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THE CONDITIONS OF KUKERSITE DEPOSITION

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ABSTRACT

By detailed stratigraphy and correlation of the borehole sections based on micropalaeontological studies of chitinozoans, conodonts and graptolites, nearly 50 layers of kukersites have been traced in the whole area of their distribution. The kukersite deposition occurred in the northern margin of the shallow carbonate shelf in the internal part of the Middle Ordovician epicratonic Baltic Sea. Kukersites deposited in a rather gentle slope between the marginal hardground zone and the shallow open shelf. It is supposed that the source organic (sapropelic) material appeared in the form of algal mats developed on the extensive hardground tidal flats, from where it was transported by tidal currents and evenly distributed by eastern coastal currents in the adjoining zone. Kukersite-mud accumulated during the regressive stage of the basin development.

The Ordovician epicontinental sea of Baltoscandia was the site of extensive carbonate deposition. The Middle Ordovician oil shale (kukersite) deposition occured at the northern margin of shallow carbonate shelf bordering the Finnish lowland (Fig.1.),/3,5/.

At the same time, a widespread black shale accumulation in the marginal part of Iapetus ocean, most likely associated with upwelling, took place /6,7/.

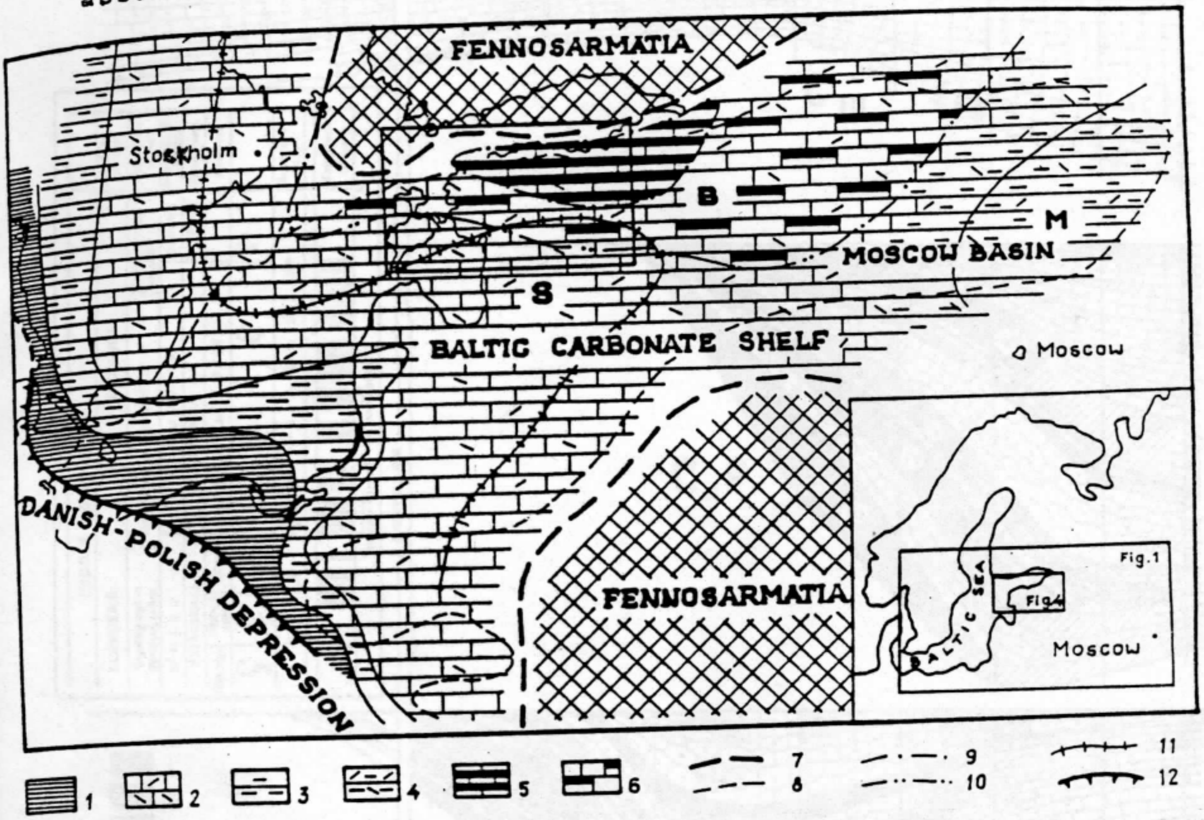

Figure 1. Setting of the kukersite-bearing deposits in the Middle Ordovician (Nemagraptus gracilis time) Baltic Basin. 1 - black shales; 2 - argillaceous detritic limestones; 3 - limy marls; 4 - detritic limy marls; 5 - rich kukersite occurences; 6 - poor kukersite occurences; 7 - supposed boundary of the sedimentation area; 8 - erosion boundary; 9 - boundary of the rich kukersite accumulation area; 10 - boundary of the kukersite accumulation area; 11 - faunal distribution boundaries: S - Scandinavian, B - East Baltic, M - Moscow; 12 - Tornquist line (platform margin).

