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Ordovician oil shale of Estonia – Origin and palaeoecological characteristics

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ABSTRACT: The main, commercially important oil shale (kukersite) deposits in the Baltic Basin of Estonia formed in shallow, subtidal shelf conditions during the Kukruse Stage (late Llandeilo-early Caradoc) regressional phase. The kerogen of kukersite, where it is composed primarily of algal lumps of the blue green alga Gloeocapsomorpha prisca, is referred to as kukersine. The distribution of the different morphotypes of the algal remains, from grape-like aggregates to globules and to flattened lumps, reflects different patterns of accumulation in the kukersite beds. The kukersine is thought to have a possible algal mat origin, derived from tidal flats. Ostracodes occur abundantly in the kukersite beds, and their distribution seems to be related to facies patterns. The thickest beds have a great abundance of ostracode species, as well as concentrations of other shelly fossils.

1 INTRODUCTION

Kukersite and organic-rich shale containing the Gloeocapsomorpha-kerogen occur at three main stratigraphic levels in Lower-Middle Ordovician sequences of the World, namely: (1) in the upper Arenig-lower Llanvirn Kunda Stage in the Baltic Basin of Estonia, in the Goldwyer Formation of the Canning Basin (Foster et al. 1986), and the Horn Valley Siltstone of the Amadeus Basin (Summons & Powell 1991) of Australia; (2) in the lower Caradoc (Nemagraptus gracilis Zone) Uhaku and Kukruse Stages of the Baltic Basin, and in the Glenwood Formation of the Iowa Basin in North America (Hatch et al. 1987); and (3) in the upper Caradoc (D. multidens and D. clingani Zones) Keila and Rakvere Stages of the Baltic Basin, in the Guttenberg Member of the Decorah Formation of the Iowa Basin (Witzke 1987) and in the Red River Formation of the Williston Basin (Stasiuk & Osadetz 1990).

The Estonian oil shales form the largest and economically most important deposits, in particular, those from levels in the late Llandeilo-early Caradoc Kukruse Stage. The deposits have been exploited since 1916, and the total output has exceeded 770 million tonnes (Bauert & Puura, in Kaljo & Nestor 1990). Currently 6 underground mines and 3 open-cut mines are in operation in NE Estonia. Because of the gentle southward dip of the strata, the overburden removed in open-cut mining operations varies from 0-70 m. Commercially developed seams may comprise several 10-30 cm thick kukersite beds, up to 3 m thick. The Middle Ordovician stratigraphy of the Estonian kukersite-bearing succession is shown in Table 1.

In terms of the maceral, the kerogen of the kukersite includes Gloeocapsomorpha as well as the Gloeocapsomorpha-kerogen, so kukersine is introduced as a convenient term for both the recognisable microfossils of Gloeocapsomorpha and kerogens presumably derived from it. In addition to the original descriptions and photos of Gloeocapsomorpha and its kerogen from the Baltic Basin (Zalessky 1916), photos of analogous material have been illustrated from Iowa (Jacobsen et al. 1988) and from the Canning Basin (Foster et al. 1986).

The ideas about an allochthonous origin for the kukersine in the Baltic Basin have been presented by Öpik (1927). More recently,

Table 1. Diagram to show stratigraphic relationships of the numbered and lettered kukersite beds to the Baltoscandian Stages and British Series

British Series	Baltoscandian Series	Baltoscandian Stages	Formations & Mbrs (Symbols)	Kukersite beds
CARADOC	VIRU (MIDDLE ORDOVICIAN)	IDAVERE	C_{III}	
		KUKRUSE	$C_{II}P$	X, IX, VII, VII, VI, V, IV, III
			$C_{II}M$	II, I
LLANDEILO			$C_{II}K$	H, G, D-F, B+C, A
		UHAKU	$C_I c^2 E$	g-h, c-d, b
			$C_I c^2 P$	x_1
			$C_I c^2 K$	

Männil et al. (1986) suggested that the origin was associated with a hardground area that presumably bordered the Fennosarmatian continent, and was a suitable environment for the development of algal-microbial mats.

The algal mat origin of kukersine has been discussed in a number of papers (Foster et al. 1990; Kõrts et al. 1991). It seems most likely from the accumulation pattern of the kukersine in the Baltic basin that it was derived from benthic algal mats associated with a neighbouring hard ground area, rather than from a planktonic source. The accumulation area of kukersine spread along the margin of the Fennosarmatian continent, from the western part of the Baltic Basin in late Arenig to the Moscow Basin by the middle Caradoc.

