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CREVASSING OF AN INLAND DUNE DURING THE 1998 FLOOD IN THE UPPER VISTULA RIVER VALLEY (SOUTH POLAND)

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Abstract: A relatively small flood in April 1998 inundated stream valleys draining the Tarnów Plateau. The flood water of one of these streams crevassed a dune. An elongated crevasse, an irregular-shaped transport zone and a crevasse splay were formed as a result. The crevasse splay consisted of several lobes, which were separated by crevasse channels. Minor fans formed at the channel outlets. All this forms were the result of rapid processes of erosion and accumulation. The dominant lithofacies in the crevasse splay sediments were fine and medium sand with horizontal (bottomset) and low-angle (topset) stratification. Trough and planar cross-stratified medium- and coarse-grained sands appear in the middle part of the vertical sequence. Most of these sediments were laid down in a high-energy environment of a sheet flow. The phase of vanishing flow left ripple marks, encountered in the highest part of the distal splay.

Key words: flood, inland dune, crevasse splay, Vistula River valley, Poland.

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INTRODUCTION

Modern crevasses and crevasse splays are described in deltaic settings and on alluvial floodplains, near river channels, especially anastomosed; they are also known from fossil alluvial deposits (see e.g. Allen, 1965; Coleman, 1969; Elliot, 1974; Farrel, 1987, 2001; Smith *et al.*, 1989; Zwoliński, 1992; Miall, 1996; Zieliński, 1998). They originate by crevassing (i. e. breaking of natural levees by flood waters) and near regulated river channels – by breaking of embankments (see Gębica & Sokołowski, 1999).

This paper presents a case of crevasses and crevasse splays formed by breakage of an inland dune – that is occurring in an atypical morphological setting. The aims of this paper are: (i) to describe morphology, lithofacies and origin of the forms, (ii) to compare the investigated forms and similar to well-known ones described in literature, (iii) to comment on the possibility of identification of crevasse splay deposits in ancient river deposits.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The study area is situated in the southern part of the Vistula River valley, near village Małec, ca. 6.5 km SE of Szczucin. This part of the Vistula River valley, carved in Miocene clays and 20 km wide, is bordered by plateaux, rising several tens of metres above the valley bottom. The valley bottom is covered with alluvial deposits of the Pleistocene terrace and the Holocene floodplain (Sokołowski, 1987). The Pleistocene terrace sediments occurs in several isolated patches (Fig. 1A) whose sandy tops have been remodelled into aeolian dunes, mostly arranged parallel to the direction of the Vistula valley. Lithology of the Pleistocene alluvium was studied in two boreholes. Both penetrated gravelly sand in the lower parts, overlain by sand of variable grain-size and total thickness of 6–8 m.

The depressions between the remnants of the alluvial terrace are used by streams of various sizes and lined with muds. They collect waters of some smaller streams draining the Tarnów Plateau, an upland that borders the Vistula valley to the south. One of these streams is the Upust with its tributary Dęba.

The studied area lies within one of the sandy patches (Fig. 1), elevated ca. 5–6 m above the Vistula channel and ca. 1–2 m above the Upust channel. A dune ridge situated in its western part, elongated in the NW–SE direction, is nearly 4 km long. Its height varies from 10 m in the southeast to 2–3 m near the north-west end.

The dune was transformed by agricultural use and is less than 2 m high where it is dissected by the crevasse. It is