According to the Baltoscandian regional stratigraphic scheme, Estonian kukersite-bearing sequence belongs to the Kõrgekallas and Viivikonna Formations of the Upper Uhaku ($C_I c^2$) and Kukruse (C_{II}) Stages, corresponding particularly to the Nemagraptus gracilis graptolite zone. Recent studies on the geological setting, composition and

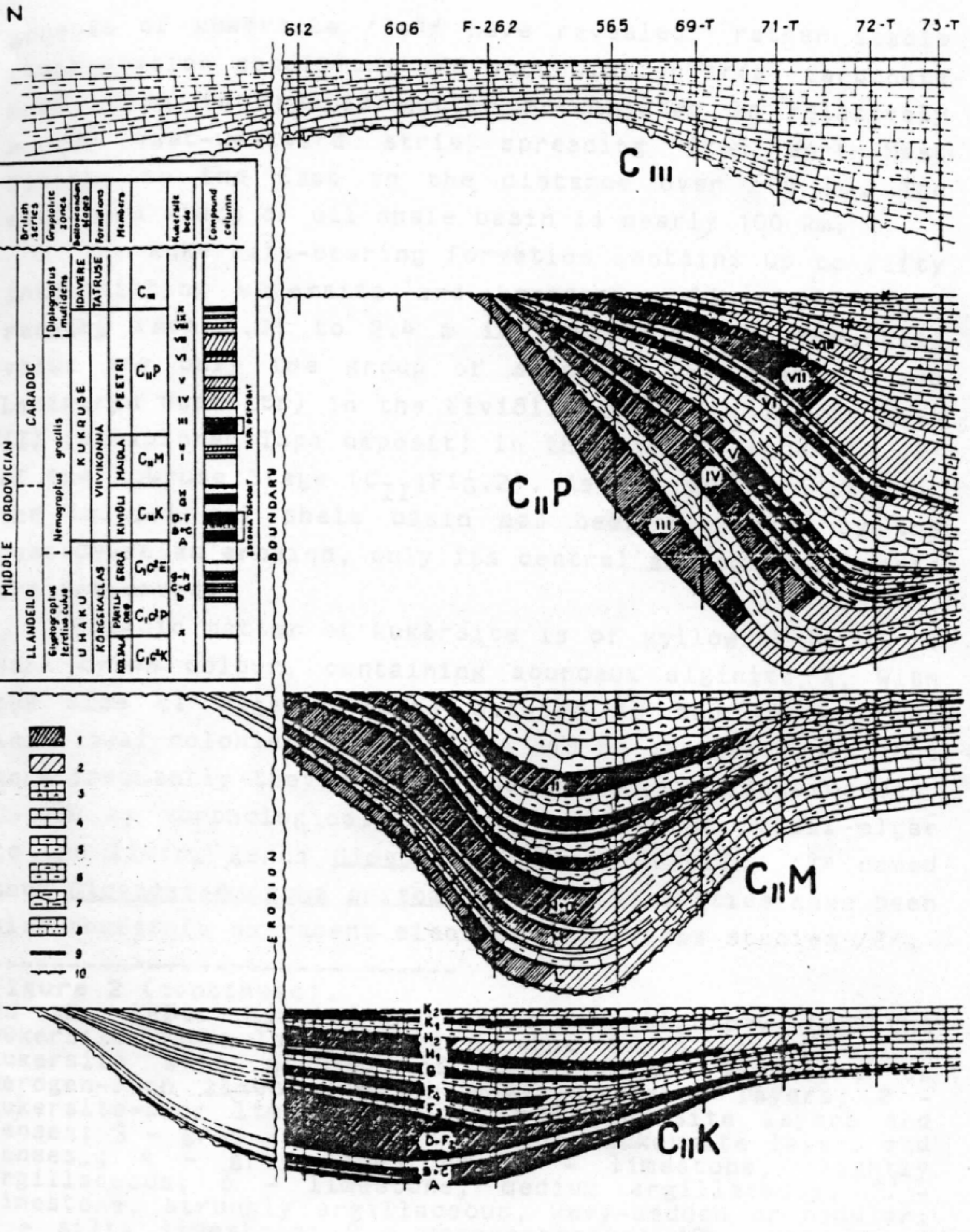

Figure 2. Regressive succession of the Kiviõli, Maidla and Peetri Members (Viivikonna Formation, Kukruse Stage) overlain by the transgressive Idavere Stage in the meridional cross-section (see Fig.4).

genesis of kukersite /3,4/ have revealed rather stable sedimentation conditions and accumulation area. Carbonate muds, rich in organic matter accumulated in relatively narrow east-westward strip spreading from North-West Estonia to the East to the distance over 600 km. The estimated width of oil shale basin is nearly 100 km.

