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Changes in the development of frost wedges in the middle Warta valley deposits (Central Poland)

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In the alluvia of the middle Warta River valley, different kinds of frost wedges and fissures such as syngenetic ice wedge pseudomorphs, epigenetic ice wedge pseudomorphs and wedges, and fissures with primary mineral infilling were documented. The formation of ice wedges of the older generation is dated to the transition from the Middle Plenivistulian to the Upper Plenivistulian, and ice wedges of the younger generation and sand wedges date to the coldest period of the Upper Plenivistulian. The thawing of some ice wedges preceded the degradation of permafrost and was due to thermokrast processes in the Upper Plenivistulian.

Key words: ice-wedge pseudomorphs, sand wedges, thermokrast, Vistulian, middle Warta River valley, Central Poland

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INTRODUCTION

A well-documented phenomenon is the occurrence of the periglacial environment in the past in areas of the today's temperate zone. The periglacial environment existed for a long time during cold periods of the Pleistocene. Evidences of that kind of conditions have been found in many sites of Central Poland (e. g., Dylik, 1967; Goździk, 1973; Klatkowa, 1996). One of the most distinctive evidences of the former existence of the periglacial environment is ice wedge pseudomorphs (e. g., Romanovskij, 1973; Goździk, 1973; Vandenberghe, Pissart, 1993). These structures developed in thick fluvial deposits of the middle Warta River valley. Investigation of periglacial structures in the Warta River alluvia was possible in the Koźmin excavation of the "Adamów" brown coal mine. During several years of research in this area, a lot of ice wedge pseudomorphs have been documented (Klatkowa, 1996; Forysiak et al., 1999; Petera, 2002; Forysiak, 2005; Petera-Zganiacz, 2008). The lack of sites located in big river valleys in Central Poland, such as the Warta valley, with the possibility to examine the whole profile of Vistulian deposits makes the Koźmin site exceptional and valuable.

STUDY AREA

The area of research is located about 20 km south of the Last Glacial maximum extent, within an extensive left-bank lower terrace of the middle Warta River valley (Fig. 1). This terrace was formed in the Younger Dryas (Turkowska et al., 2004; Forysiak, 2005). In the external part of the terrace, Younger Dryas deposits lie on a thin (0.5–2 m) Plenivistulian series and fluvioglacial sand or till. In the internal part, under the Younger Dryas cover, fluvial deposits occur, mainly at the Planivistulian age, with the thickness of nearly 20 m (Forysiak et al., 1999; Petera, 2002). The vistulian series consists of several levels of mineral deposits and four organic levels (Fig. 2). Accumulation of alluvia during the Vistulian favoured development of both syngenetic and epigenetic ice wedges.

In the study area, the Warta River valley coincides with the Adamów graben – one of the grabens formed within the Konin elevation (Widera, 1998). Subsidence of the graben resulted in accumulation of thick Quaternary series.

