DISTRIBUTION PATTERN OF THE ORDOVICIAN DISCONTINUITY SURFACES, EAST BALTIC REGION

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The discontinuity surfaces (DS) have a wide distribution in the Ordovician rocks of the East Baltic region. Here they have been studied for over a hundred years already. Up to now the most detailed review of the distribution of these DS in the whole region has been given by L. Põlma (1982). The study of new cores of northern and middle Estonia during the last decade has essentially helped to specify the distribution pattern of DS in this area.

The occurence of DS is especially high in the lower part of the Ordovician (in the northern belt between the Latorp and Kukruse stages (B_I-C_{II}), in the central belt - between the Latorp and Uhaku stages (B_I-C_Ic). Their absolute maximum in the whole Ordovician is more than 350 (Viki core, Saaremaa Island). The maximum frequency (number of hiatuses per My) has been recorded in the Llanvirn and Llandeilo (in the northern belt > 20, in the central belt - >5). In the other series their number is much (2-5 times) lower.

The DS are impregnated by different minerals - pyrite, phosphate (francolite), goethite and hematite. They can also be nonimpregnated or covered with a fine glauconitic lamina (Põlma, 1982).

In the present article the distribution pattern of various DS in all stages and the subdivision of the Ordovician on this basis will be given. The corresponding data will be presented in the DS distribution schemes.

Key words: discontinuity surfaces (DS), Ordovician, types of impregnation, Estonia, East Baltic region.

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INTRODUCTION

Discontinuity surfaces (further abbreviated DS) have a wide distribution in Estonian Paleozoic rocks. After their first description by Kupffer (1876), they have been dealt with by many authors (Lamanski, 1905, Orviku, 1940; 1961 a; b; Jaanusson, 1961; Einasto, 1964; 1989; Nõlvak, 1972; Põlma, 1982; Bauert, 1989). These studies concentrate on different aspects of DS: their morphology, type and intensity of impregnation, etc., also on their genesis and areal distribution. Up to now the most detailed review of the distribution of the Ordovician DS in the whole East Baltic region has been given by L. Põlma (1982). Depiction of the distribution pattern of the DS has been improved and changed essentially during the last decade. First of

all an unpublished manuscript by L. Pólma* based on data from 35 cores of the Baltic region (22 of them from Estonia) ought to be mentioned. The study of about 300 new cores got at this period in the course of geological mapping of northern and middle Estonia has essentially helped to specify the distribution pattern of the DS in the North Estonian Confacies Belt and in the Transitional zone.

In the following an attempt will be made to give a systematic review of the distribution pattern of the post-Tremadocian Ordovician DS. The part of the review concerning the Estonian area is mainly based on the data obtained from 150 cores, studied by the author. In addition some other sources have been used: data from the above 22 cores, studied by L. Pólma: 50 core descriptions from northern Estonia by the geologists of the Geological Survey K. Suuroja, A. Haas, Anne and Ain Põldvere, several core descriptions from southern Estonia by K. Kajak and E. Kirs (Geological Survey). The part concerning the Latvian and Lithuanian areas is based exclusively on the abovementioned unpublished report by L. Pólma. In the DS distribution schemes types of impregnation (marked by various hatchings), the number of DS and location of boreholes and outcrops are shown. The data used for northern Estonia are presented only partly.

The number of DS could not be considered as absolute since their fixing depends on different factors, such as the outcome of core, preciseness of the description, secondary lithological changes (e.g. dolomitization destroys most of weak DS), exactness of the determination of the straton limits. To show the amount of DS established and the preciseness of their fixing, the Väo Formation (Lasnamägi Stage in its initial limits, Orviku, 1940) can be presented as a good example. By K. Orviku (1940, Profil Tafel IV) there are 6 DS, by L. Pólma (1982) - 50, in the field description of R. Einasto 80 DS have been mentioned; in addition to this 10 hardly noticeable DS were recorded by the examination of the polished slabs. Regardless of the aforesaid, the numbers presented here are important for comprehension of the statistical background of this phenomenon.

NUMBER OF DISCONTINUITY SURFACES

The number of DS in the Ordovician exceeds considerably that supposed before (Pólma, 1982 - 200 DS). The maximum amount of DS in one section is more than 350 (Viki core from Saaremaa), the total of stages maximums - more than 550. DS are the most frequent in northern Estonia, especially in its western and northwestern parts, being there nearly twice as numerous as in the eastern part (Table 1 and Fig. 1). The number of DS decreases particularly to the south. Their maximum amount in the Central Baltoscandian Confacies Belt is 115 (Dzeberne core section), the total of stages maximums is 170. In the central part of the belt the number of DS is smaller, in places (Priekule, Sturi cores) even less than 30. Although the data about the Southern Confacies Belt are scarce, certain increase in the DS number can be noticed (the average of 5 cores is 55 DS; the total of stages maximums 215).