The kukersite-bearing formation contains up to fifty intercalating kukersite and kerogenous limestone seams ranging from 0.01 to 2.4 m in thickness. Of commercial value are only the group of seams A...F_2 (Estonia and Leningrad deposits) in the Kiviõli member ($C_{II}K$) and seam III (unexplored Tapa deposit) in the Peetri Member ($C_{II}P$) of the Kukruse Stage (C_{II};Fig.2). As the northern part of the initial oil shale basin has been destroyed by the post-Devonian erosion, only its central and southern parts are preserved.

Organic matter of kukersite is of yellowish brown to dark brown colour, containing abundant alginite A, with the size of algal remains between 10 and 40 μm. The individual colonies of the algae can be distinguished, but more frequently they are aggregated forming large masses. Guided by morphological similarity of these fossil algae to the living genus Gloeocapsamorpha, Zalessky /8/ named them Gloeocapsamorpha prisca. These similarities have been also confirmed by recent electron microscope studies /2/.

Figure 2 (continued).
On the left: Middle Ordovician stratigraphy for the kukersite accumulation time in the North Estonia. 1 - kukersite with nodules of kerogen-rich limestone or kerogen-rich limestone with wavy kukersite layers; 2 - kukersite-poor limestone with thin kukersite layers and lenses; 3 - grey limestone with thin kukersite layers and lenses.; 4 - grey limestone; 5 - limestone, slightly argillaceous; 6 - limestone, medium argillaceous; 7 - limestone, strongly argillaceous, wavy-bedded or nodular; 8 - silty limestone; 9 - metabentonite; 10 - hardground (discontinouity surface).