The kukersine from the Baltic Basin is described below in terms of its distribution patterns and allochthonous origin. Only the precursor organism as well as the Gloeocapsomorpha prisca-kerogen is discussed. G. macrocysta that occurs in the late Caradoc Rakvere Stage of the Estonian sequence, and has been distinguished in the Galena Group of North America, is of a different origin.

2 KEROGEN OF KUKERSITE

2.1 Morphotypes of algal lumps

Kukersine is comprised of algal lumps (Fig. 1) the average diameter of which varies from 50 to 500 um; they rarely reach dimensions of 1-2 mm.

Studying the morphological characteristics, structure and distribution of these kerogen lumps, that might be called kuckers, it seems reasonable to differentiate three basic types (detailed description will be published separately):

I type - grape kuckers (aggregates) are composed of clusters of well-preserved capsule-like blue-green algal remains with relatively little homogeneous organic matrix. Aggregates are yellowish to yellowish-brown in colour (Fig. 1A,B).

II type - globular kuckers exhibit poorly preserved algal remains, with a more homogeneous organic matrix. They are brownish in colour (Fig. 1C,D).

III type - these are caramel-type, usually flattened lumps, and comprised of homogeneous organic matter, without capsule-like algal remains (presumably they never existed in them). Their colour is reddish brown (Fig. 1E,F).

Globular lumps are sometimes covered with caramel-type organic matter or surrounded by it. The latter may represent the gelatinous matter of the algal mat (former slimy matrix). The aggregates may have been former "colonies".

General size and shape of the kuckers may have been determined by the structure of the mat, thickness of the algal mat laminae (1-3 mm), sedimentation processes (including frag-