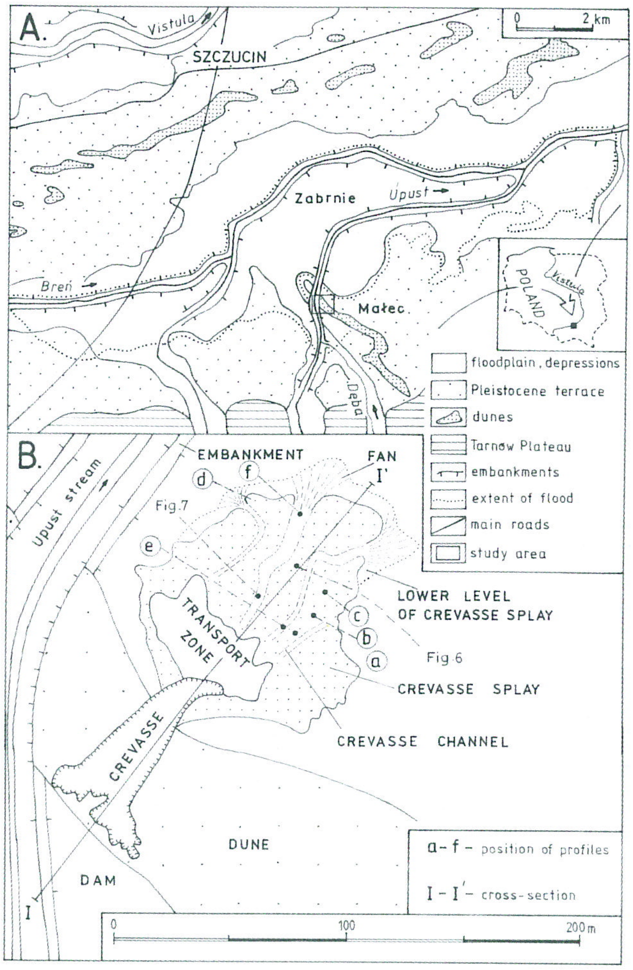

Fig. 1. Geomorphologic sketch of the Vistula river valley near Szczucin with the extent of flood (**A**) and the location of crevasse and crevasse splay (**B**)

built of sand, mostly fine- and medium-grained. The course of the dune is parallel to the Dęba and Upust valleys and diagonal to other dune forms in the Vistula valley (see Fig. 1A). This anomalous course of the dune is the result of its formation by accumulation of aeolian sand on a natural levee, built of horizontally stratified, fine-grained sand, locally interstratified with sandy silt now exposed in the crevasse. The low (up to 70 cm), flattened natural levee was wet and overgrown with plants before the accumulation of the aeolian sand took place. This is indicated by irregular cementation of sand and by rhizoliths (root moulds – Klappa, 1980) ca. 3 cm in diameter. Some of them included spheroid concretions of concentric internal structure. They consisted of sand cemented with carbonates, including siderite. The same kind of cement binds the levee sand.

SPRING 1998 FLOOD IN THE VISTULA RIVER VALLEY

A prolonged rainfall of several days in April 1998 caused rise of water levels in the streams that drain the Tarnów Plateau. Embankments of the Upust were breached near Zabrnie on April 22. This led to the flooding of an area of nearly 30 sq. km, mainly between the Upust and the Breń (Fig. 1A). The extent of the flood was studied in the field on April 23 and on the authors' photographs taken during a lightplain reconnaissance on April 24.

The water rising in the upper, non-levied course of the Upust and Dęba formed a small reservoir dammed by the embankment and the dune. Here, the water table reached the crests of embankment and dune (about 2.5 metre high). The dammed water breached the dune on April 23 at night. The direct mechanism of crevassing is not known in details. It is possible that high saturation of dune sand led to its liquefaction and piping erosion.

MORPHOLOGY, LITHOFACIES AND ORIGIN OF FORMS

Morphology

Water flowing from the lake crevassed the dune down to the natural levee. An elongated crevasse and, an irregularly-shaped transport zone also crevasse splay were formed. Selective cementation of the levee sediments resulted in the formation of a wavy erosional surface at the crevasse bottom. Erosional remnants of irregular shape and broad turrets or mushrooms, several tens of centimetres high (Figs 3, 4) formed where the concentration of the cement was highest. The crevasse was wedging out (Figs 1B, 2) gradually to the north-east; its was slightly wider than 50 m in the widest place and ca. 80 m long. It was also deepest (2 m) in the widest place (Fig. 3). It slightly turned to the east at the end, following the course of a slightly elevated field-boundary strip and a shallow rill along it.

At the outlet of the crevasse there was a transport zone – with no deposit and flattened crops – that resulted from the high energy of the flow.

The crevasse splay consisted of several smaller lobes (see Figs 1B, 2). The greatest lobe was up to about 80 m long. It ended in a slipface up to 40 cm high, which prograded across the sandy Pleistocene terrace. The lobes were separated by crevasse channels. Their distinct margins, a few centimetres high at the beginning and increasing downstream to about 40 cm, were not erosive, but appear to have been created by the aggradation of the lobes.

Minor fans that formed at their outlets partly coalesced at the feet of the bars (Figs 1B, 2). and formed the lower level of the splay – a belt up to about twenty metres wide and ten to twenty centimetres high, slightly higher only at the apices of the fans.