In the northern belt the number of DS is the highest in the interval B_I-C_I (50-80 %); in the central and southern belts in the interval B_I-C_{Ic}, accordingly 65-90 % and 60-75 %.

The greatest number of DS in one stratigraphical unit has been recorded in the Väo Formation where over an extensive area more than 40 surfaces are distributed. The absolute maximum is 167 (Viki core). The number of DS is great (40) also in places in the Volkhov, Kunda, Uhaku, Kunda and Pirgu Stages.

The occurrence frequency of DS in a section is especially high in the northern belt, being the greatest in the Volkhov Stage (in eastern Estonia -

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* Chapter "The impregnation types of the discontinuity surfaces in the East Baltic and their connection with the structural-facial zones" in report "Breaks in Paleozoic sedimentation in North-East Baltic" by E. Pirrus, R. Einasto, etc., Depository of manuscripts of the Institute of Geology of Estonia.

Table 1

Extreme numbers of the Ordovician DS in different confacies belts of the East Baltic region

Stage		Maximum				Min.	Cores		
		Northern belt		Central belt	Southern belt	Central belt	Max.		Min.
		western Estonia	eastern Estonia				Viki	Dzeberne	Priekule
Porkuni	F_{II}	>5	4	10	11	1	3	>10	>6
Pirgu	F_{Ic}	42	>30	>15	30	-	1	>15	-
Vormsi	F_{Ib}	7	7	-	5	1	1	-	1
Nabala	F_{Ia}	20	11	15	10	-	>20	15	1
Rakvere	E	11	16	2	3	-	6	-	-
Oandu	D_{III}	10	7	1	10	-	5	-	-
Keila	D_{II}	13	3	1	1	-	1	-	-
Jõhvi	D_{I}	9	5	-	1	-	5	-	-
Idavere	C_{III}	6	22	1	3	-	2	-	-
Kukruse	C_{II}	39	25	5	9	-	7	-	-
Uhaku	C_{Ic}	62	36	>30	>30	>10	62	>30	>10
Lasnamägi	C_{Ib}	167	49	>20	>30	-	167	7	>5
Aseri	C_{Ia}	8	>20	>20	>25	1	8	>20	1
Kunda	B_{III}	50	45	>20	>3	-	49	4	-
Volkhov	B_{II}	40	60	>10	>15	2	>20	11	2
Latorp	B_{I}	10	25	>20	>3	-		3	2
Σ		>500	>365	>170	>215	>27	>355	>115	>27

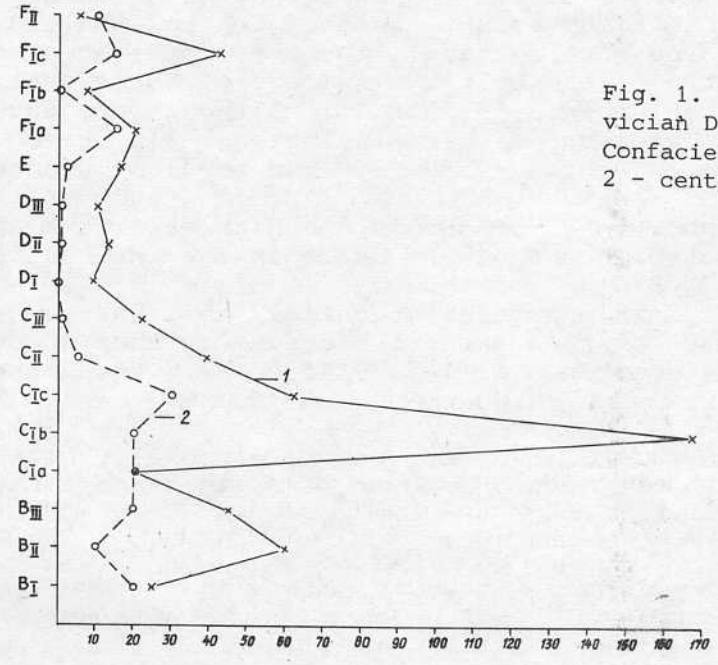

Fig. 1. Maximum number of the Ordovician DS in the Northern and Central Confacies Belts. 1 - northern belt. 2 - central belt.

>30, in western Estonia - 20 DS per meter). Remarkably high frequency of DS is also noticed in places in the Kunda and Lasnamägi (>13) and Uhaku stages (>13). In the central belt these indices are almost everywhere ≤2, except the Aseri (>5) and Kunda (3) stages. The frequency of hiatuses (amount per My) is the greatest in the beginning of the Middle Ordovician (Llanvirn, Llandeilo), in the northern belt - > 20, in the central belt - > 5. In the Arenig, Caradoc and Ashgill these indices are considerably smaller - in the northern belt - 3-5 times, in the central belt - 2-4 times (Fig. 2).