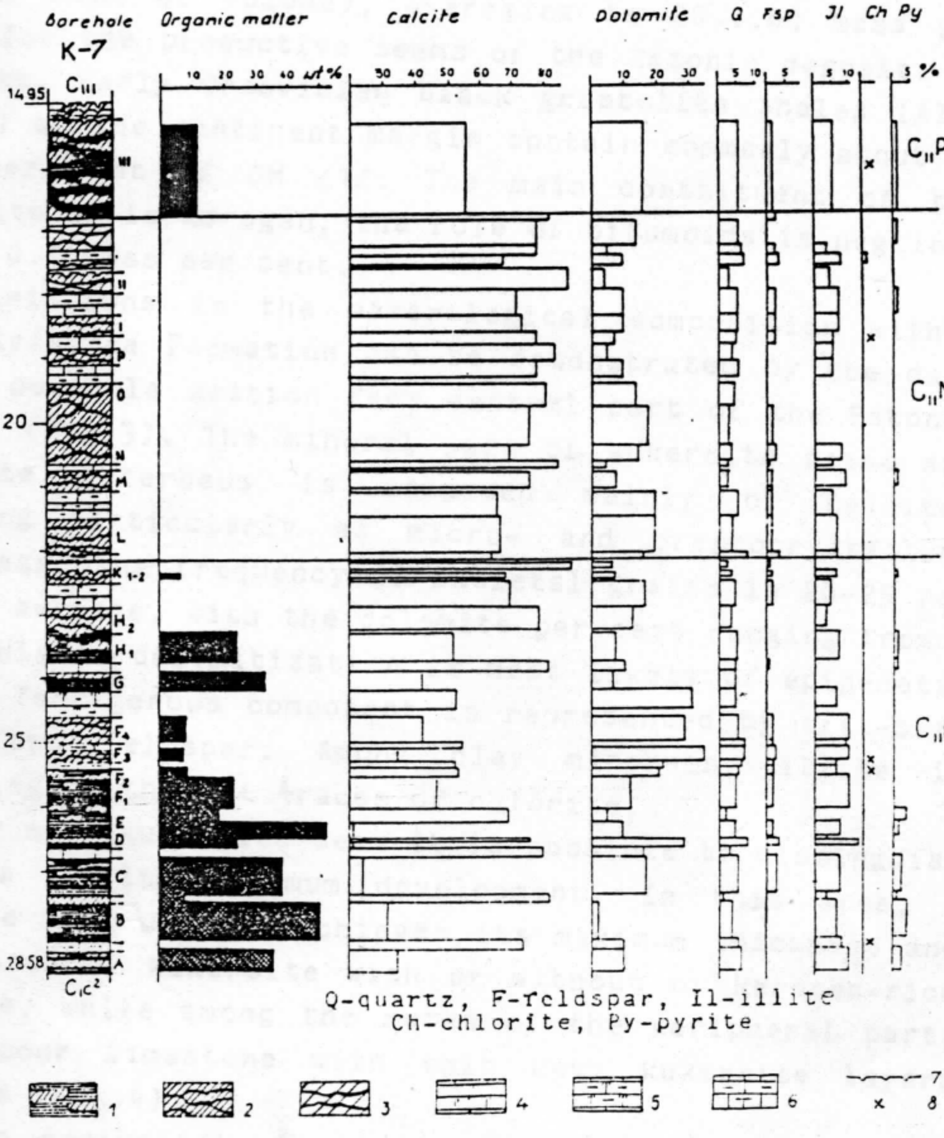

Figure 3. Mineral composition of the Viivikonna Formation in the central part of the Estonia Deposit (borehole K-7) by semiquantitative X-ray diffractometry. 1-kukersite with nodules of kerogen-rich limestone; 2-kerogen-rich limestone with wavy kukersite layers; 3-kukersite-poor limestone with thin kukersite layers and lenses; 4-limestone, slightly dolomitic; 5-limestone, dolomitic, slightly argillaceous; 6-limestone, argillaceous; 7-hardground (discontinouity surface); 8-mineral traces.

Organic matter (OM) is dispersed in mineral groundmass or concentrated in individual kukersite layers, where the content of OM reaches 60 per cent of rock mass (75 per cent of volume), averaging in 20...60 mass per cents for the productive seams of the Estonia deposit. In contrast, Early Ordovician black graptolite shales (Alum shales) of the continent margin contain commonly about 10 mass per cent of OM /1/. The main constituent of the kukersite OM is kerogen; the role of bitumoids is neglible - only 0.7 mass per cent.

Variations in the mineralogical composition within the Viivikonna Formation can be demonstrated by the data of the borehole section from central part of the Estonia deposit (Fig.3). The mineral part of kukersite seams and carbonate interbeds is composed mainly of calcite, occurring particularly as micro- and cryptocrystalline groundmass. The frequency of skeletal grains is 20-25 per cent in average, with the dolomite per cent ranging from 5 to 10. Higher dolomitization is most likely of epigenetic origin. Terrigenous component is represented by silt-size quartz and feldspar. Among clay minerals, illite is dominating, with some traces of chlorite.

For each kukersite seam it is possible to distinguish the area of its maximum development. In this area, a kukersite seam usually achieves its maximum thickness and is composed of kukersite with or without of kerogen-rich limestone, while among the rocks of the peripheral part, kerogen-poor limestone with thin wavy kukersite layers dominates (Fig.4).

From sedimentological viewpoint, the most prominent feature of Estonian kukersite formation is the accumulation of OM alongside the northern hardground zone. It is observed that thickness of kukersite seams alters regularly from the North to the South reaching its maximum in some distance from the hardground and then decreases slowly. Thinning of kukersite seams to the South is accompanied by diminishing of OM content until kerogenous limestone is replaced by argillaceous carbonate rocks.

