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SEDIMENTARY STRUCTURES IN THE LOWER SALMIAN OF THE STAVELOT MASSIF (BELGIUM) AS INDICATIONS OF TURBIDITE SEDIMENTATION

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ABSTRACT. - The Lower Salmian (Tremadoc-Lower Ordovician) in the Stavelot Massif mainly consists of siltstones and sandstones interstratified with pelitic rocks. Numerous sedimentary structures indicate these siltstones and sandstones to be turbidites; most of them are relatively thin low-density turbidites, but thick high-density turbidites also occur in channelized sequences. Northerly paleocurrents predominate.

INTRODUCTION.

The Stavelot Massif (fig. 1) is a complex Caledonian structure composed of Devillian, Revinnian and Salmian (DUMONT, 1847). According to GEUKENS (*in* ROBASZYNSKI and DUPUIS, 1983) the Devillian, Revinnian and Salmian (table 1) are of Middle Cambrian, Upper Cambrian and Tremadoc-Lower Ordovician ages respectively.

The Lower Salmian or Salmian 1 discussed here has its lower limit at the contact with the underlying Revinnian (Rv5), mainly composed of black shales but locally rich in magmatic (mainly volcanic) rocks. The overlying Salmian 2 is composed of red and violet mainly pelitic rocks rich in iron and manganese and includes the coticules in the metamorphic zone.

The Lower Salmian in the Stavelot Massif, measured in the Chevron syncline (fig. 1), is approximately 750 m thick. It consists of siltstones and sandstones interstratified with massive mudstones and finely laminated mudstones and siltstones (the so-called "quartzophyllades"). GEUKENS (1965) divided the Salmian 1 into Sm1a, Sm1b and Sm1c. The siltstones and sandstones occur in individual beds mostly between 3 and 60 cm thick but exceptionally up to 180 cm thick. Their colour is dark blue, grey or greenish. They contain numerous sedimentary structures. The aim of this paper is to describe these sedimentary structures as an indication for the depositional mechanism of these siltstone and sandstones beds. They can be divided into two distinct types based upon their thickness : type 1 beds are 3 to 60 cm thick, type 2 beds are 90 to 180 cm thick.

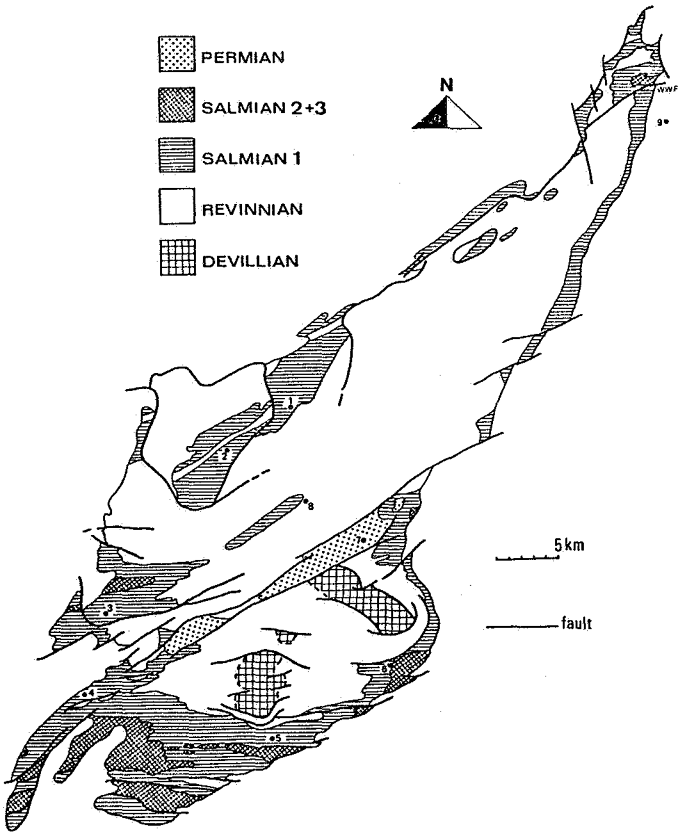

Fig. 1

Geological map of the Stavelot Massif, after GEUKENS (unpublished, 1981). Figures indicate localities mentioned in text : 1 = Sart, 2 = Spa, 3 = Chevron, 4 = Bra, 5 = Vielsalm, 6 = Recht, 7 = Malmédy, 8 = Francorchamps, 9 = Grosshau. RWF = Rother-Wehbach fault.

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Thickness	Unit	Subunit	Formation
>1000m	Sm 3	b, a	Salmian
	Sm 2	c, b, a	
	Sm 1	c, b, a	
>1900m	Rv 5		Revinnian
	Rv 4		
	Rv 3		
	Rv 2		
	Rv 1		
>600m	Dv 2		Devillian
	Dv 1		

Table 1 - Lower Paleozoic stratigraphy in the Stavelot Massif, thicknesses after WALTER (1980).