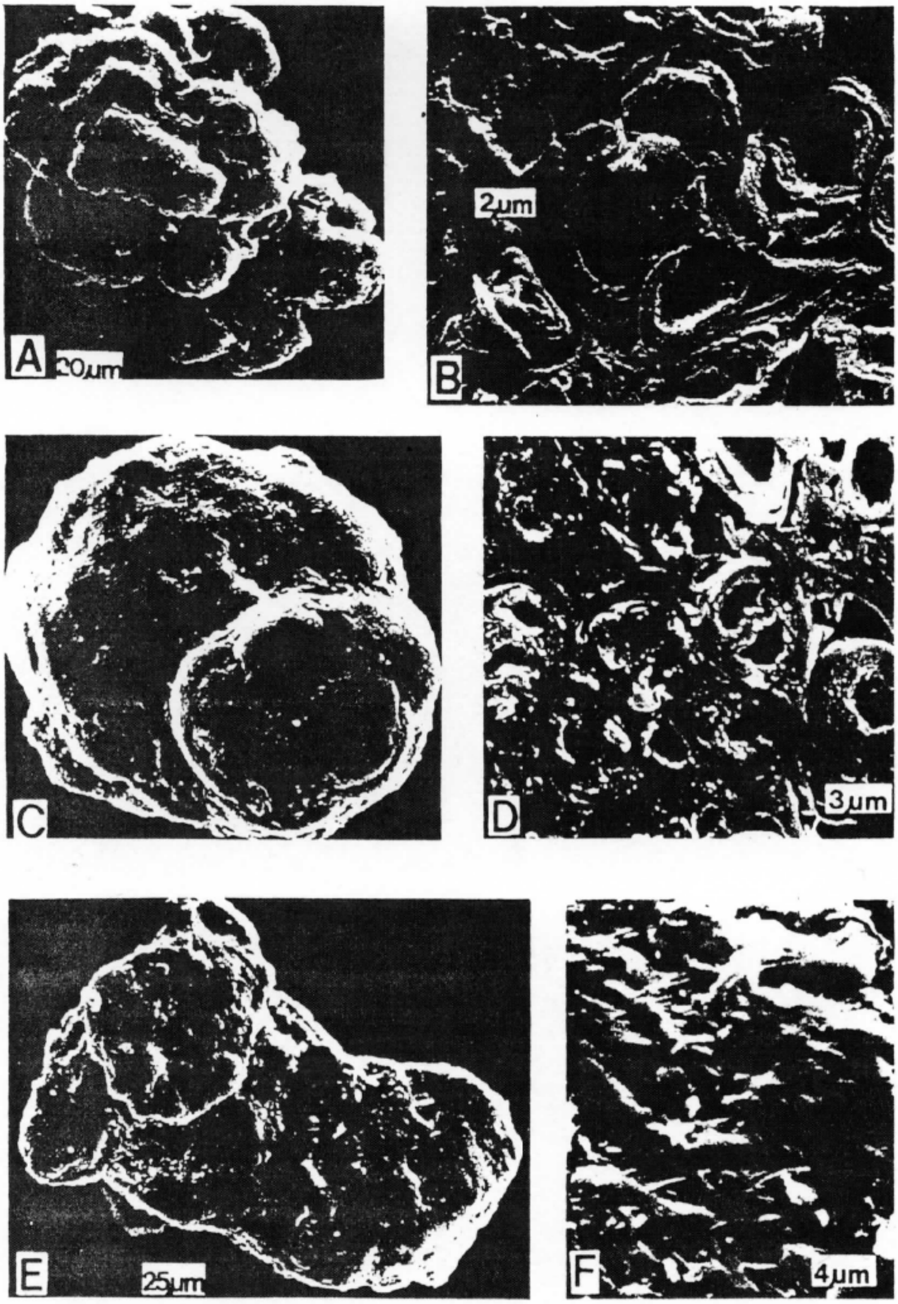

Fig. 1. Morphotypes of algal lumps (kuckers). A,B - I type, Kohtla borehole K-7 , Kukruse Stage; A, from bed F2 (limestone), and B, from bed C (kukersite). C,D - II type; C from Krapivno, Keila Stage (scale bar same as for A); D from Ülemiste, Kukruse Stage, bed C (kukersite). E, F - III type; E from Krapivno, Keila Stage; F from Kohtla borehole K-7, Kukruse Staage, bed B (kukersite).

mentation, degradation, and generation as secondary aggregates).

Jacobson et al (1988) have distinguished two organic matter assemblages in the oil source rocks of the Middle Ordovician Guttenberg Member in the Iowa Basin, and analysed their oil yield. They found that Assemblage A, which was associated with the organic-walled microfossil Gloeocapsomorpha, was substantially more oil prone. Of the two assemblages,