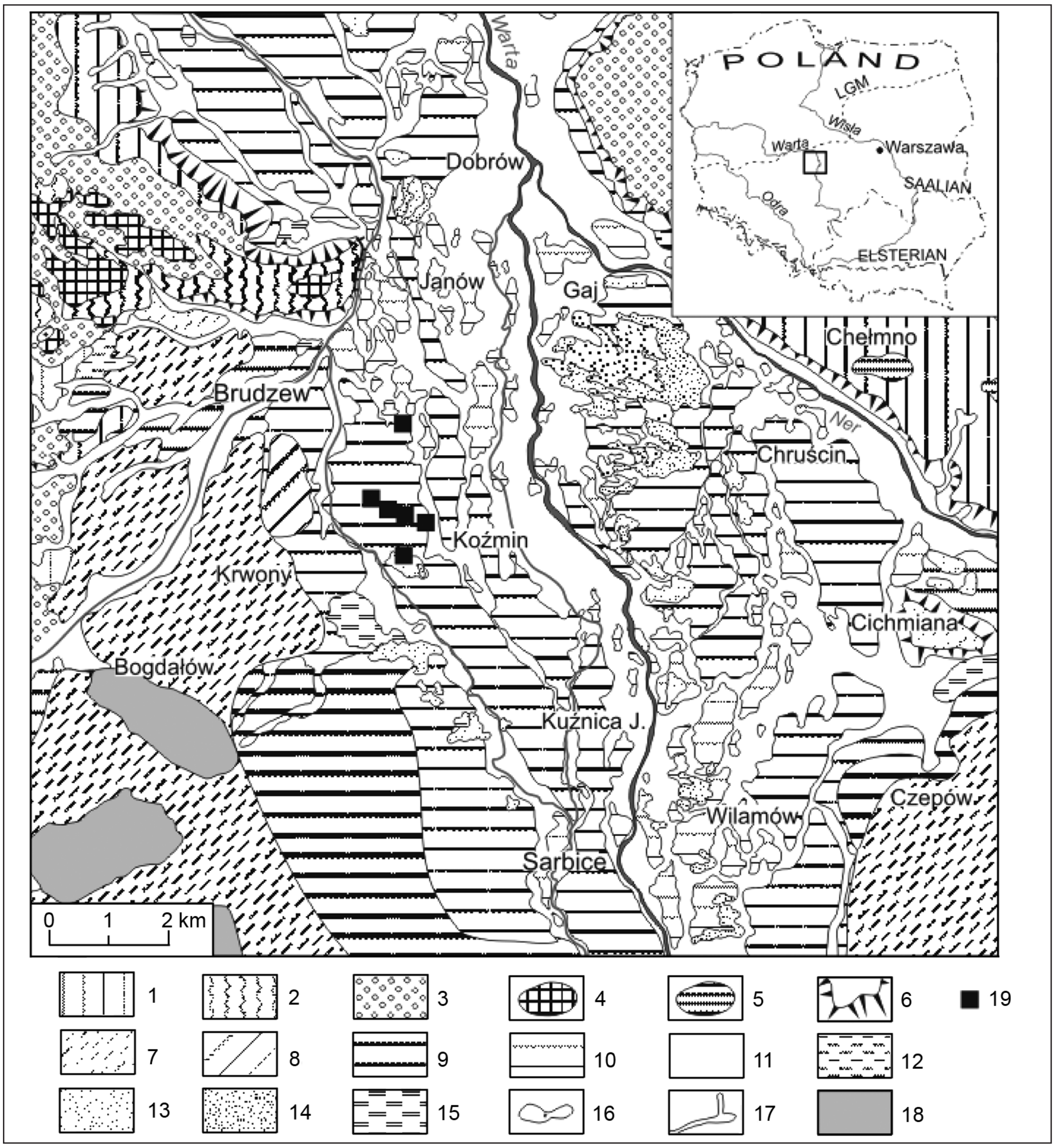

Fig. 1. Geomorphological map of the Warta River valley (after Forysiak, 2005)
1 – plains, *2* – hummocky plains, *3* – fluvioglacial plains, *4* – marginal moraine hillocks, *5* – kames, *6* – slopes, *7* – lower terrace of marginal valley, *8* – erosional terrace, *9* – high terrace, *10* – low terrace, *11* – valley floor, *12* – lacustrine plains, *13* – aeolian plans, *14* – dunes, *15* – peatbog, *16* – closed depressions of various origin, *17* – valleys of various origin, *18* – landfills and areas changed by exploitation, *19* – study sites

1 pav. Vartos upės geomorfologinė schema (pagal Forysiak 2005)
1 – lyguma, *2* – kalvota lyguma, *3* – fliuvioglacialinė lyguma, *4* – galinės morenos kalvos, *5* – keimai, *6* – šlaitai, *7* – apatinė terasa, *8* – erozinė terasa, *9* – aukšta terasa, *10* – žema terasa, *11* – slėnio dugnas, *12* – ežerinė lyguma, *13* – eolinė lyguma, *14* – kopos, *15* – durpynas, *16* – įvairios kilmės uždaros įdubos, *17* – įvairios kilmės slėniai, *18* – sąvartiniai ir kąsiniai, *19* – tyrimų vietos

PERMAFROST WEDGES

In the study area, permafrost wedge structures occurred in the form of syngenetic ice wedge pseudomorphs, epigenetic ice wedge pseudomorphs and sand wedges.

Syngenetic ice wedge pseudomorphs were characterized by a significant length (about 6 m) and an irregular shape including vanishing of parts of the structures (Fig. 3). They represented syngenetic pseudomorphs with mineral secondary infilling. The structures were described in detail by Klatkowa (1996). According to Klatkowa, they started to develop in cold periods of the Early Vistulian. However, the lower parts of these structures cut the mineral-organic sediments dated by the TL method to about 102 ka BP and according to pollen analysis to the Early Vistulian age. Ice wedges became syngenetic in the overlying Plenivistulian sand (Petera, 2002; Petera-Zganiacz, 2008).