MINERALOGY.

The grain size of the siltstone and sandstone beds ranges from medium and coarse silt to very fine and fine sand. The rocks are composed of quartz, detrital mica, detrital feldspar, opaque minerals and a very fine-grained matrix that constitutes 10 to 40 % of the rock. The rocks are generally rich in detrital mica; if this mica is considered to be derived from metamorphic source rocks, most of the rocks can be petrographically described as subgraywackes following the classification of FOLK (1954), see fig. 2.

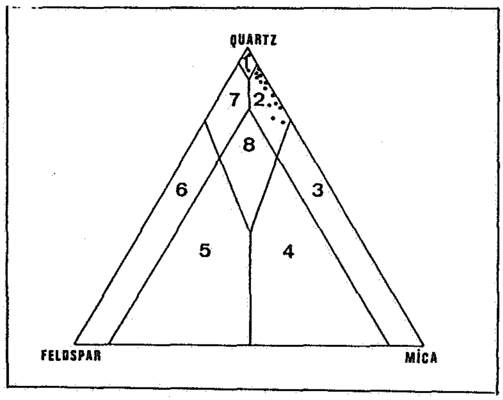

Fig. 2
Mineralogical classification diagram for terrigenous sedimentary rocks, from FOLK (1954) ;
1 = orthoquartzites, 2 = subgraywackes, 3 = graywackes, 4 = feldspatic graywacke, 5 = impure arkose, 6 = arkose, 7 = subarkose, 8 = feldspatic subgraywacke. Points represent modal analyses of 15 Lower Salmian silstone and sandstones. Note that this classification does not take into account the matrix content of the rocks.

The accessory minerals are mainly zircon, tourmaline and rutile. GRAULICH (1952) mentions several other heavy minerals occuring in very low quantities. On average 25 % of the zircons (with a range from 5 up to 50 %) are idiomorphic or subidiomorphic. The remaining zircons are well-rounded (polycyclic) and about a third of them are pink. The high percentage of idiomorphic zircons indicates an important first cycle magmatic component in the source rocks.

SEDIMENTARY STRUCTURES IN TYPE 1 SILTSTONES AND SANDSTONES (3-60 cm.).

1. STRUCTURELESS BEDS.

Some siltstones and sandstone beds contain no sedimentary structures at all. In most cases the structureless nature is probably a primary phenomenon, but locally severe tectonism may have obscured existing structures.

2. GRADED BEDDING.

Graded bedding is frequently observed together with other structures, mainly horizontal lamination; it rarely occurs in the absence of any other structures. The grading is not always visible macroscopically due to the general fine grain size of the rocks, but microscopically it mostly consists in a upwards increase of the matrix content (content grading, cf. McBRIDE 1962). True grading as an upwards fining of the sediment with good vertical separation of different grain sizes also occurs but less frequently.

3. HORIZONTAL LAMINATION.

This structure consists in laminae alternately rich and poor in relatively coarse grains, generally distinguishable by the darker colour of the fine-grained laminae (plate IA). The lower and upper limit of the laminae are generally sharp. The laminations are probably caused by fluctuations in energy during vertical falling-out from suspension in a current.

4. CROSS-LAMINATION.

This structure is very frequent in these rocks. The ripple sets are always small-scale (amplitude generally 1 or 2 cm, at the most 5 cm), asymmetrical and unidirectional within the same sedimentation unit. Observations in perpendicular rock sections allow to conclude that the shape of the ripples is lingoid.

When several ripples sets are superposed, they form nearly always a ripple-drift cross-lamination. In most cases the shape of the individual ripples is very distinct; the lee and stoss side laminae are preserved and there is a striking continuity of individual laminae from one ripple to another. A typical example can be seen in plate IE. There is often a concentration of dark fine-grained material on the lee sides and in the ripple troughs; this segregation is sometimes very pronounced. In some cases the ripples are covered by a relatively thick mud layer, indicating deposition from a pulsating current (plate ID). The climbing angle is moderate to steep. This description fits the ripple-drift cross-lamination type B described by JOPLING and WALKER (1968) and by ALLEN (1970, 1973) and the supercritically climbing ripples described by HUNTER (1977). Sometimes the erosion is greater on the stoss side so that the stoss side laminae are no longer preserved, as was found for ripple-drift cross-lamination type A and the subcritically climbing ripples described by the above-mentioned authors.

The occurrence of ripple-drift cross-lamination indicates a high sedimentation rate from suspension. According to JOPLING and WALKER (1968) the difference in type depends on the proportion of material in suspension to material moved by traction. According to ALLEN (1970) the climbing angle depends on the ripple height and the ratio of vertical sedimentation rates to horizontal transport rates. The fact that type B is here most frequent, indicates a relatively high vertical sedimentation rate, that is sedimentation from a dense suspension. This structure is described in fluviatile and deltaic environments and also in turbidites (ALLEN, 1982a, p. 368-370). In turbidites ripple-drift cross-lamination is "the usual if not exclusive type" (KUENEN, 1967).