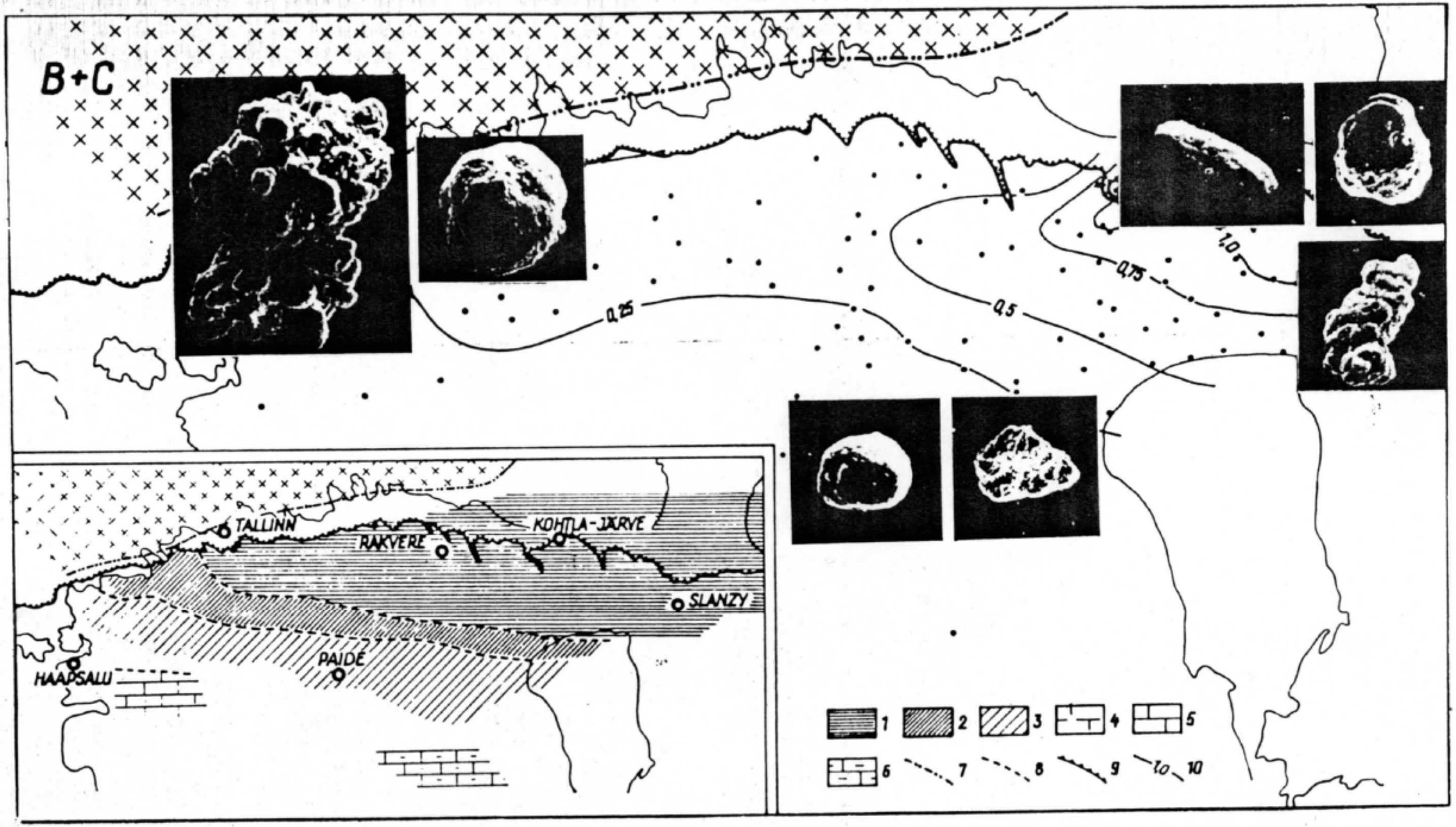

Fig. 2. Maps to show the distribution of dominant morphotypes of algal lumps (kuckers) in the kukersite bed B + C (lower Kukruse Stage). The facies schemes are after H. Bauert. Key to legend for both inset and larger maps as follows: 1 - kukersite with nodules of kukersineous limestone, 2 - kukersineous limestone with wavy kukersite layers, 3 - kukersinic limestone with thin kukersite layers, 4 - interpreted limestone, 5 - limestone, 6 - slightly argillaceous limestone, 7 - boundary of the hardground area, 8 - facies boundary, 9 - erosion boundary of the Kukruse Stage, 10, - isopach, metres. Note also areas with crosses are inferred as land, and fine continuous line represents the present-day Estonian shoreline. Also note that the algal lumps illustrated at top right are from Kohtla, centre right are from Ervita, and top left are from Ülemiste - see locations in Figs 4, 5. Specimens are represented at the same scale to emphasize relative size differences. Map scale: distance on inset map from Tallinn to Kohtla-Järve is 150 km; larger map is approximately twice the enlargement of the inset map - it is the same scale are larger maps of Fig. 3-5.

Assemblage A is more closely equivalent to the Estonian kukersine and contains its distinguishable morphotypes.

2.2 Lateral distribution patterns of kuckers

2.2.1 Kukersite bed: Grape kuckers of the largest size (diameter = 0.5-0.8 mm) are found to predominate in the proximal part of the kukersite bed (Fig. 2, Ülemiste) bordering the once existing hardground area. The kuckers deposited basinward were smaller (Fig. 2, Ervita).

The thickest kukersite beds ("B", "E", "III"), in their maximum thickness of development, are usually composed of caramel-type homogeneous, platy kuckers. In a shoreward direction, the kuckers of the bed are larger and rounded in shape. The aggregate kuckers retain their shape in the thick beds probably because they have more resistant capsule-like remains in them.

2.2.2 Limestone bed: There is no specific differentiation of the kuckers in the limestone beds. Small unaggregated kuckers or very loose aggregates predominate in kukersineous limestone, and small globular kuckers are most common in argillaceous limestone.

3 ORIGIN OF ALGAL REMAINS

The fact that Gloecapsomorpha prisca is of blue-green algal affinity and a photosynthesizing organism has been reaffirmed lately in a number of studies (for list see Foster et al. 1990), although there still exist difficulties and doubts about more detailed specification within the group (coccoidal or filamentous) as well as in choosing the appropriate morphological criteria given the problems of preservation of the material.

G. prisca could be interpreted as a cluster of capsule-like remains that were physiologically connected in a "colony of individuals" (a typical life-form for blue-greens) being devoid of the organic matrix that surrounds the clusters of capsule-like structures. Such clusters are best preserved in the proximal (more shoreward) part of the kukersite bed.

Single, oval or elongated capsule-like remains are from 2-4 um in diameter and occur as coccoidal dyads in the kukersine (see Fig. 1B). But this does not mean that they could not have been derived from filamentous algae.

Specific nitrogen fixating or capsule-like cell structures - heterocysts and akinetes, with their massive multi-layered envelope on the external surface of the original cell wall - are the most likely to be preserved. The innermost laminated layer contains complex glycolipids which are thought to act as permeability barriers(Fay 1983). Every twentieth cell might become a heterocyst. Akinetes or resting cells transform also from vegetative cells and accumulate large reserves of cyanophycin polypeptide and glycogen, and deposit a thick extracellular capsule.

This interpretation is only one of many possibilities but much of the organo-geochemical data would seem to support it.

4 ORGANOGEOCHEMICAL CHARACTERISTICS OF KUKERSINE

Aromatic hydrocarbons and phenols have been distinguished as important components of oil derived from the kukersite kerogen (Kogerman 1931; Rausepp 1959; Klesment 1985). These compounds were thought to have been formed as a result of secondary processes - cyclic polymerization of fatty acids in an oxygen-rich environment during early stages of lithification.