The top part of these structures reached organic series dated to 24–36 ^{14}C ka BP (Fig. 2). Ice wedge pseudomorphs were about 3 m long. The width of the structures was rather small – only 10 to several centimeters. This dimension does not reflect the width of the original structures, because during the thawing of ice wedges and the degradation of permafrost they could be strongly deformed (Harry, Goździk,

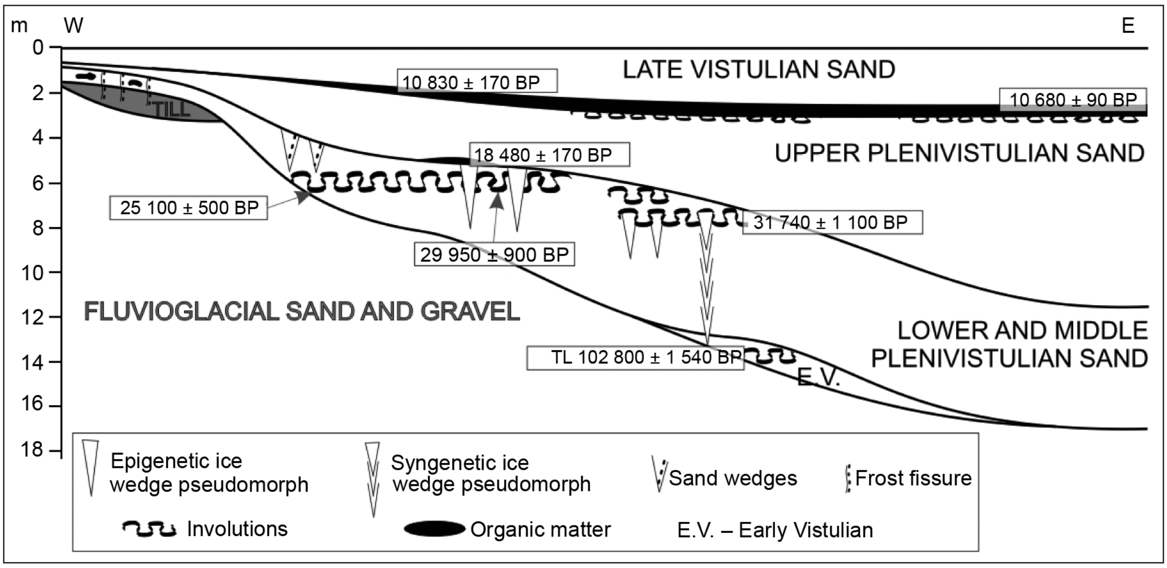

Fig. 2. Scheme of location of ice wedge pseudomorphs and sand wedges in deposits of the lower terrace of the Warta River valley (selected dates are presented)

2 pav. Ledo pleištų pseudomorfai ir smėlio pleištai apatinėje Vartos upės slėnio dalyje

1988). The outline of the structures was relatively clear, particularly in sandy-silt or organic deposits. The upper parts of the pseudomorphs were filled with sandy-silt material containing fragments of peat removed from the former surface (Figs. 4, 5). A vertical lamination was visible. The lower parts of the wedges were filled with material from the fissure walls. Systems of faults adjacent to the pseudomorphs were present as a trace left by thawing ice (Goździk, 1973; Burbridge et al., 1988; Klatkowa, 1996). All the described structures showed typical features of epigenetic ice wedge pseudomorphs (e. g., Goździk, 1973; French, Goździk, 1988; Harry, Goździk, 1988). Ice wedge pseudomorphs developed in the thick Plenivistulian

Fig. 3. Syngenetic ice wedge pseudomorph (photo by H. Klatkowa, 1996)

3 pav. Singenetinė ledo pleišto pseudomorfa (H. Klatkowos fotografija)