5. SEDIMENTARY DEFORMATION STRUCTURES.

A. Deformed foresets.

In some cases of cross-lamination, the laminae are not straight or regularly curved but show irregular undulations and are sometimes even recumbently folded (plates ID and IID). This deformation is thought to be caused by current drag on a liquefied sediment layer (ALLEN and BANKS, 1972; DOE and DOTT, 1980; McKEE *et al.*, 1962; RUST, 1968).

B. Convolute and corrugate lamination.

This deformation structure is very frequent in the Lower Salmian sedimentary rocks. The structure fits the classical description of convolute lamination, to wit a series of broad synclinal folds separated by narrow anticlines in which individual laminae can be traced through several successive folds; the deformation is limited to a single bed or part of a bed (plate IC). However a considerable number of the observed deformation structures does not show the regular synclinal-anticlinal morphology : the folds are chaotic and may vary in a short distance from upright to recumbent (plate IB). DAVIES (1965) describes very similar structures as corrugated bedding. According to DAVIES (1965) and ELLIOTT (1965) the difference between corrugated and convoluted bedding is a matter of more horizontal plastic flow in the former than in the latter.

No generally satisfactory explanation has yet been given for these types of sedimentary deformation structures. We will not review here the extensive literature on the subject, but most authors agree that the sediment must have been hydroplastic or liquefied during deformation. We think that dewatering is the most probable cause of deformation, as has also been suggested by DAVIES (1965) and LOWE (1975).

C. Load casts.

Load casts are frequent phenomena in the siltstones and sandstones. Most of the load casts observed are a few dm wide, but smaller cm-scale examples also occur. They mostly do not penetrate the underlying sediment more than 10 cm. Load-casted ripple marks have also been observed (plate IIA).

D. Flame structures.

Flame structures are relatively rare and in the cases observed are very small-scale structures. A typical example is given by plate IIA.

E. Dewatering structures.

In some beds the regular horizontal or oblique laminations are locally interrupted or bent upwards (plate IIB). This structure is very similar to the elutriation columns described by CORBETT (1972) or the fluidisation channels from LOWE (1975), and is thought to be caused by interstitial water escaping upwards through the sediment. This structure seems to approach convolute lamination.

6. FLUTE CASTS.

The examples observed are up to 15 cm large; according to the classification by ALLEN (1982b, p. 255), they can be described as parabolic (plate IIC). It is not a frequent structure.

7. SHALE CLASTS.

Some beds contain in their lower part dark flattened mudstone fragments. They are usually well-rounded. They are similar to the clay pebbles and shale clasts described by several authors, among others CHIPPING (1972) and ENOS (1969). They are thought to be formed by erosion of fragments from a semi-consolidated mud layer by a vigorous current and subsequent transport and rounding. These shale clasts occur only in the lowest sandstone beds of the Salmian 1.

8. SOLE TRAILS.

These occur very rarely on the sole of some beds. They consist of 1 to 6 cm long irregularly curved semi-cylindrical trails showing no preferred orientation. They resemble predepositional sole trails as described by SEILACHER (1962) and are probably formed by the filling of organic crawling and grazing traces by a sediment-laden current.

9. SEQUENCES.

It is a very important observation that the previously described sedimentary structures occur closely associated in sequences of the BOUMA (1962)-type. We have observed 11 different sequences that are depicted in fig. 3. The sequences C, D, F and I are the most frequent. The sequences are often associated with a more or less distinct upwards fining of the sediment. Some typical sequences are shown in plates IA, IC and IIA.

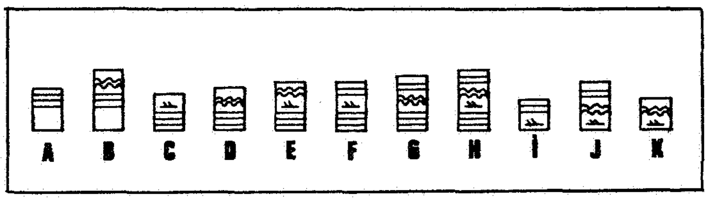

Fig. 3 - Sequences of sedimentary structures observed in type 1 siltstone and sandstone beds. Symbols are the same as in fig. 4.

10. INTERPRETATION.

None of the sedimentary structures described here is in itself diagnostic of a specific sedimentation process or sedimentary environment. Their association however provides good evidence for the nature of the depositional mechanism :

- upwards fining of the sediment concurrent with sequences of sedimentary structures that indicate deposition from a gradually weakening current;
- ripple-drift cross-lamination indicating high sedimentation rates from a dense suspension in an unidirectional current;
- numerous and very frequent sedimentary deformation structures indicating very plastic water-saturated sediments and generally high sedimentation rates;
- flute casts and shale clasts indicating the erosive nature of the currents.