Large amounts of phenolic compounds were earlier known to exist in sporopollenin pyrolysis derivatives (Schenck et al. 1981). But recent studies on extant blue-green algae have confirmed the existance of biopolymers highly resistant to non-oxidative chemical treatment (Chalansonnet et al. 1987). Six species of blue-greens were studied and a high content of a resistant polymer located in the cell envelope, distinguished as the filamentous alga Schizothrix sp.

Considering that kukersine comprises different morphotypes it can be assumed that their organogeochemical characteristics and oil yield potential are different. The oil yield is presumably higher in kukersine containing capsule-like algal remains.

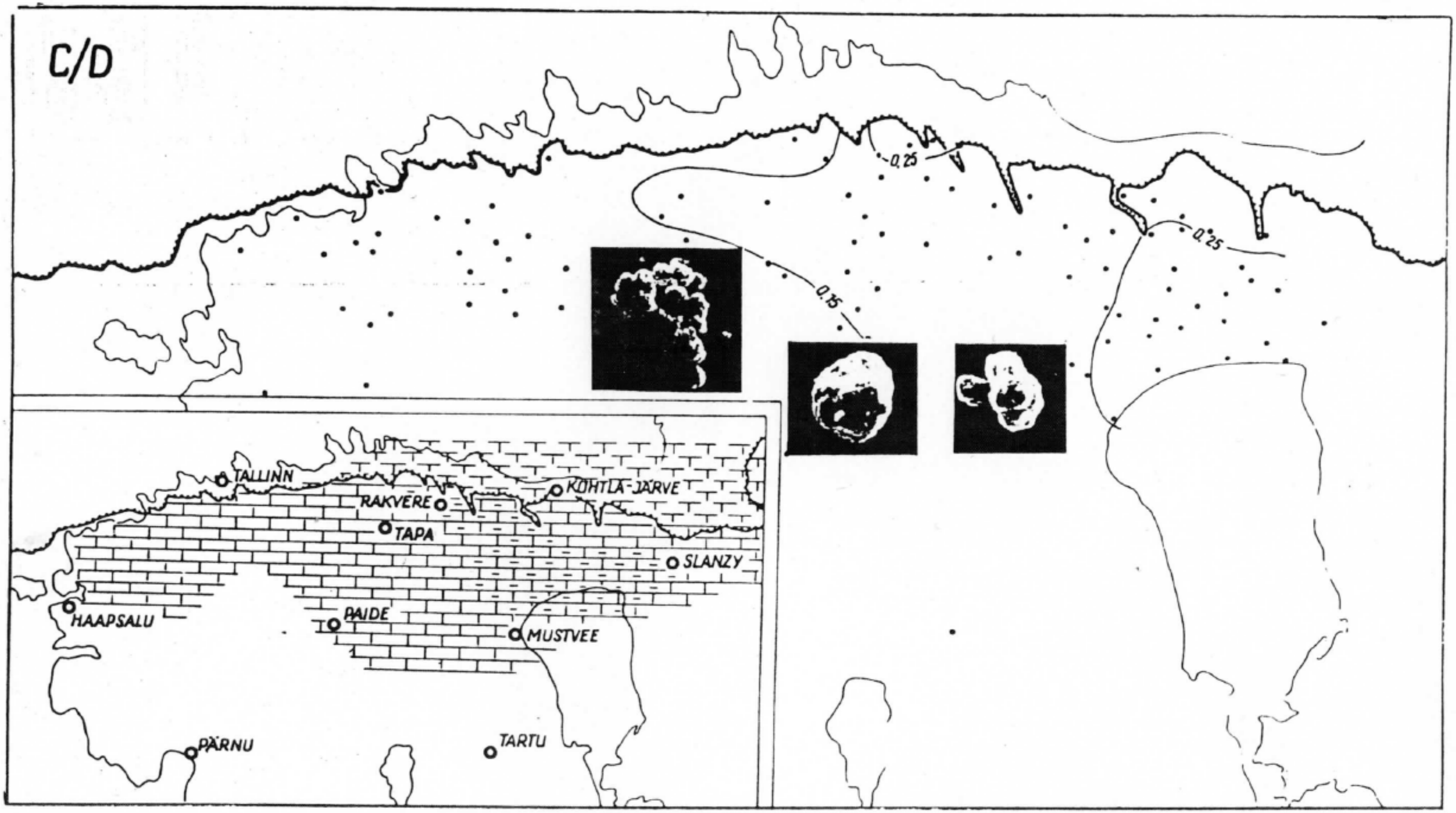

Fig. 3. Maps to show the distribution of dominant morphotypes of algal lumps (kuckers) in the limestone bed C/D (lower Kukruse Stage). For key to legend see Fig. 2. Note that the larger map is at the same scale as the larger maps in Figs. 2, 4-5, but that the localities Ülemiste, Kohtla and Ervita have been omitted. The distance on the inset map from Tallinn to Kohtla-Järve is 150 km; the larger map is approximately twice the enlargement of the smaller map.