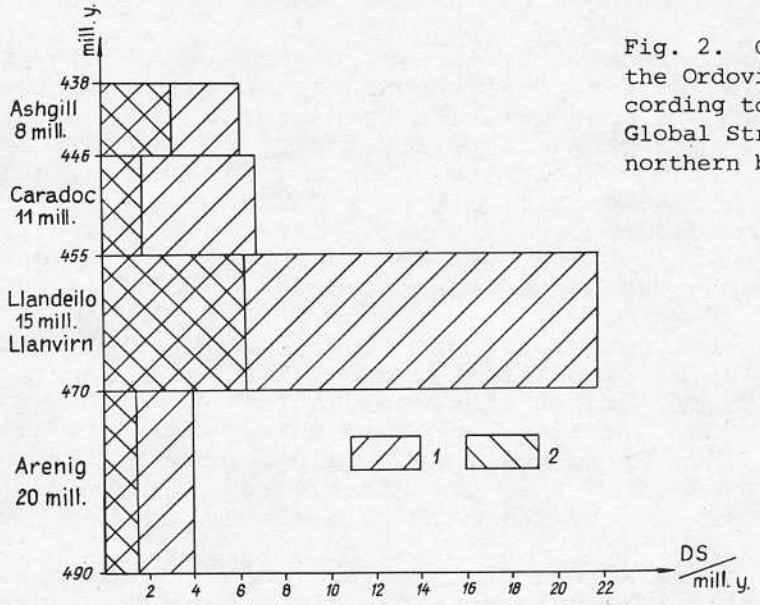

Fig. 2. Occurrence frequency of the Ordovician DS (per My.) According to Corvic, Bassett, 1989. Global Stratigraphic Chart. 1 - northern belt; 2 - central belt.

THE IMPREGNATION TYPES OF THE DISCONTINUITY SURFACES

Compared to the other gegions and periods, the Ordovician section of the Baltic region stands out for variety of impregnation types, among which the pyritic, phosphatic, goethitic, hematitic ones have been distinguished. The DS can also be nonimpregnated or covered with a fine glauconitic lamina (Pólma, 1932). The type of impregnation depends directly on the facial character of the surrounding rocks. The distribution pattern of different DS is essentially varied in separate confacies belts and stages. In the following a short account on the lateral distribution pattern of various impregnation types will be presented.

The mineral component of the various impregnation appearances has been determined by X-ray diffractometer (Pólma, 1982). This report is based on the visual estimation considering the similarity with the previously mentioned standards.

Pyritic DS which are of the most wide and universal distribution, are of black, violet-black or bluish-black colour, as a rule with a strong impregnation. This impregnation type is present here and there in all Ordovician stages, occurring in highly different facies (anywhere except multi- and red-coloured facies) in all confacies belts. In D_{II}-E, in the northern belt also in F_{II}, practically only pyritic DS are distributed. They are the most rare in the Arenig, where the multi- and red-coloured facies are predominant.

The other impregnation types are of a more specific distribution.

Goethitic DS are of various shades of yellow colour, as a rule with a strong impregnation. They are also present in all confacies belts of the Ordovician basin and have not been registered only in some cores (Jashunai,

Kórgessaare). At that they are mainly related with the particoloured rocks of the central belt. In the transitional zone more than half of all DS are goethitic, occurring the most frequently in the interval B_I-$C_I b$ (especially in B_{II}-B_{III}).

Hematitic DS are of red or brownish-red colour, with a relatively strong impregnation. They are present in the same intervals as the goethitic ones, but their areal and facies distribution is remarkably narrower, being mainly restricted to the redcoloured sediments of the Central Confacies Belt. Since they have the same colour as the surrounding rocks, it might be difficult to distinguish them. The percentage of such DS in different Ordovician sections is varying between 10-40 %, their maximum number can exceed 40.

Phosphatic DS are of beige or violet-brown colour, as a rule with a weak impregnation. According to X-ray diffractometrical testing, they are impregnated by francolite with a scarce pyrite admixture. They occur only in pure of slightly argillaceous grey carbonate rocks in the northern and southern belts and in the transitional zone, but are entirely missing in the red- and multicoloured and aphanitic carbonate rocks.

In the central belt these DS occur only very rarely. They are present mainly in the interval B_I-D_I, $F_I aP$ and $F_I b$, being especially frequent in the interval B_{III}-C_{III} where every stage shows at least 10 DS (the absolute maximum is 167 DS).

Nonimpregnated DS are erosional surfaces. They can be easily determined only at the contacts of different rock types. The real number of the nonimpregnated DS is undoubtedly higher than the figure established by now. Most of them occur on B_I, $C_I c$, C_{II} and F_{II}. More rarely they can also be met in B_{II}, D_{III}, $F_I a$ and $F_I b$. Up to now they have not been registered in $C_I a$, D_I and $F_I b$. The most frequently they are distributed in the northern belt; in the central belt they occur almost, exclusively in the Porkuni Stage.