From this evidence it appears logical to interpret these sediments as turbidites. If we introduce the sedimentary structures in the well-known BOUMA (1962)-classification, we can state that the Tb, Tc and Td intervals are the most frequent as well as the sequences Tbc, Tbcd and Tcd.
The fine grain size of the sediment and the rare occurrence of the Ta interval and of erosive structures indicate that the sediments are low-density turbidites; they may also be called facies D-turbidites according to MUTTI and RICCI-LUCCHI (1975) or distal turbidites according to WALKER (1967). Some typical sequences of these turbidites interstratified with mudstones are depicted in fig. 4 ABC.

SEDIMENTARY STRUCTURES IN TYPE 2 SILTSTONE AND SANDSTONE BEDS (90-180 cm).

The thick siltstone and sandstone beds can be divided into two distinct varieties; both are however closely associated :

- a first variety is totally structureless, neither laminations of any kind nor grading can be detected;
- a second variety is for the greater part structureless but the topmost 10 to 20 cm show horizontal lamination, ripple-drift cross-lamination or convolute lamination; this coincides with a distinct upwards fining of the sediment. The grain size changes from fine sand in the structureless part to medium silt at the top of the bed.

In both types, load- and flute casts are frequent.

The thick beds with graded tops show structures very similar to the previously described turbidites. Because of their thickness and the importance of the Ta interval, they are probably high-density turbidites (facies C - turbidites according to MUTTI and RICCI-LUCCHI (1975) or proximal turbidites according to WALKER (1967)).

As the first structureless variety is closely associated with these turbidites, it is probable that the sedimentation process is somewhat analogous. Thick structureless sandy beds can be explained as high-density turbidites with direct suspension sedimentation (LOWE, 1982; HISCOTT and MIDDLETON, 1979); in this process neither grading nor traction structures are formed. Similar sediments have also been described as fluxoturbidites (CARTER, 1979).

Two sequences in which these type 2 turbidites occur are depicted in fig. 4 DE.

DISCUSSION AND GEOLOGICAL SIGNIFICANCE.

In the lowermost part of the Salmian 1, the type 1 turbidite siltstones and sandstones are interstratified with dark often graptolitic mudstones. This interval coincides with the Sm1a described by GEUKENS (1965), see table 2. Fig. 4 ABC shows some typical examples of such sequences.

Sm1c	finely laminated mudstones and siltstones with locally thick sandstone beds.
Sm1b	: 100m Finely laminated mudstones and siltstones interstratified with turbidite siltstones and sandstones.
Sm1a	mudstones interstratified with frequent turbidite siltstones and sandstones.

Table 2 - Stratigraphic table of the Lower Salmian.

The type 2 thick siltstone and sandstone beds occur associated with type 1 beds in sequences in which the proportion of mudstones is very low; amalgamations are frequent (see fig. 4 DE). They occur in restricted zones which laterally pass into "normal" type 1 turbidites and interstratified mudstones. Because of poor exposure the nature of the contact is never clear, but the thick-bedded sequences are probably only a few hundred metres wide. The occurrence of laterally restricted zones with "proximal" turbidites in an environment dominated by "distal" turbidites is a well-known phenomenom; they are mostly interpreted as infillings of broad submarine channels (CARTER, 1979; CHIPPING, 1972; CORBETT, 1972; NORMARK and PIPER, 1969; WALKER, 1966, 1978). This observation illustrates that the proximal or distal character does not necessarily depend upon distance from the source but may also depend on the channelized or non-channelized nature of the deposits. These channelized deposits occur only in the lower part of the Salmian 1 (Sm1a and lowermost Sm1b); we have observed them near Recht, west of Francorchamps and east of Malmédy.

Higher up in the stratigraphy (the Sm1b, see table 2), the turbidite siltstones and sandstones are less frequent and are interstratified with thick sequences of finely and irregularly laminated mudstones and siltstones (the "quartzophyllades"). In the Sm1c turbidites beds are absent.

The association of turbidites with graptolitic shales and the presence of channelized sequences indicate a relatively deep depositional environment. However, we do not think the environment was very deep, because the "quartzophyllades" of the Sm1b show several indications of gradually shallowing conditions as the turbidite deposits gradually disappear. At the top of the Lower Salmian sequence (the Sm1c) thick continuous sandstone beds occur which are very probably of shallow water origin, and locally unmistakable wave influence can be observed in the siltstones. We therefore do not think that the turbidites were deposited in a submarine fan environment several kilometers deep, but rather in a near-continent basin-to-shelf transition zone with a depth of several hundred metres.

It is not the first time turbidites are described in the Stavelot Massif : GEUKENS (1962) described turbidites in the Revinnian 3 and BRABERS (1981) also interpreted Lower Salmian sedimentary rocks as turbidites.