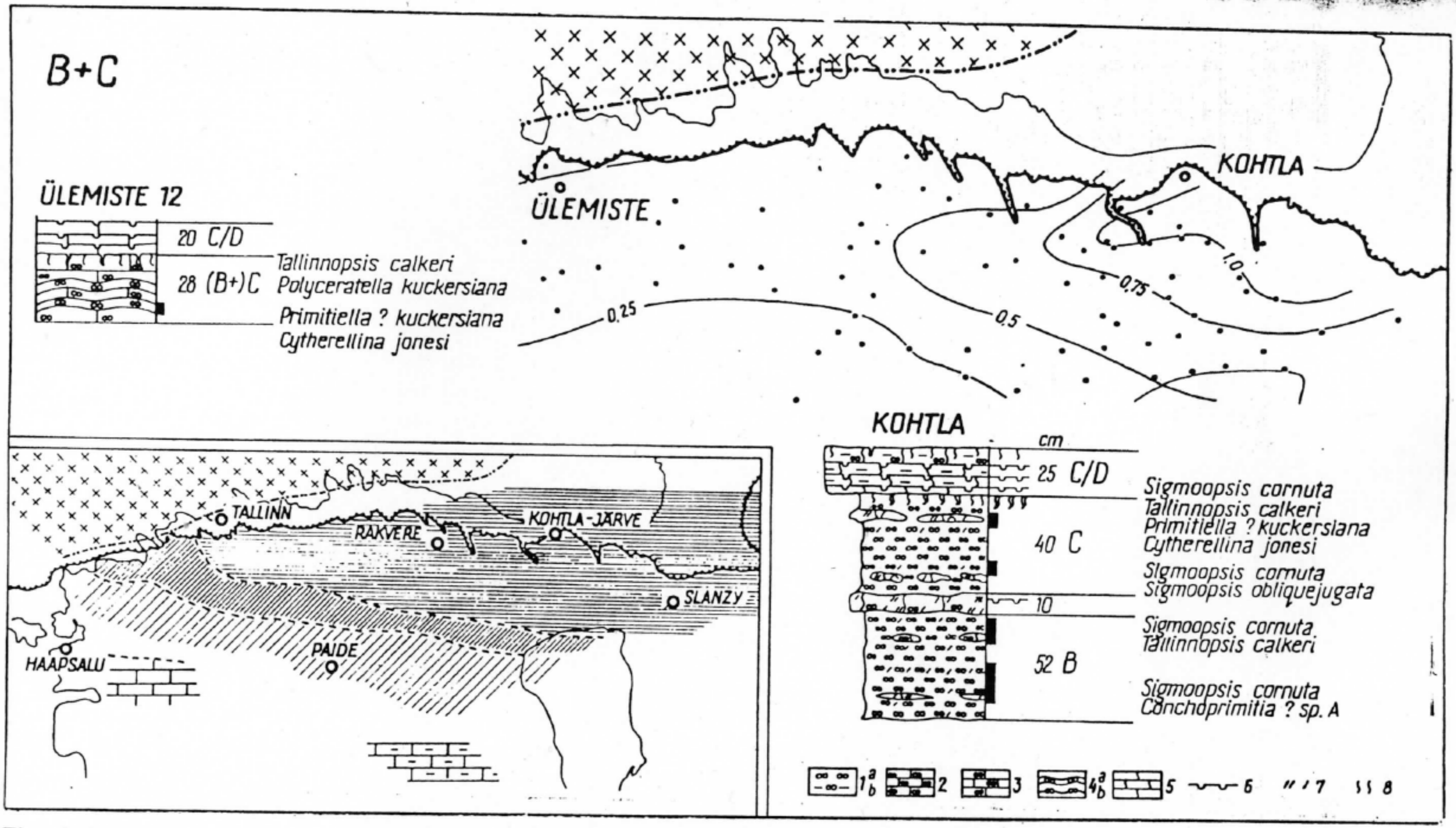

Fig. 4. Maps and stratigraphic columns to show location of dominant ostracodes in kukersite bed B + C (lower Kukruse Stage). Key to larger map, as follows: 1a - kukersite, 1b - argillaceous kukersite, 2 - kukersineous limestone, 3 - kukersinic limestone, 4a - lenses of kukersite, 4b - laminations of kukersite, 5 - bioturbated limestone, 6 - discontinuity surface, 7 - skeletal debris, 8 - bioturbation. For key to inset palacogeographic map see Fig. 2. Numbers shown on stratigraphic columns are in centimetres; numbers of contours, in metres. For scale of maps, see Fig. 5 caption.