Lithofacies

The splay sediments were studied in a dozen of trenches dug to its base. The individual lithofacies were assigned letter codes (see Miall, 1978). Scales of the lithofacies were described according to classification by Zieliński (1995), that is as small-scale (up to 6 cm in thickness) and medium-scale (6–60 cm, in the described sediments most commonly up to 30 cm). As the material in the splay came from the dis-

Fig. 2. The Upust Stream, embankments, dune, crevasse and crevasse splay (oblique air photo)

sected dune, it included only sand. Its textural variability was also accentuated by its changing structure.

The vertical facies sequences in the lobes were dominated by small- and medium-scale horizontally stratified sandy lithofacies (*Sh*), which made up the whole of the sequence in the proximal parts of the lobes and formed the lowest member in all sections of the middle and distal parts (Figs 5b–d, 6). Near the middle part of the lobes it was overlain by other sandy lithofacies – medium-scale one, with low-angle cross-stratification (*Sl* – Fig. 5b).

In the middle part of the lobes, above the *Sh* lithofacies or, rarely, above the vertical sequence *Sh* → *Sl*, usually occurred a single medium-scale set of trough cross-stratification (lithofacies *St* – Figs 5c, 6). It was replaced distally by sandy lithofacies with gentle, often tangential, planar cross-stratification (lithofacies *Sp*). Near the fronts of the lobes, stratification in lithofacies *Sp* had angular basal contact. The upper part of the sediment sequence consisted again of lithofacies *Sl*. The top part of the succession in the distal part of the splay was made of sand with small-scale cross-stratification (ripplemarks – lithofacies *Sr* Fig. 5d).

So typical for the proximal part of the lobes is lithofacies *Sh* alone, passing laterally to sequences *Sh* → *Sl* or *Sh* → *St* → *Sl*, observed towards the middle part (Figs 5a–c, 6). The last, in turn, passes distally into the most complex sequence *Sh*(*Sl*) → *Sp* → *Sl* → *Sr* (Fig. 5d).

Lithofacies *Sh* and *Sl* consisted of fine- and medium-grained sand, locally with a slight admixture of silt. Slightly coarser grains were in lithofacies *Sr*. The coarsest fraction (medium-grained with admixture of coarse-grained) was characteristic for lithofacies *St* and *Sp*. These lithofacies also contained sporadic silty or silty-clayey soil aggregates up to 3 mm in diameter, sporadically concentrated as discontinuous layers in the sets.

The sediments of the crevasse channels also displayed lateral and vertical variations. Sandy lithofacies of small and medium scale arranged in a vertical sequence *Sh* → *St* → *Sl* (Figs 5e, 7) appeared in one of the channels (narrow

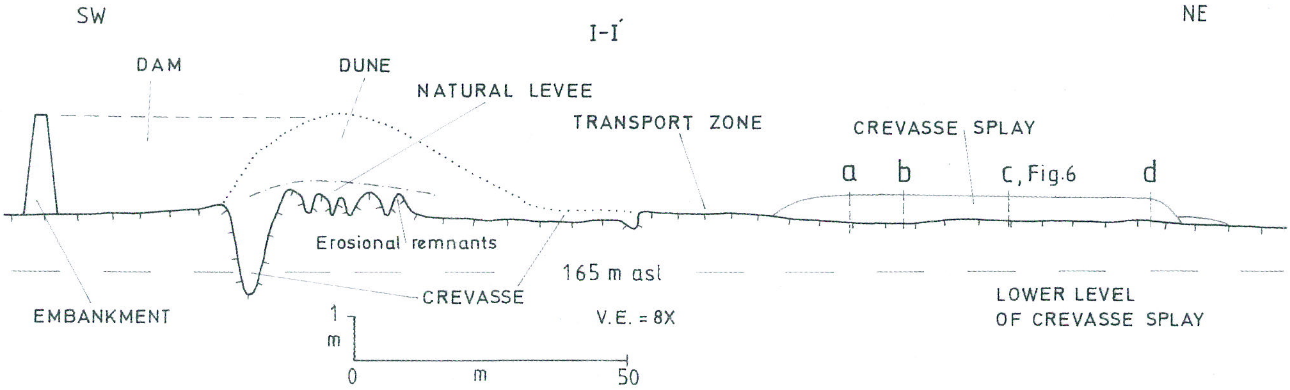

Fig. 3. Schematic cross-section through crevasse, transport zone and crevasse splay; a–d – position of profiles (see Figs 1 and 5)