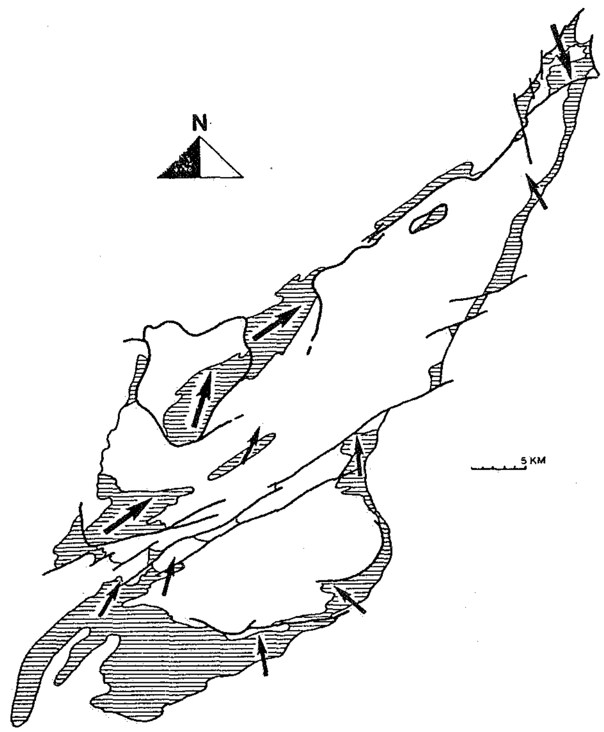

Fig. 5 - Paleocurrent directions measured in turbidites in the Sm1a. Thick arrows = mean directions based upon more than 20 measurements; thin arrows = based upon less than 20 measurements. Striped = Salmian.

PALEOCURRENTS.

Paleocurrent directions in the turbidites were measured from flute casts and cross-laminations and corrected for tectonic tilting following RAMSAY (1961). In the Sm1a the turbidite beds show transport directions dominantly towards the NNE and NNW (fig. 5), while in the Sm1b they are dominantly towards the NE (fig. 6). The northward transport direction is consistent with a gradual decrease in turbidite bed thickness towards the north, that probably reflects a deepening of the Salmian sedimentary basin in that direction. The "Dachschiefer" facies near Grosshau (fig. 1), which consists of graptolitic shales with only rare thin siltstone beds, probably represents the deepest currently exposed part of the sedimentary basin.

A problematic feature occurs north of the Rother-Wehbach fault (GEUKENS, 1957, see also fig. 1) where the turbidite beds are again frequent and thick. GEUKENS (1984) explains this observation by assuming an originally greater distance between both parts of the Stavelot Massif and a subsequent northward thrusting of them. The paleocurrents in the Sm1a of the northern part are towards the SSE (fig. 5); it is therefore possible that this zone is part of a slope limiting the Salmian sedimentary basin towards the north, as this would explain the southward transport directions.

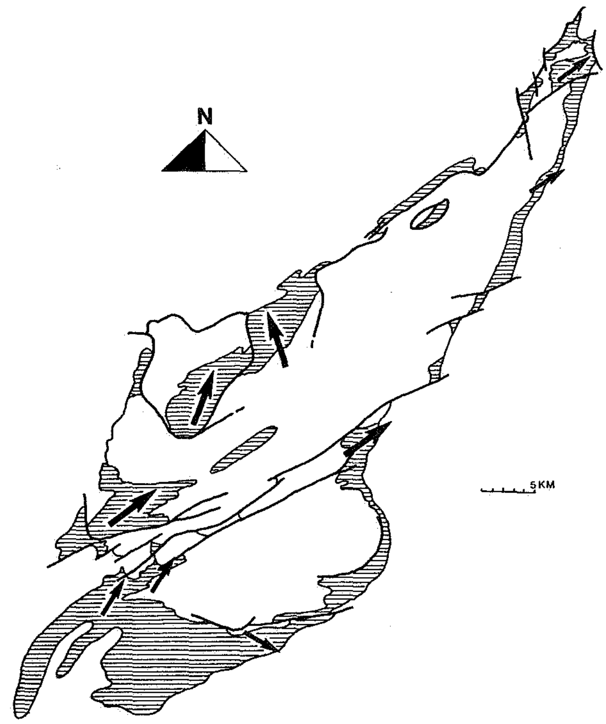

Fig. 6 - Paleocurrent directions measured in turbidites in the Sm1b. Same symbols as in fig. 5.