Fig. 4. Epigenetic ice wedge pseudomorph of younger generation

4 pav. Epigenetinė ledo pleišto pseudomorfa

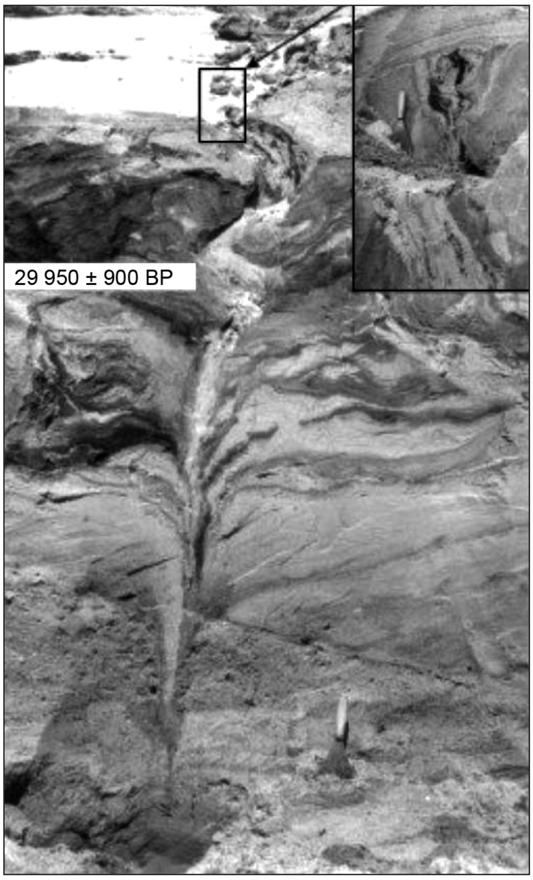

Fig. 5. Epigenetic ice wedge pseudomorph of younger generation; top part of the structure was eroded, fragments of peat inside the pseudomorph are visible

5 pav. Ankstyvosios generacijos epigenetinio ledo pleišto pseudomorfa. Viršutinė pleišto dalis nueroduota, matyti durpių pėdsakai vidinėje pseudomorfos dalyje

fluvial deposits, and they are slightly eroded at the top (Fig. 5) or / and overlain (Fig. 6) by Upper Plenivistulian river alluvia.

Epigenetic ice wedge pseudomorphs were formed in the Plenivistulian in two generations. Pseudomorphs of the older generation initiated to form from the organic layer ^{14}C dated to ~24–36 ^{14}C ka BP (Fig. 2), during transition from the Middle to the Upper Pleniviatulian. Ice wedges of the younger generation started developing in the Upper Plenivistulian from the organic series dated to ~18.5 ^{14}C ka BP, in the period of maximum cold during the Last Glacial: 20–18 ^{14}C ka BP (e. g., Vandenberghe, Pissart, 1993; Goździk, 1995; Klatkowa, 1996).

Generally, the process of thawing of ice wedges, both syngenetic and epigenetic, occurred during the permafrost degradation and was induced by climate amelioration at the end of the Vistulian. However, the particular conditions prevailing in the study part of the Warta River valley during the Plenivistulian led to a premature thaw of some ice wedges. A very intensive fluvial accumulation took place in the Upper Plenivistulian. The former river reached the external part of the valley, partly eroded peat dated to ~18.5 ka BP, and covered the surface with sand (Figs. 2, 5, 6). The water of that river, flowing over the surface with ice wedges, caused their thawing, so the thermokrast processes became active. That kind of phenomena was observed in the contemporary arctic zone (e. g., Fortier et al., 2007). Migration of the river might have resulted even in formation of taliks under condition that water was deep enough (Crampton, 1979; Washburn, 1979; Shur, Jorgenson, 2007). The thawing of ice wedges and infilling of structures had to be fast. Certainly, the described ice wedges thawed after accumulation of the peat dated to