Fig. 4. Erosional remnants in crevasse bottom (scale is 50 cm high)

structures of darker tone on the air photograph) in the proximal part of the crevasse splay. Stratification in the lower, small-scale *Sh* set was indistinct; the overlying layer was formed of two or three medium-scale *St* sets. Near the outlet of another depression a thin (a dozen centimetres) compound set was made up at the bottom of fine sand with indistinct horizontal lamination (lithofacies *Sh*). Distinct ripple cross-lamination appeared in the upper part. So sandy lithofacies of small or, at most, medium scale, of the *Sh* → *Sr* sequence were present here (Fig. 5 f).

Interpretation and discussion

The horizontal and low-angle cross-stratified lithofacies in vertical profiles of crevasse splays have been demonstrated by several workers as dominant or of secondary importance (e. g. Cherven, 1978; Hiller & Stavrakis, 1984; Smith, 1984; Eberth & Miall, 1991; Platt & Keller, 1992, Brodzikowski *et al.*, 1997, Zieliński, 1998; Gębica & Sokołowski, 2001).

Here, the common occurrence of this lithofacies at the base suggests that initial deposition has taken place during shallow sheet-flows, from turbulent supercritical flow in conditions of upper plane bed, possibly with local presence of antidunes. These conditions may indicate the beginning of the dissection of the dune ridge and onset of the violent flow of the dammed waters.

The cross-stratified lithofacies are also characteristic in crevasse-splay profiles (cf. as well Fielding, 1984; O'Brien & Wells, 1986; Eberth & Miall, 1991; Miall, 1996; Brodzikowski *et al.*, 1997; Zieliński, 1998; Gębica & Sokołowski, 2001). In the described splay, subcritical flow conditions were established with the development of the crevasse in the middle and distal parts and they enabled deposition of lithofacies *St* sediments from three-dimensional, and *Sp* from two-dimensional, low megaripples. The lateral differentiation of the bedforms reflects rather changes in velocity than in depth (see e. g. Ashley, 1990). It seems that this type of deposition lasted for a very short time. With dropping water level the flow was shallowing again. This, in turn, resulted in washing out of the bedforms and deposition of low-angle cross-stratified sand of lithofacies *Sl* (cf. Zieliński, 1993 – him lithotype D-3).

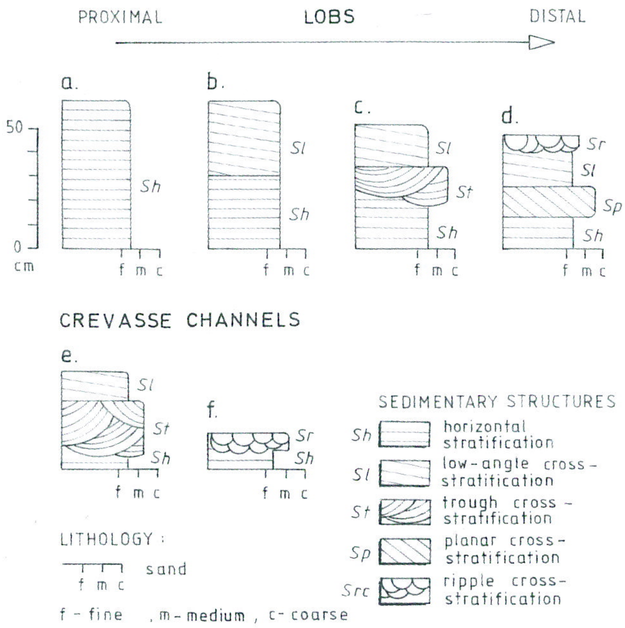

Fig. 5. Selected sediment profiles (see Figs 1 and 3)