A tectonic rotation of the northern part of the Stavelot Massif (GEUKENS, 1984) cannot be more than 20 or 30° : we therefore do not think the anomalous paleocurrent directions can be explained by tectonic rotation; moreover in the Sm1b the paleocurrents do seem to fit the regional pattern (fig. 6). The contrast with the Dachschiefer zone is too sharp to be primary, so that the Rother-Wehbach fault must

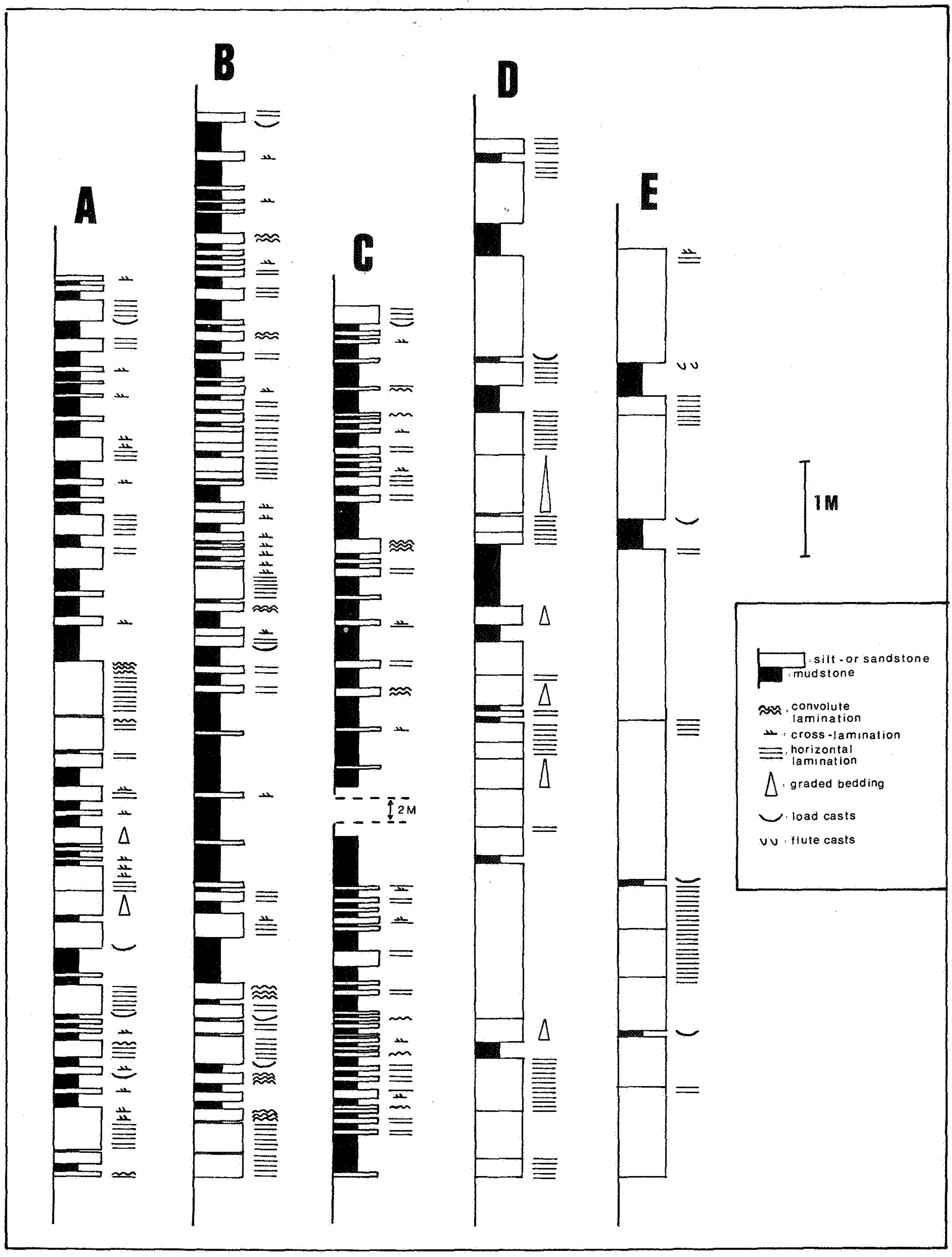

Fig. 4

Sequences of lithologies and sedimentary structures in some representative outcrops of the Lower Salmian.

A = Pont des Villettes near Bra (Bra 55/3 : 247,83; 114,54)

B = Targnon near Chevron (La Gleize 49/8 : 250,22; 123,00)

C = Parfond Bois near Sart (Sart 50/1 : 262,42, 135,88)

D = Hé Stienne near Francorchamps (Stavelot 50/5 : 265,00; 127,60)

E = Burg near Recht (Recht 56/2 : 268,73; 115,06) be an important feature. It is probable that this fault caused a considerable part of the original sedimentary basin to disappear, thereby approaching two zones that were originally much more widely separated.

CONCLUSION.

The Lower Salmian (Tremadoc-Lower Ordovician) in the Stavelot Massif mainly consists of siltstones and sandstones interstratified with pelitic rocks. The siltstones and sandstones are petrographically subgraywackes. Two types have been distinguished. Type 1 beds are 3 to 60 cm thick and show graded bedding, ripple-drift cross-lamination, numerous sedimentary deformation structures and occasionally erosional structures. They are probably low-density turbidites. Type 2 beds are 90 to 180 cm thick and are structureless or graded at the top; they are interpreted as high-density turbidites occurring in channelized deposits. The depositional environment is not thought to be very deep. The paleocurrent directions are dominantly towards the north, reflecting a northward deepening sedimentary basin.