In addition to these so-called "pure" types frequently DS of mixed types with two-fold impregnation (phosphatic + pyritic, pyritic + goethitic etc.) have been recorded. In places the impregnation occurs only on single `tips` of DS. Therefore it can sometimes be met only in the outcrops and may easily be missed in cores due to their restricted width.

The glauconitic lamina is found almost without exception in the sediments containing a lot of glauconite: B_I, B_{II} (max. 5 DS); $F_I aP$ (max. 7.). In these stages frequently more than half of DS, mostly of the pyritic and phosphatic types, are covered with a lamina. In places a thin glauconitic impregnation has also been formed (Lindström, 1979).

SUBDIVISION OF THE ORDOVICIAN ON THE BASIS OF THE DS DISTRIBUTION PATTERN

The characteristics and distribution pattern of DS are highly different in the northern and central belts. Considering these features, the transitional zone is quite similar to the northern belt. Therefore in the following they are dealt with together as the northern belt s.l. (Fig. 3).

In the northern belt the following intervals are distinguished on the grounds of the type and number of DS: B_I-B_{II}, B_{II}-D_{II}, D_{III}-$F_I aS$, $F_I aP$-$F_I b$ and $F_I c$-F_{II}.

B_I-B_{II} (Fig. 4). In both stages goethitic DS are predominant, in places also phosphatic and rarely pyritic DS are represented. In some cases DS are covered with a glauconitic lamina. The number of DS increases from the west (in both stages commonly less than 10) to the east (in the Latorp Stage max. 60 DS). Zonation based on DS is absent.

B_{III}-D_{II} (Fig. 4). This interval, (especially its middle part - $C_I b$-C_{II}) shows a very clear zonation. Southward from the erosion line the following DS zone can be distinguished: pyritic, pyritic-phosphatic and phosphatic. In addition to them in the Kunda and Aseri stages goethitic DS are represented. In southern and eastern Estonia they from an independent zone. In the Uhaku and Kukruse stages along with pyritic DS nonimpregnated ones occur.

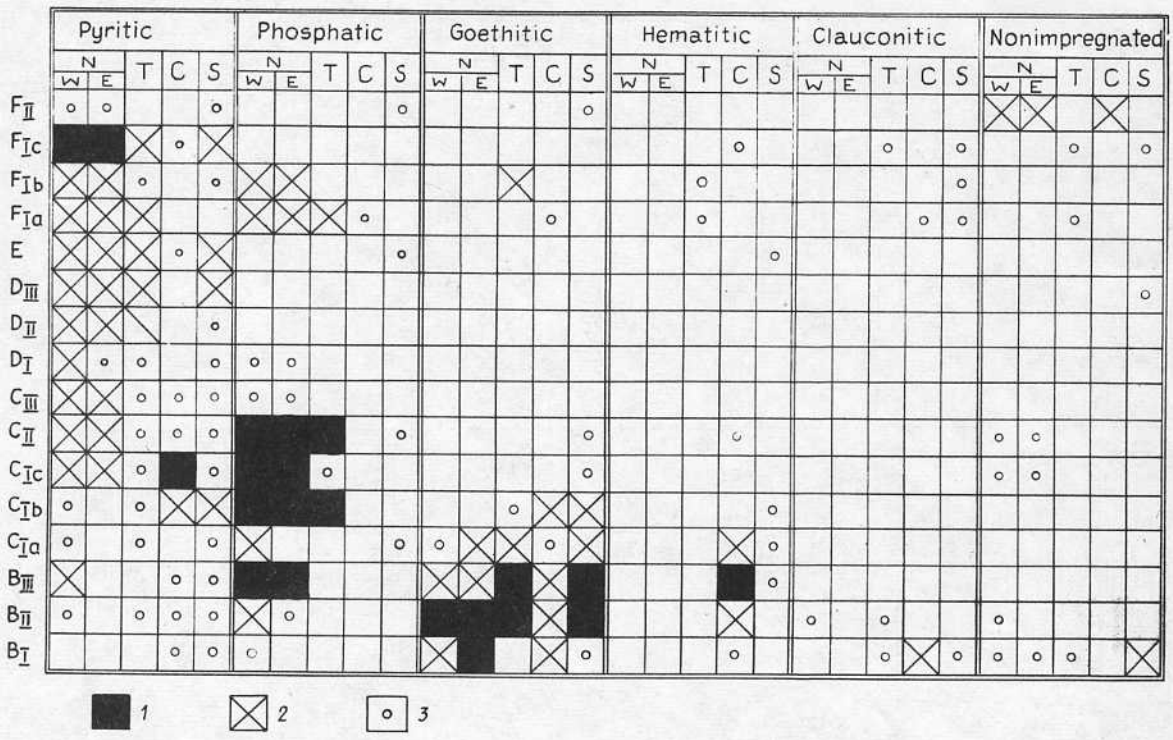

Fig. 3. Distribution of various DS impregnation types in different confacies belts. 1 - abundant occurrence, 2 - widespread moderate occurence, 3 - sporadic occurrence. Confacies belts: N - northern, W - western Estonia, E - eastern Estonia; C - Central; S - Southern; T - Transitional zone.