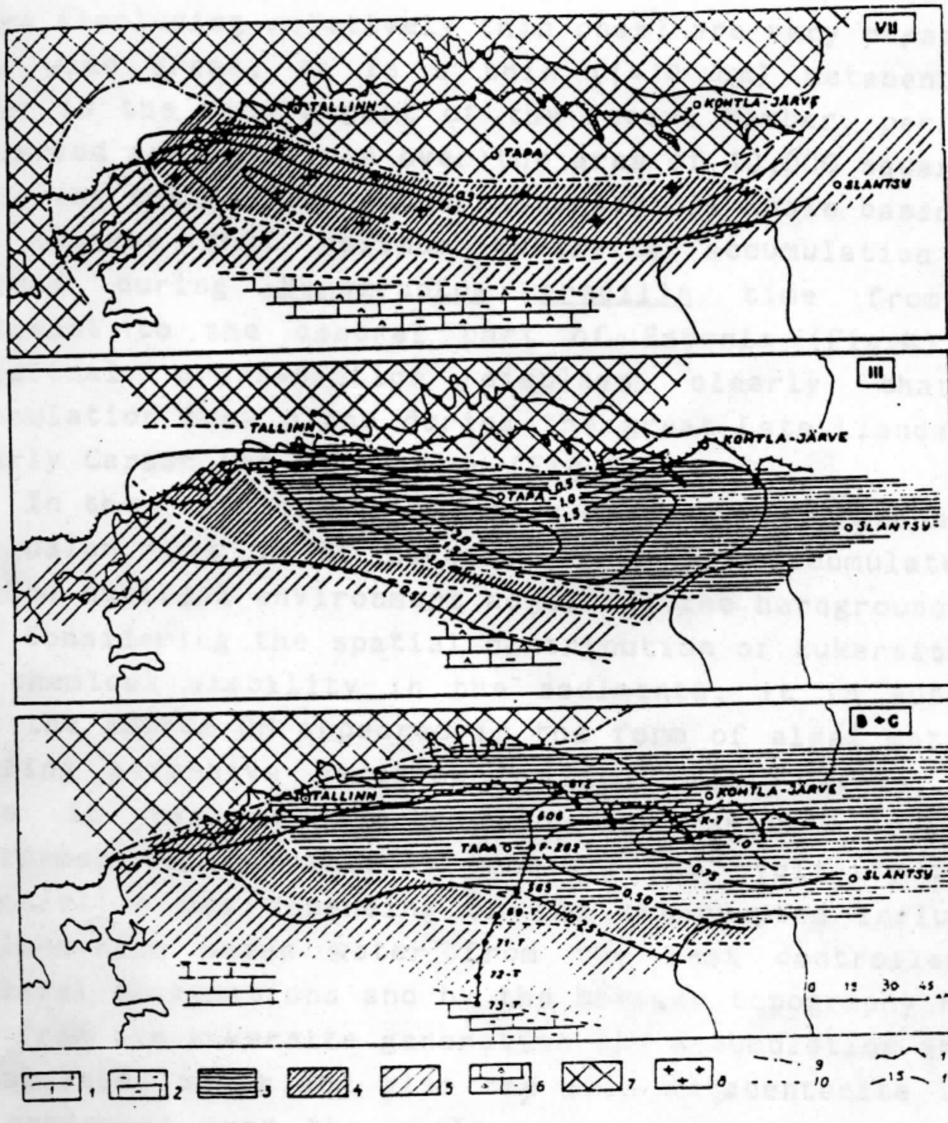

Figure 4. Facial sketch-maps for the kukersite seams: B+C, III and VII. For the position of the seams in the section, see Fig.2. 1-grey pure limestone; 2-limestone, slightly argillaceous; 3-kukersite with nodules of kerogen-rich limestone; 4-kerogen-rich limestone with thin wavy kukersite layers; 5-kerogen-poor limestone with thin kukersite layers and lenses; 6-limestone with thin kukersite layers and lenses; 7-hardground (non-deposition area), 8-fine-dispersed pyrite; 9-boundary of the hardground area; 10-facial boundary; 11-recent erosion boundary of the Kukruse Stage; 12-isopach,m.

From central accumulation area to the West, it is possible to follow how the kukersite seams are wedging out, forming discontinouity surfaces. It is remarkable that kukersite seams (including relatively thin ones) are very persisting over wide areas, as is a thin (1-10 cm) metabentonite layer in the middle part of the Peetri Member, perfectly preserved and traceable over the area of 10,000 square km. Following the development of Estonian oil shale basin, one may observe that maximum kukersite accumulation area shifted during Nemagraptus gracilis time from the northeast to the central part of Estonia (Fig.4). The meridional cross-section displays clearly that OM accumulation took place during the great Late Llandeilian - Early Caradocian regression (Fig.2).

In the light of the existing data we have reached the conclusion that OM of kukersite-type was accumulated in shallow subtidal environment adjoining the hardground area /3/. Considering the spatial distribution of kukersite and its chemical stability in the sediments, it is supposed that the source OM appeared in the form of algal mats /4/ covering extensive hardground (tidal flat) areas, from where it was transported to the shallow subtidal environment of deposition. Probably the cyclicity of OM accumulation was depending on the interrupted influx of nutrient-rich ocean water from the West controlled by sea-level fluctuations and by the barrier topography right West from the kukersite generation and accumulation areas. As kukersite seams and also the thin metabentonite layer are preserved over the whole sedimentation area without any remarkable evidence of scouring, it may be concluded that the influence of bottom currents was neglible. The absence of storm deposits indicates mild climatic conditions for this region in the early Middle Ordovician. Rich and diverse bottom fauna (more than 300 species recorded) and the lack of evidences indicating anoxia suggest normal salinity and good aeration of bottom waters.

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