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PLATE I.

A. Sequence of basal structureless part passing upwards into horizontal lamination, associated with upwards fining of the sediment. Sample from Sm1a near Bra (Bra 55/3 : 250,02; 112,45).

B. Corrugated bedding consisting in chaotic sedimentary folds. Sample from Sm1a near Chevron (Harzé 49/7; 249,88; 123,22).

C. Sequence of horizontal lamination passing upwards into convolute lamination, associated with upwards fining of the sediment. Sample from Sm1b near Vielsalm (Vielsalm 56/1 : 263,70; 111,35).

D. Cross-lamination with current ripples covered by mud layers. Note deformed foresets. Sample from Sm1a near Sart (Sart 50/1 : 262,40; 136,41).

E. Ripple-drift cross-lamination type B showed well-preserved current ripples. Sample from Sm1b near Vielsalm (Vielsalm 56/1 : 263,70; 111,35).

Scale is in cm.

PLATE I.

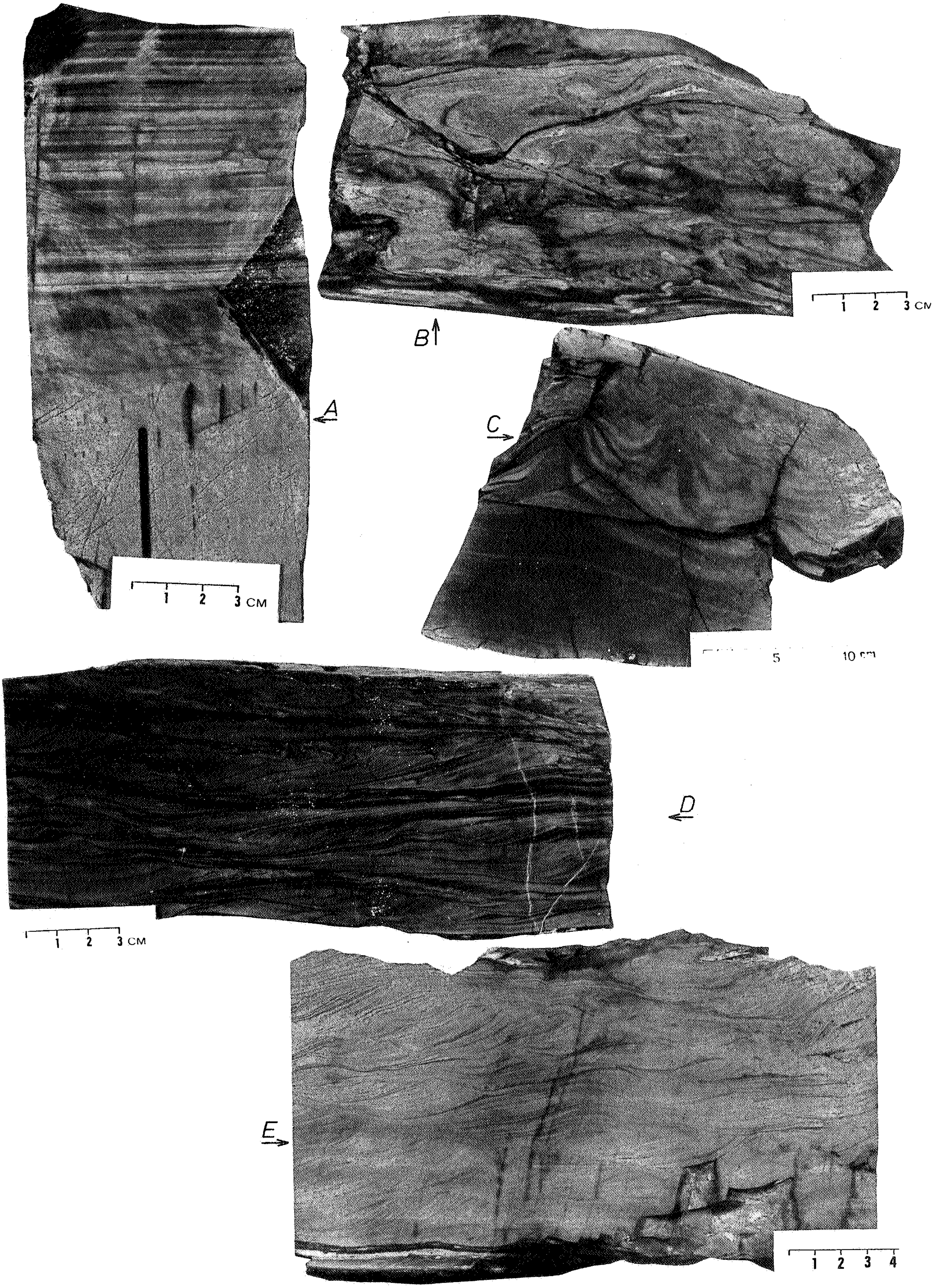


PLATE II.