Within the whole interval a gradual lateral migration of the zone boundaries can be noticed. In the both Kunda and Aseri stages the pyritic DS zone is located on Hiiumaa Island. In the Lasnamägi Stage this zone shifted northward of the contemporary erosion line. The former position it gained in the Uhaku Stage. In the Kukruse and Idavere stages the pyritic zone extends from eastern to western Estonia.

Phosphatic DS form an independent zone for the first time in the Valgejõgi Member ($B_{III}V$). In the Kunda Stage as a whole only a mixed (pyritic-phosphatic) zone is represented (Fig. 4). In the Aseri Stage already the phosphatic zone is present (in addition to goethitic DS). It extends wedge-like from the western islands up to middle Estonia (Fig. 4).

In the Lasnamägi and especially in the Uhaku stages a wide (up to 20--30 km) mixed pyritic-phosphatic zone can be distinguished both south- and northward of the phosphatic one. In the Kukruse and Idavere stages the latter is narrower and, as a rule, is missing on the southern side.

In the Jõhvi Stage the described zonation is not so clearly expressed and is difficult to describe (Fig. 5). In western Estonia and on the islands only pyritic DS are distributed. The phosphatic zone is narrow (20 km) and wedges entirely out in eastern Estonia. The number of DS is small (1-3). Northward of the phosphatic zone the DS are lacking in an extensive area.

D_{II}-F_IaS (Fig. 5). In the whole belt only piritic DS are distributed, differing only in number. In the Keïla Stage the largest number (max. 13) of DS is located in the area between Keila and Vasalemma (western Estonia), in north-eastern Estonia they are mostly missing. In the Oandu Stage their maximum occurrence has been recorded on Hiiumaa Island (4-10 DS). In the mainland their number is remarkably smaller (1-4). In the Rakvere Stage the frequency of the DS is areally very unstable (1-16), yet slightly increasing southward. In the Saunja Formation (Nabala Stage), some (1-3) pyritic DS occur only in places in the north-eastern Estonian outcrop area.

F_IaP-F_Ib (Fig. 5). This interval shows a remarkably distinct zonation. In the northern part of the area only pyritic DS are present forming an east-westward zone (in a relatively limited area). Areally the DS number varies very abruptly. To the south the purely pyritic zone is succeeded by

