

Sole Markings Produced by Graptolite Remains

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The Silurian siltstones revealed by the Lębork bore-hole (Eastern Pomerania) show a profusion of interesting sole markings. The siltstones are represented by thin (of the order of several cm.) beds interbedded with dark shales. The interbedded siltstones and shales are 1300 m. thick. They are Ludlovian in age [1]. The total thickness of the Silurian deposits encountered in the Lębork bore-hole exceeds 2200 m.

The siltstone beds were laid down by turbidity currents. They commonly exhibit an indistinct vertical grading of grain size, and poorly delineated top surfaces, while their soles are always sharp. The vertical succession of internal sedimentary structures displayed by some composite siltstone beds suggests rapid depositional events.

On the sole of a thin (6 mm.) siltstone bed, cored at 2629 m. depth, graptolite remains (*Pristiograptus* sp. indet.) were found at the down-current ends of short groove marks (Fig. 1 a; Pl. I). These remains are two short (7—8 mm.) fragments of rhabdosomes, aligned almost parallelly to the current flow. They face one another by their ventral parts.

The widths of the grooves under consideration (below 1 mm.) closely correspond to those of the various tool marks occurring in the Silurian of the Lębork bore-hole. These marks observed on dozens of different soles, show a surprising uniformity in width (usually 0.2—2 mm.). The lengths of the discontinuous tool marks, known from the Silurian of the Lębork bore-hole, in most cases do not exceed several millimeters.

The uniform dimensions of the tool marks suggest that the objects which left them were always of the same type, or at least of comparable dimensions. The specimen from a 2629 m. depth indicates that graptolites cut the marks. However, graptolites were not the only objects that scratched the bottom. Minute unidentified shells of lamellibranchs and brachiopods (Fig. 1 c; Pl. I), occurring on many siltstone soles, were probably also responsible for the formation of tool markings. Enigmatic (faecal?) pellets, usually clayey and calcareous, and sometimes replaced by pyrite (Fig. 1 d; Pl. I), might also have grooved the soft, muddy substratum. Frequently, if not in most cases, tool marks were produced by transported fragments of shale.

Small fragments of shale, scattered randomly within the siltstone beds, were encountered fairly often in the Silurian of the Łębork bore-hole.

The siculae of graptolites found at the down-current ends of grooves are directed up-current. This is presumably due to the fact that rhabdosomes of *Pristiograptinae* rested in the position of least resistance to the current with their siculae up-current. Thus the current would flow along the ventral walls of thecae, which formed a small angle with the general direction of current filaments. In the case of an opposite orientation, i.e. with the siculae down-current, the apertures of thecae inclined at a significant angle to the trend of streamlines would strongly resist the current. In addition, the proximal parts of rhabdosomes are usually narrower than distal ones, and thus would offer a correspondingly smaller hydraulic resistance.

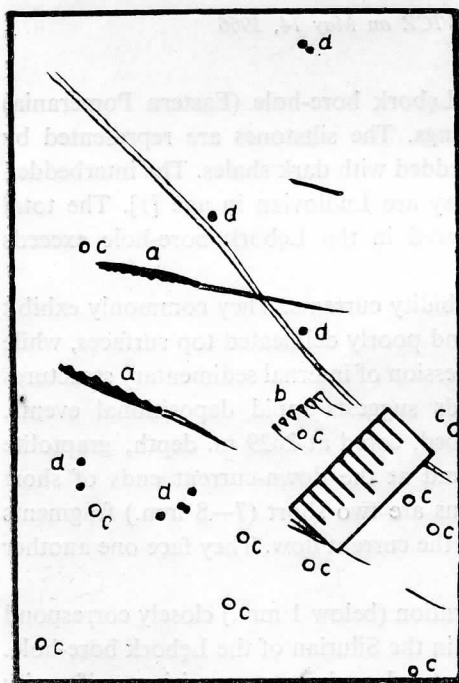


Fig. 1. Graptolites at the down-current ends of short grooves. After the photograph presented in Pl. I. Current from right to left. Łębork bore-hole, core from 2629 m. depth. Scale marked in millimeters

a — graptolites, b — transverse set of prod marks with tiny twisted grooves at the up-current ends, c — minute shells of lamellibranchs and brachiopods, d — faecal (?) pellets