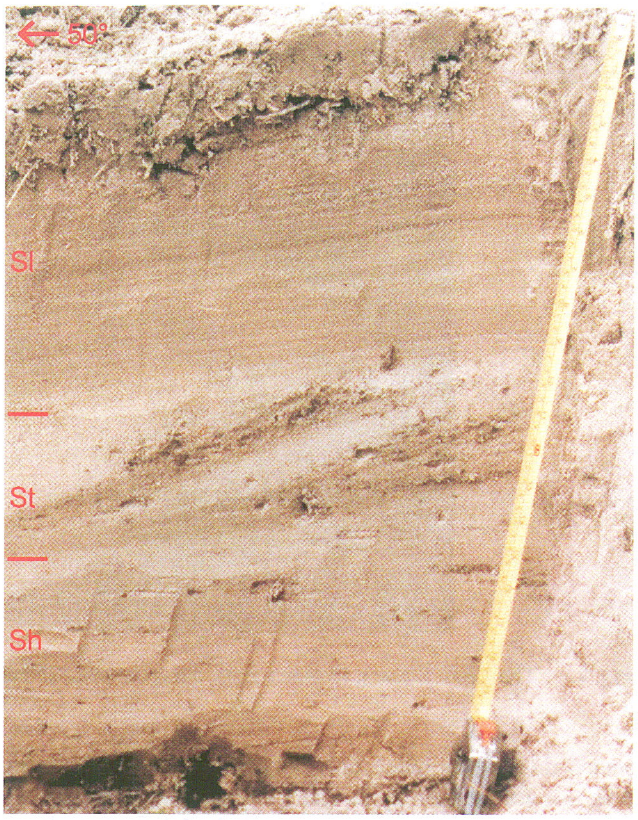

Fig. 6. Lobe deposits. In lower part – horizontally stratified sand (lithofacies *Sh*), in middle part – trough cross-stratified sand (lithofacies *St*), at the top low-angle cross-stratified sand (lithofacies *Sl*). Scale is 50 cm hig

The phase of waning flood and of low energy flow at the final stage is indicated by lithofacies *Sr*, laid down in conditions of the lower part of the lower flow regime (rippled bed).

The crevasse channels were probably not yet present in the earliest phase of the splay formation, as is suggested by the occurrence of lithofacies *Sh* at the base. Only the later filling proves a greater depth of flow (lithofacies *St*).

Brodzikowski *et al.* (1997) suggest that generally, supercritical shallow currents, passing downstream into subcritical currents are typical of the crevassing zone. It is true, but only for middle part of the investigated splay.

The described splay has thus many features similar to the forms created in conditions not influenced by human activity. This similarity seems to result from: (i) only slight dissection of the dune substratum, (ii) the structure of the dune itself, which in many aspects resembles natural levees built of sand and silty sand, and (iii) the lack of cohesive fine-grained sediments (mud, clayey mud or oxbow-lake mud).

All these features distinguish also the described splay from similar forms formed a year earlier as a result of breaching artificial levees near the Vistula channel (Gębica & Sokołowski, 1999, 2001), where deep incision of the floodplain opened access to coarse-grained older deposits, including boulders, and the presence of muds caused appearance of large mud balls on the one hand, and a marked increase in density of flood waters – leading to deposition of slurry flow-type sediments on the other hand. This is another confirmation that the textural and also partly structural, characteristics of alluvial deposits are not always controlled mainly by the flow power, but often by the availability of sediments of specific grain-size (see also e.g. McKee *et al.*, 1967) or high cohesion.

On the other hand, the lithofacies successions in the described splay may be also considered somewhat similar to braided river deposits. The predominance of lithofacies *Sh* and *Sl* make these deposits similar to the lithotype of shallow, broad, flat-bottomed, also ephemeral, channels. On the other hand the partial concentration of flow with individualisation of channel forms (lobes and crevasse channels) with differentiated bedforms (lithofacies *St* and *Sp*) may suggest transition towards the lithotype of braided channels with bars (see e.g. McKee *et al.*, 1967; Tunbridge, 1984; Zieliński, 1993, 1997; Miall, 1996).

IMPLICATIONS FOR INTERPRETATION OF ANCIENT CREVASSE SPLAY DEPOSITS

The described splay is specific because it formed in a atypical morphological setting and in hydrological conditions determined by human activity, and may be considered only a geological curiosity. Although traces of water flow on aeolian dune fields and even of dune erosion have been repeatedly reported (e.g. Falkowski, 1971; Laskowski, 1982; Langford, 1989; Langford & Chan, 1989; Trewin, 1993), traces of dune crevassing have never been described before. This forms described here indicate some probability of the crevasse splay formation in the past also as a result of dune crevassing, particularly on fluvial terraces.