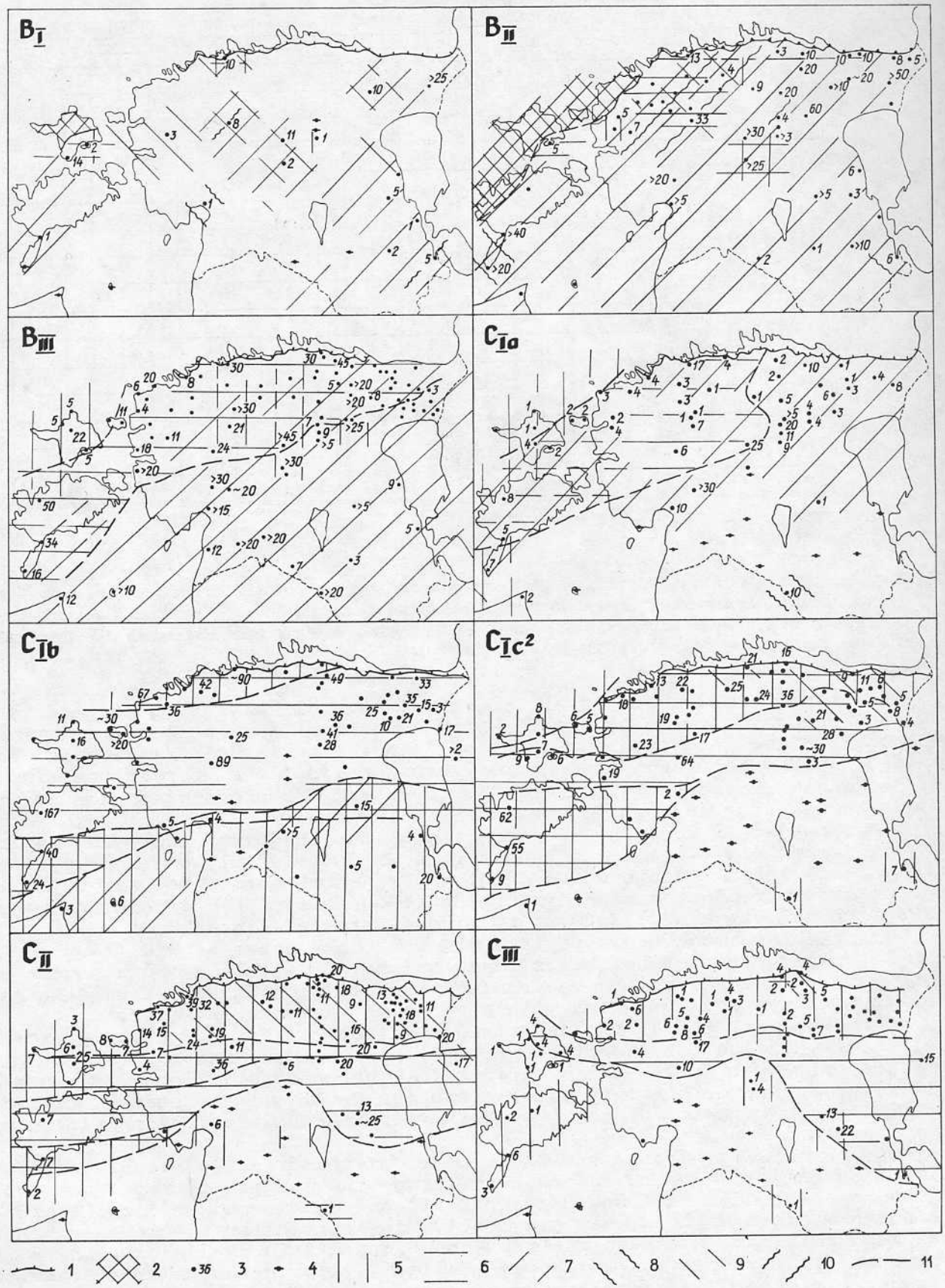

Fig. 4, 5 (see p. 23)