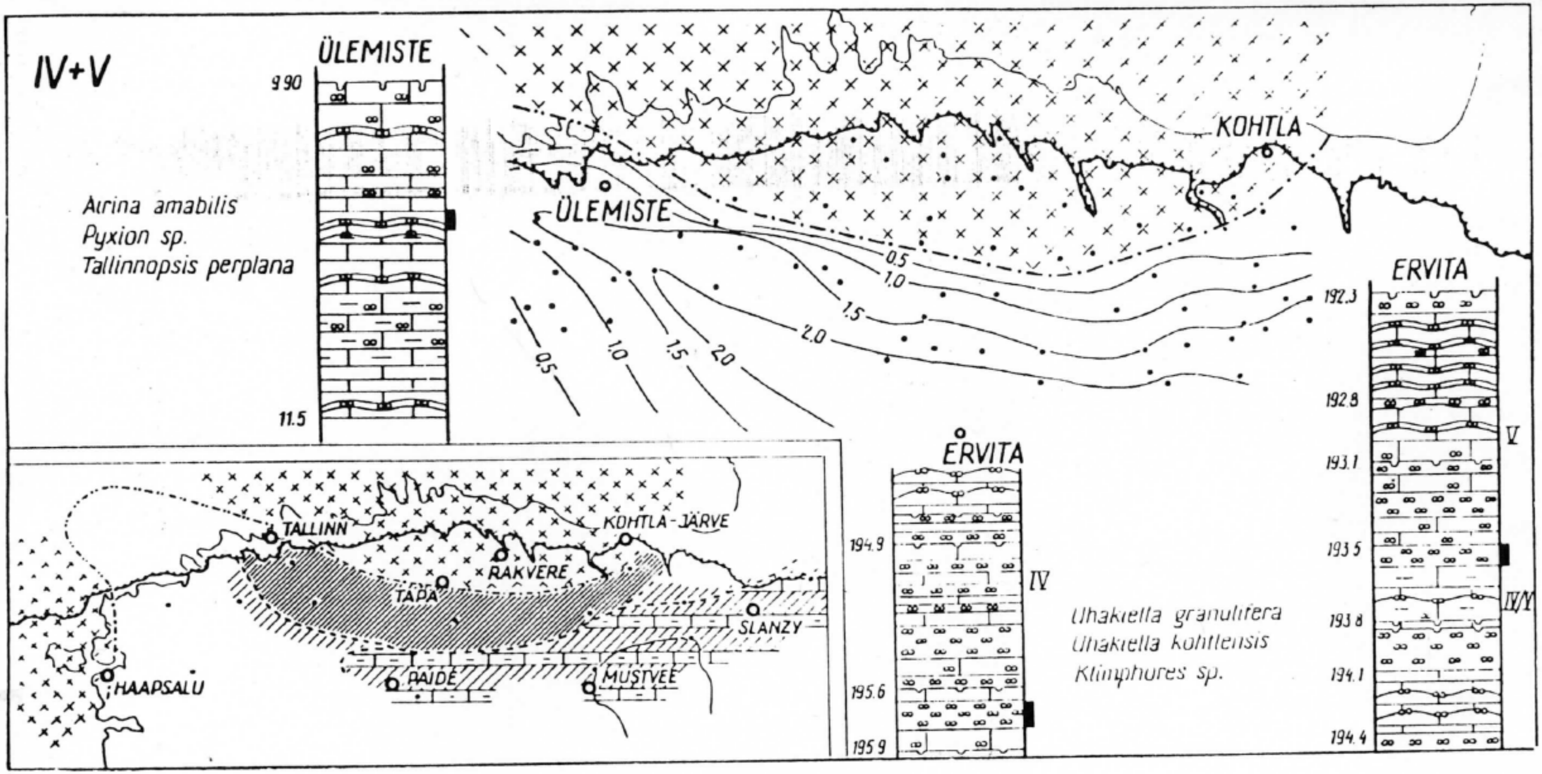

Fig. 5. Maps and stratigraphic columns to show location of dominant ostracodes in the kukersite bed IV + V (upper Kukruse Stage) Key for the inset palaeogeographic map is shown in Fig. 2. Key for the stratigraphic columns is shown in Fig. 4 Note that as drawn the Ervita section is shown in two parts but should only represent one column. Numbers shown on contours and boreholes are in metres. Scale: distance on inset map from Tallinn to Kohtla-Järve is 150 km; distance on larger map from Kohtla to Ülemiste (near Tallinn) is 145 km.