A. Sequence of cross-lamination passing upwards into horizontal lamination with local folding. Note distinct flame structures at the base of the bed and upwards fining of the sediment. Sample from Smla near Sart (Sart 50/1 : 262,40; 135,88).

B. Horizontal lamination with dewatering channel in upper part of the bed. Sample from Smlb near Spa (Spa 49/4 : 255,24; 134,22).

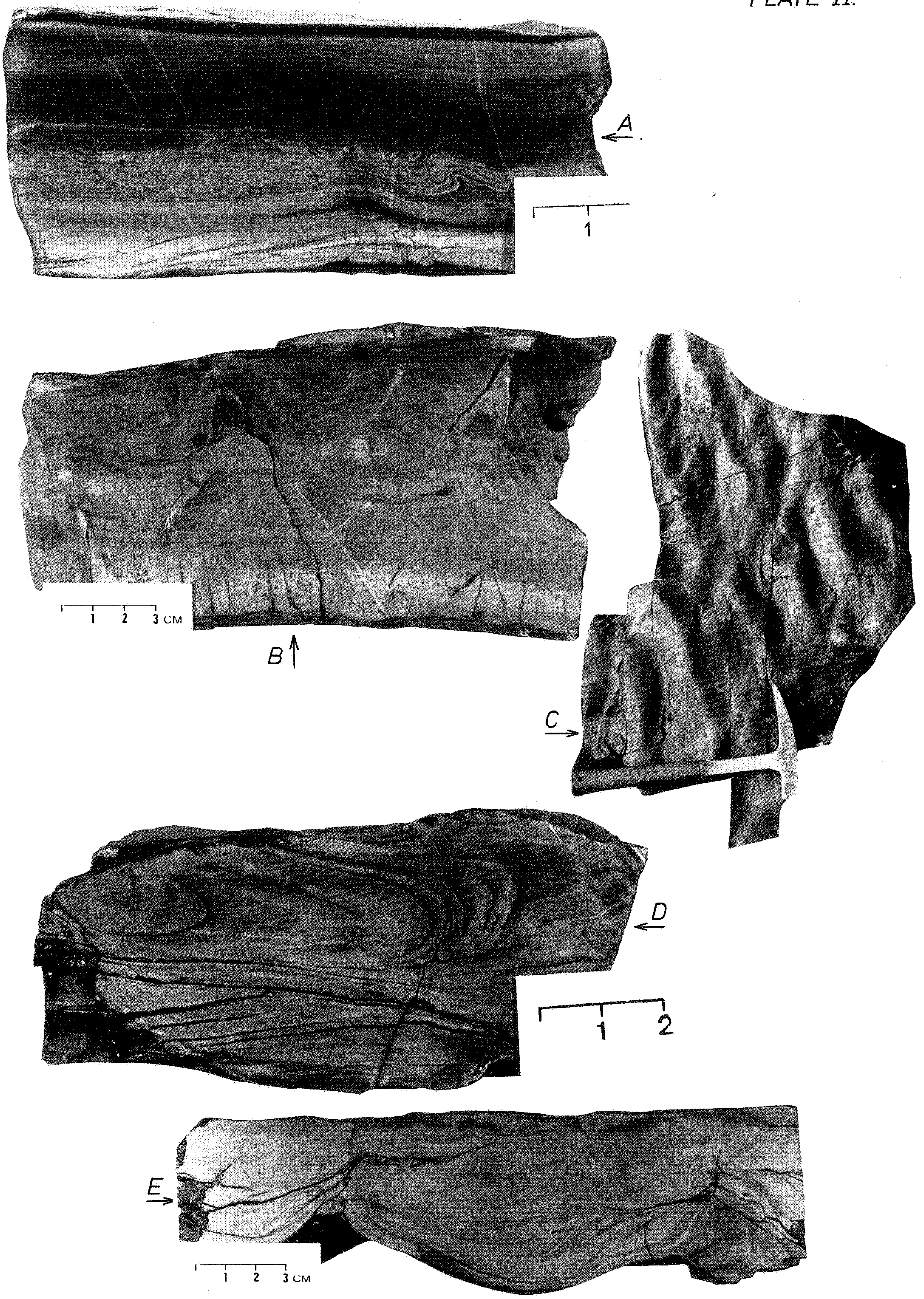
C. Flute casts. Outcrop from Smla near Recht (Recht 56/2 : 268,73; 115,06).

D. Recumbently folded cross-lamination. Sample from Smla near Bra (Bra 55/3 : 248,10; 114,35).

E. Load-casted ripple marks. Sample from Smla near Sart collected by VAN THOURNOUT, exact localisation unknown.

Scale is in cm; hammer is 33 cm. long.

PLATE II.



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