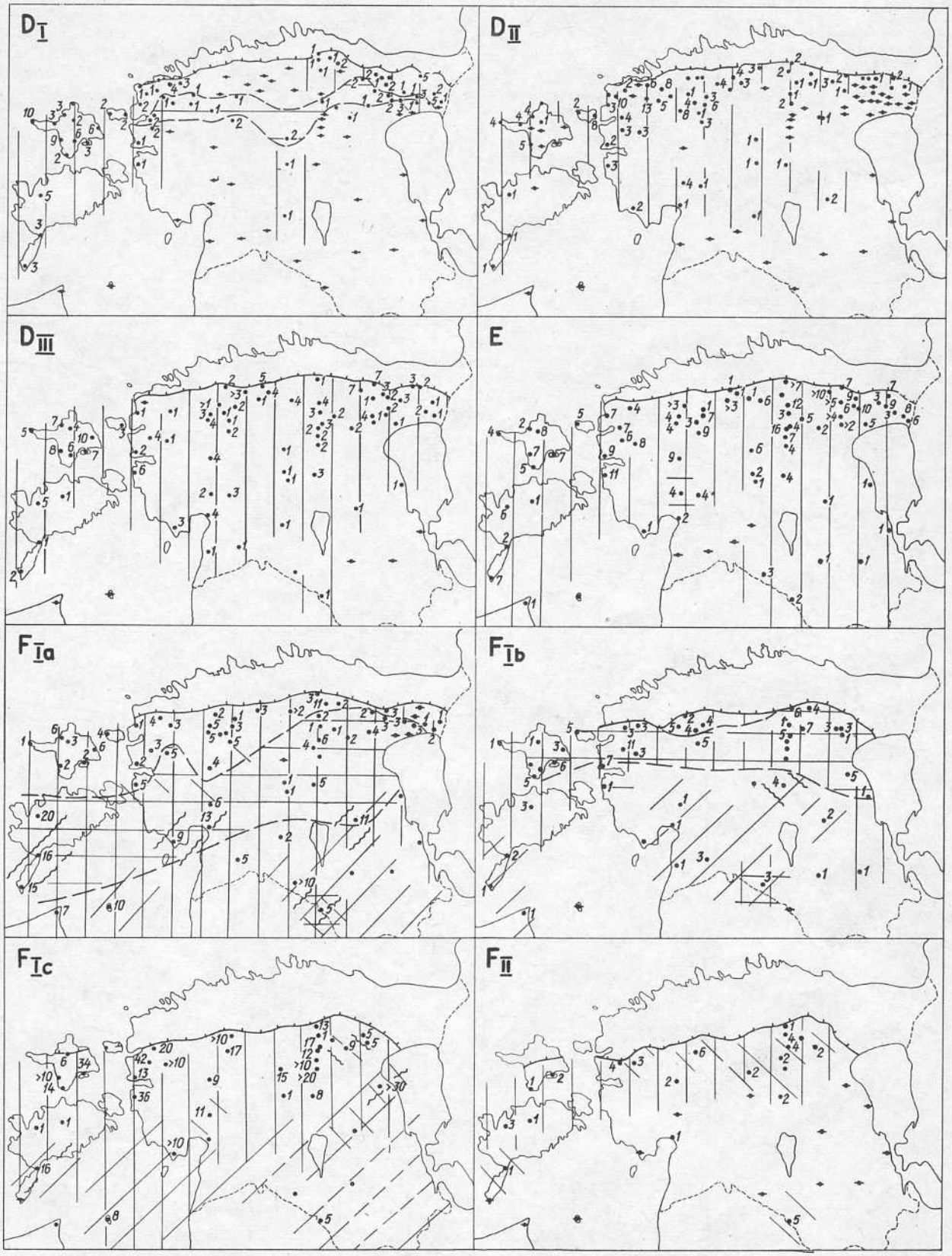

Fig. 4, 5. Distribution of DS on the Estonian territory. 1 - erosion line, 2 - wedged-out area of the stage, 3 - borehole, outcrop; the number of DS, 4 - borehole where DS are missing, 5-8 - DS impregnation types: 5 - pyritic, 6 - phosphatic, 7 - goethitic, 8 - hematitic, 9 - non-impregnated DS, 10 - DS covered with the glauconitic lamina, 11 - boundary of the DS impregnation zone.

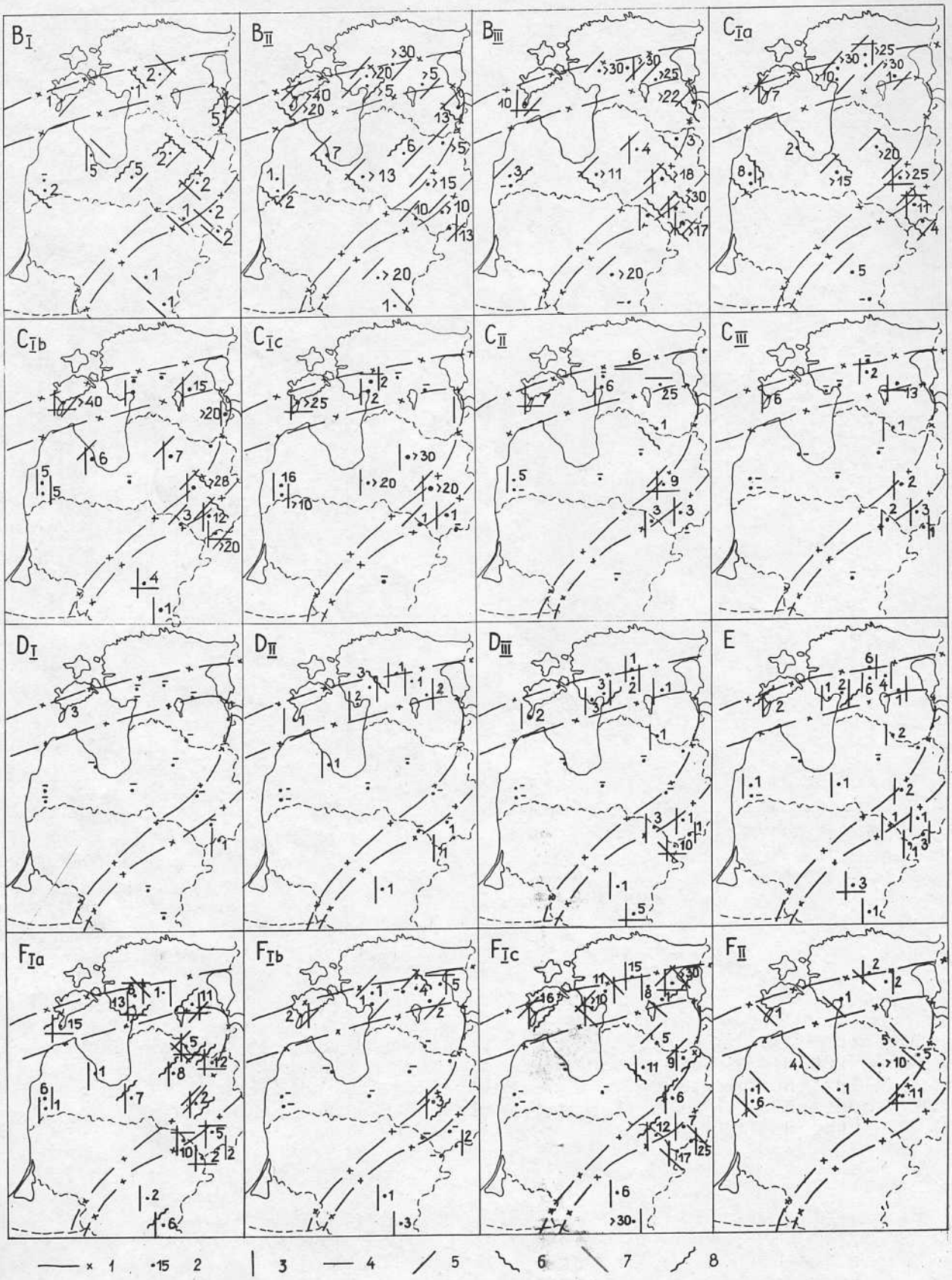

Fig. 6. Distribution of DS in the Central and Southern Confacies Belts and in the transitional zone. 1 - transitional zone, 2 - borehole, the number of DS, 3-6 - DS impregnation type: 3 - pyritic, 4 - phosphatic, 5 - goethitic, 6 - hematitic, 7 - nonimpregnated DS, 8 - DS covered with the glauconitic lamina.

the mixed pyritic-phosphatic one. In the southern part of this zone in the Paekna Formation several (1-3) DS are in places covered with a glauconitic lamina, rarely also (1-2) nonimpregnated DS are present.

