн, Иво Паалитс

ЦЕРАТОПИГЕВОЕ РЕГРЕССИВНОЕ СОБЫТИЕ (ЦРС) РАННЕГО ОРДОВИКА: КОРРЕЛЯЦИЯ И БИОДИНАМИКА НА ВОСТОЧНО-ЕВРОПЕЙСКОЙ ПЛАТФОРМЕ

Резюме

Позднетремадокский (ранний ордовик) "цератопигевый известняк" распространенный в южной Норвегии, Швеции и возможно в северной Польше позволяет решить вопрос о глобальном событии и многократно проявленной регрессии, которая в других частях Восточно Европейской платформы выражена перерывом в осадконакоплении или субмаринными поверхностями размыва. Биостратиграфически "цератопигевый известняк" отвечает самым верхам конодонтовой **зоны Paltodus deltifer**, граптолитвой зоне **Kiaerograptus supremus**, верхам трилобитовой **зоны Apatokephalus serratus** и верхам акритарховой ассоциации **Athabascaella playfordii**. Однако в других частях мира этот временной интервал ознаменован вымиранием кордилодиевых конодонтов, битскальных граптолитов и вероятно почти всех оленидовых трилобитов. Можно предположить, что причиной этой глобальной регрессии было кратковременное, но значительное по площади распространения материковое олединение в пределах ордовикского суперконтинента Гондваны, и менее вероятна связь с импактными или орогенными процессами.