Fig. 7. Crevasse channel deposits. In lower part – horizontally stratified sand (lithofacies *Sh*), in middle part – trough cross-stratified sand (lithofacies *St*), at the top low–angle cross-stratified sand (lithofacies *Sl*). Outcrop is 45 cm high

The distinction of the sediments that result from dune crevassing, especially in small exposures of sandy braided-stream alluvial sediments may create some difficulties in interpretation. These may result from: (i) similarity of lithofacies in crevasse splays and channel sediments – except of differentiation of thickness and (ii) the lack in the substratum of the crevasse splays of fine-grained vertical accretion flood-plain sediments, which is more typical of braided rivers, and at the same time is one of the main criteria of distinguishing the crevasse-splay sediments in the sequences of meandering rivers deposits.

FINAL REMARKS

This succinct summary of the investigation shows: (i) crevassing may involve dunes and not only natural levees or embankments, (ii) the sedimentary structures and the grain size of the sediments – fine and medium sand with horizontal (bottomset) and low-angle (topset) stratification, medium and coarse sand with trough and planar cross-stratification in the middle part of vertical sequence – indicate the distinct resemblance between the studied and the crevasse splays created by crevassing of natural levee, (iii) textural and also partly structural characteristics of splay deposits are not always controlled mainly by the flow power, but often by the availability of sediments of specific grain-size, (iv) crevasse splays could form by crevassing of inland dune also in past, but their identification in profiles of ancient river deposits may be difficult.

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Streszczenie

KREWASOWANIE ŚRÓDLĄDOWEJ WYDMY W DOLINIE GÓRNEJ WISŁY PODCZAS POWODZI W 1998 ROKU

Piotr Gębica & Tadeusz Sokołowski

W obszarze badań położonym około 6,5 km na południowy wschód od Szczucina (Fig. 1), większą część doliny Wisły zajmuje terasa plejstoceńska o piaszczystym i zwydmionym stropie. Od południa dolinę obrzeża Wysoczyzna Tarnowska. Rozlewne opady deszczu w kwietniu 1998 roku spowodowały wezbrania strumieni drenujących Wysoczyznę (m.in. Upustu). W miejscowości Małec wał przeciwpowodziowy Upustu łączy się z wydmą nadbudowującą niski wał brzegowy. Doszło tu do zablokowania przepływu wód powodziowych i utworzenia niewielkiego jeziora zaporowego. Wypływające z jeziora wody rozcięły wydmę tworząc krewasę i glif krewasowy (Fig. 1, 2). W dnie długiej do 80 metrów i głebokiej do 2 metrów krewasy utworzyły się kilkudziesięciocentymetrowej wysokości ostańce erozyjne (Fig. 3, 4). Niejednolity glif składał się z kilku piaszczystych lobów przypominających poprzeczne lub językowate łachy śródkorytowe piaszczystych rzek roztokowych. Rozdzielały je kanały krewasowe.

Loby o miąższości do 60 cm (Fig. 3,5) w części proksymalnej budował drobny i średni, rzadziej gruby piasek litofacji *Sh* (kody literowe litofacji wg Miall, 1978 i Zieliński, 1995 – Fig. 5). W kierunku części dystalnej była ona zastępowana pionowymi sekwencjami litofacji *Sh*→*Sl*, *Sh*→*St*→*Sl* oraz *Sh*(*Sl*)→*Sp*→*Sl*→*Sr* (Fig. 5a–d, 6). Kanały krewasowe w części proksymalnej wypełniał piasek o pionowej sekwencji litofacji *Sh*→*St*→*Sl* (Fig. 5e, 7), a wczęści dystalnej o sekwencji *Sh*→*Sr* (Fig. 5f).

Dominacja litofacji *Sh* wskazuje na dużą rolę w formowaniu glifu zalewów warstwowych kształtujących górne płaskie dno w warunkach przepływów nadkrytycznych. Skanalizowany przepływ podkrytyczny był krótkotrwały i w jego czasie tworzyły się niskie formy dna (3 i 2 wymiarowe wydmy – litofacje *St* i *Sp*). Opadanie fali powodziowej wyznacza dno ripplemarkowe (litofacja *Sr*).

Krewasowanie wydm śródlądowych zachodziło być może w przeszłości. Osady opisanego glifu przypominają jednak osady korytowe piaszczystych rzek roztokowych z płaskim dnem lub ich przejście w kierunku rzek roztokowych z rozwiniętymi formami koryta. Te cechy, w połączeniu z brakiem osadów drobnoziarnistych przyrostu pionowego w podłożu glifu, mogą utrudniać wyróżnianie osadów glifów o ta- kiej genezie w profilach aluwiów piaszczystych roztok.