The above considerations may prove useful for directional interpretation of oriented graptolites in the absence of other current markings. In most cases, parallel-oriented graptolites do not point with their proximal ends in one direction. If this is the case, one may deduce the current direction from the orientation of the siculae of the majority of rhabdosomes. However, any paleogeographic conclusion deduced from current directions determined this way should be regarded with great caution.

The most remarkable tool markings in the Silurian of the Łębork bore-hole are those composed of several minute prod marks with their down-current steep walls aligned transverse to the direction of flow (Fig. 1 b; Pl. I; Pl. II). These markings are presumably due to the dragging and saltation of graptolite remains. The tiny parallel grooves ending with prods were probably cut by the thecae of graptolite rhabdosomes. This is evidenced by the fact that the spacing of the small prods



Pl. I. Graptolites at the down-current ends of short grooves. Current from right to left. Łęborg bore-hole, core from 2629 m. depth. Scale marked in millimeters.

Photograph by the Photographic Laboratory of the Geological Institute, Warsaw



Pl. II. Tool markings upon elongated, indistinct scour markings. Note a transverse set of prod marks with tiny parallel grooves at their up-current ends (upper left). Current from bottom to top. Lębork bore-hole, core from 2470 m depth. Scale marked in millimeters

Photograph by the Photographic Laboratory of the Geological Institute, Warsaw

composing the mentioned markings is the same as that of the thecae of graptolites acting as grooving tools (*Pristiograptinae*).

Smith [2] was the first and as yet the only author to report graptolites resting across parallel grooves with the thecae stuck into the sediment at their ends. Smith's interpretation of these markings (p. 427) is as follows:

"It is thought that movement was probably caused by a mud flow over the graptolite bearing surface, and that the graptolite was projecting into the overlying sediment and was pushed along by the flow. This movement of the graptolite caused its thecae to cut grooves in the underlying sediment (...). It was at first thought that movement of the graptolite might have been caused by water currents. This suggestion was rejected because the stipe was unlikely to have had sufficient weight to groove the underlying sediment particularly if supported in water, and also because the stipe would turn over or become orientated in the direction of flow of the water current".

The finding of graptolites at the down-current ends of single groove markings proves that under certain flow conditions, graptolites might have been transported by bottom traction. The variety of markings produced by transported graptolites reflects the variety of their positions at the moment of striking the bottom. This in turn suggests the presence of vortices which affected their motion.

The structure illustrated in Fig. 1 b and Pl. I is of special interest. It shows a transverse set of prod marks, with tiny twisted grooves at their up-current ends. It is thought that these markings were probably left by a graptolite arrested for a while in a position transverse to the current and at a small angle to the bottom. Thecae at one end of the rhabdosome touched the soft muddy substratum, scratching it. It was this brief contact between the graptolite and the bottom which induced a feeble, short-lived eddy. The graptolite was slightly rotated forward. The thecae placed near the axis of rotation made twisted grooves, with relatively large prods at their down-current ends.

The currents transporting graptolite remains by traction were obviously weak, and of low density. Otherwise, the rhabdosomes, having a relatively low specific gravity, could not have touched the bottom. However, it should be borne in mind that the rhabdosomes acting as tools might have been derived not only from graptolites resting upon the bottom, but also from those buried in unconsolidated sediments. These graptolites, devoid of soft parts, could be filled with mud. This caused presumably an increase in their weight to such an extent that they might have touched the bottom.

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REFERENCES

- [1] H. Tomczyk, *Kwart. Geol.*, **8** (1964), 506—523.
- [2] J. D. D. Smith, *Geol. Mag.*, **94** (1957), 425—428.