5 PALAEOECOLOGICAL REMARKS

In connection with a probable allochthonous origin of kukersine, the fauna of kukersite beds has been studied to reveal whether a specific kukersine-mud benthic assemblage may have existed. The rich Kukruse Stage fauna has been known for a long time, from the works of H. Bekker and A Öpik. Special attention was focused on distal (basinward) parts of the kukersite beds and their transitions into adjacent microfacies, and across facies boundaries.

The ostracode fauna of the thinner kukersite beds seems to reflect local facies conditions. Thicker beds (for a compound stratigraphic column, see Männil 1986), and beds associated with stronger discontinuity surfaces ("B", "C", "G-H", "I", "III") contain specific kukrusean dominants of the North Estonian Confacies Belt (see Männil in Kaljo & Nestor 1990, including Tallinnopsis calkeri, Polyceratella kuckersiana and Primitiella? kuckersiana (Fig. 4).

The kuckersite bed "IV"-"V" has its maximum thickness in the Transitional Zone (between the North Estonian and Central Baltoscandian Confacies Belts) but is characterized by ostracode dominants more typical of the Central Baltoscandian Confacies Belt (Fig. 5).

Presumably the organic matter was already inert when transported into the subtidal areas, having little specific influence on the ostracode assemblages.

SUMMARY

Gloeocapsomorpha prisca kerogen of kukersite occurs in the form of algal lumps, and presumably was of blue-green algal (cyanobacterial) mat origin.

Kukersine accumulated on a shallow subtidal carbonate shelf, so kukersite is a specific rock, the main characteristic components of which are the Gloeocapsomorpha prisca-kerogen and carbonate matter.

REFERENCES

Chalansonnet, S., C. Laugeau, E. Casadevall, C. Berkaloff, G. Peniguel & R. Couderc 1987. Cyanobacterial resistant biopoloymers. Geochemical implication of the properties of Schizothrix sp. resistant material. Organic Geochemistry, vol. 13, no. 4-6: 1003-1010.

Fay, P. 1983. The blue-greens (Cyanophyta - Cyanobacteria) Inst. Biol. Stud. Biol., 160: 1-88.

Foster, C.B., G.W. O'Brien & S.T. Watson 1986. Hydrocarbon source potential of the Goldwyer Formation, Barbwire Terrace, Canning Basin, Western Australia. APEA Journal, 26: 142-155.

Foster, C.B., R. Wicander & J.D. Reed 1990. Gloeocapsomorpha prisca Zalessky 1917: a new study. Part II: Origin of kukersite, a new interpreation. Geobios 23: 133-140.

Hatch, J.R., S.R. Jacobson, B.J. Witzke, J.B. Risatti, D.E. Anders, W.L. Watney, K.D. Newell & A.K. Vuletich 1987. Possible Late Middle Ordovician organic carbon isotope excursion: evidence from Ordovician oils and hydrocarbon source rocks, Mid-Continent and East-Central United States. Amer.Assoc. Petrol. Geol., Bull. 71: 1342-1354.

Jacobseon, S.R., J.R. Hatch, S.C. Teerman & R.A. Askin 1988. Middle Ordovician organic matter assemblages and their effect on Ordovician-derived oils. Amer. Assoc. Petrol. Geol., Bull. 72: 1090-1100.

Kaljo, D. & H. Nestor (eds.) 1990. Field Meeting Estonia 1990. An excursion guidebook. Estonian Academy of Sciences, Tallinn: 1-209.

Klesment, I. 1985. On the genesis of the Baltic oil shales: Oil Shale, vol. 2: 12-22 (in Russian).

Kogerman, P. 1931. On the chemistry of the Estonian oil shale "kukersite": 1-141.

Kõrts, A., R. Männil, L. Põlma & R. Einasto 1991. Epochs and depositional environments of kukersite-type (algal) organic matter accumulation in the Ordovician and Silurian of Estonia. In: Important bioevents in Earth History. Proc. XXXII session, All-Union Palaeont. Soc. USSR (in press; in Russian)

Männil, R. 1986. Stratigraphy of kukersite-bearing deposits $C_{I}b$-C_{III}. In V. Puura, (ed.) Geology of the kukersite-bearing beds of the Baltic oil shale basin: 12-24 (in Russian).

Männil, R., H. Bauert & V. Puura 1986. Peculiarities of kukersite accumulation. In V. Puura (ed. Geology of the kukersite-bearing beds of the Baltic oil shale basin: 48-54 (in Russian).

Öpik, A. 1927. Beiträge zur Kenntnis der