The number of phosphatic DS in the Paekna Formation varies from 1 to 10 (mainly 3-4), in the Vormsi Stage - from 1 to 3. The amount of pyritic DS is correspondingly 1-10 (mainly 3-4) and 1-4. In the Vormsi Stage, on Saaremaa Island, southward of the mixed zone the pyritic zone is distributed.

F_Ic-F_{II} (Fig. 5). In both stages mainly pyritic DS are distributed in the Northern Confacies Belt, in places co-occurring with a few nonimpregnated DS. In the Pirgu Stage sometimes hematitic DS are present, some of them being covered with a glauconitic lamina.

In the Central Confacies Belt the periods established on the basis of the DS distribution pattern are different from the northern belt. Here the following intervals have been distinguished: B_I-C_Ia, C_Ib-C_Ic, C_{II}-E. Between F_Ia-F_{II} the distribution pattern is different in all stages.

B_I-C_Ia. (Fig. 6). The DS are mainly with the goethitic impregnation. Along with them in the central part of the belt 1-5 (very rarely up to 10--20) hematitic DS are distributed. In the Latorp and Volkhov stages up to 5 DS are covered with a glauconitic lamina. Very rarely some (1-3) pyritic DS are present.

C_Ib-C_Ic. (Fig. 6). In both stages many (mainly >5; in C_Ic frequently >10, in places even >30) pyritic DS occur. The DS are entirely lacking in the northern part of the central belt. In the Lasnamägi Stage in the middle part of the belt along with the pyritic DS single goethitic DS are distributed.

C_{II}-E (Fig. 6). In this interval DS are practically missing in the central belt. Only on some levels 1-2 DS occur in places. (By way of exception in C_{II} 5 pyritic DS have been registred in Aispute core, western Latvia).

F_Ia (Fig. 6). In the whole belt pyritic DS (mainly 6-7) are distributed, in places co-occurring with some goethitic (up to 3), non-impregnated (1) and phosphatic (1) DS. Here and there some of them (up to 7) are covered with a glauconitic lamina.

Fb-Fc (Fig. 6). In both stages a few mostly goethitic DS (1-5) occur only in the northern part of the belt (in southern Estonia). Rarely single pyritic, hematitic and phosphatic DS are present in the Vormsi Stage. In the central part of the belt the DS are entirely lacking.

F_{II} (Fig. 6). The DS, 1-10, mainly 4-5 in number, are distributed only in the central part of the belt. Only in single cases mostly nonimpregnated DS have been registered in southern Estonia as well.

DISCUSSION AND CONCLUSIONS

The principal aim of this paper was to give a systematic review of the lateral and stratigraphic distribution of the DS in the East Baltic Ordovician, laying main stress on their number and type of impregnation. From the data obtained the following conclusions can be drawn:

1. In the sequence, beginning from the Lasnamägi Stage the number of DS varies analogously both in the northern and central belts (Fig. 1).

2. The number of DS and frequency of breaks are the greatest in the Llandeilo both in the central and northern belts (Figs 1, 2).

3. On the grounds of the number of DS and distribution patterns of various impregnation types several particular intervals can be selected in the Ordovician section. As a rule, their stratigraphic limits do not coincide in the northern and central belts. There is some evidence of their dependence on the type of sediments. Especially interesting is the lateral and stratigraphic distribution pattern of the phosphatic DS. On these problems a more detailed report is being prepared (Saadre, 1993, in prep.).

Some comments should also be made on other aspects of the DS. Since detailed registration of the morphology of DS is a very time-consuming process, the corresponding data available are more scarce. The author does not possess sufficient data to give an analogous review of the spatial morphological varieties of the DS. Nevertheless, the importance of such a re-

search ought to be emphasized, as it could also serve as a significant clue to solve the problems of DS genesis.

In the authors opinion most of the DS in the East Baltic Ordovician are of the submarine origin. Judging from morphological and structural characteristics undoubtedly a part of them have initially been hardgrounds, but evidently many of them represent softgrounds (buried in not entirely hardened shape). The subaereal genesis of DS in this region ought to be taken as an exception. The more characteristic examples of this genesis (microkarst origin) are some DS from the Kukruse Stage (Bauert, 1989) and the Oandu Stage - both with deep (more than 10 cm) carvings impregnated with pyrite.

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