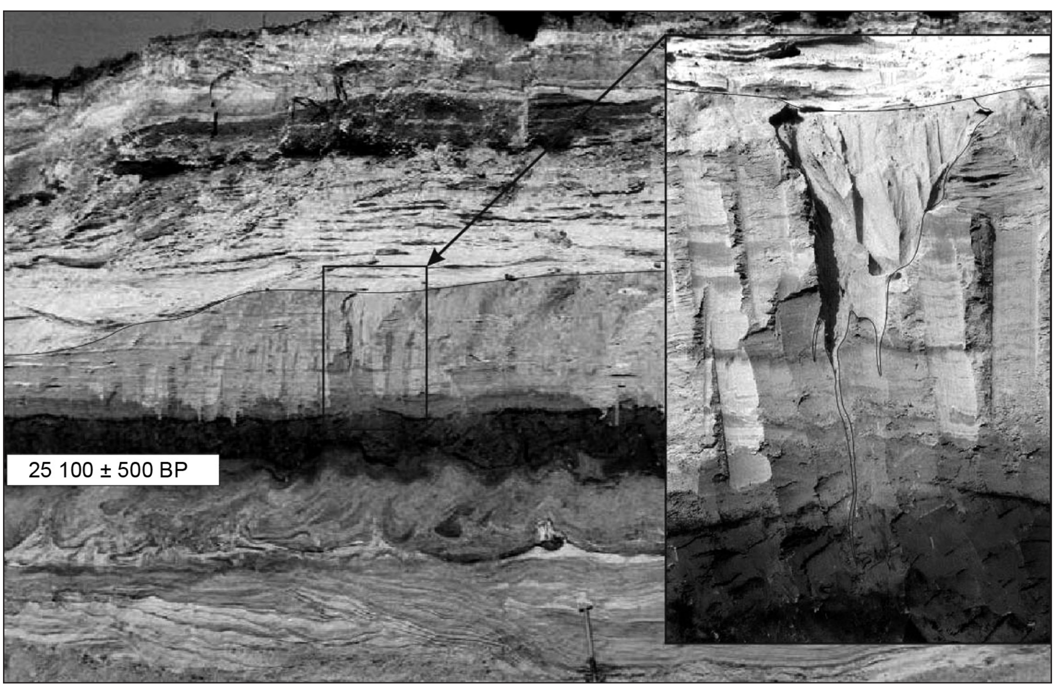

Fig. 6. Sand wedge in the Upper Plenivistulian deposits. Top part of the structure is eroded

6 pav. Smėlio pleištas viršutinės Plenivyslos nuogulose. Viršutinė pleišto dalis nueroduota

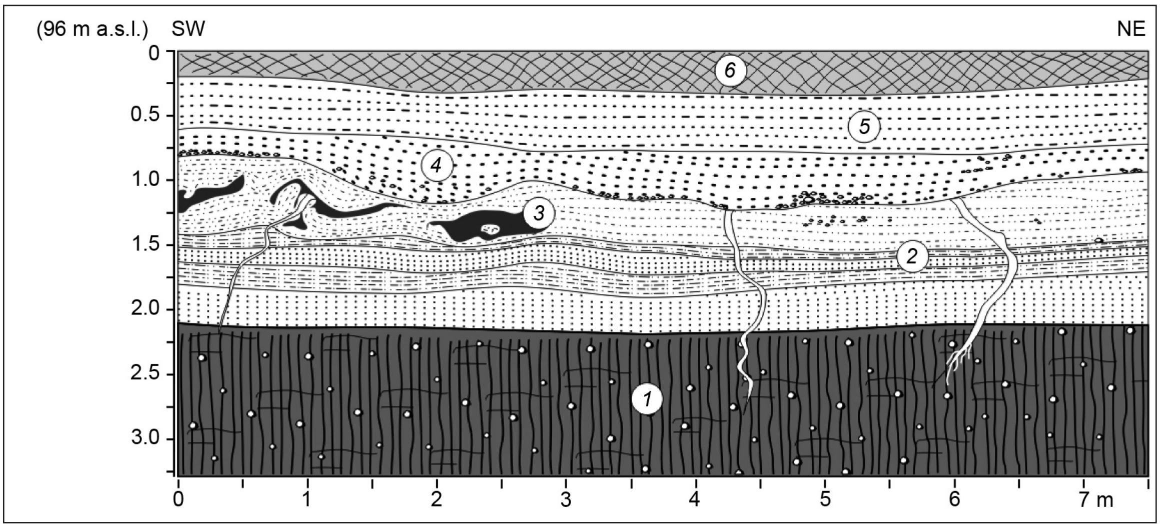

Fig. 7. Thin epigenetic ice wedge pseudomorph developed in the external part of the terrace
Wartanian: *1* – till; Plenivistulian: *2* – sand with silt, *3* – organic matter, *4* – sand; Late Vistulian (?): *5* – sand with silt, *6* – soil

7 pav. Plona ledo pleišto pseudomorfa susidariusi išorinėje terasos dalyje
Vartos nuogulos: *1* – morena; Plenivyslos: *2* – smėlis ir aleuritas, *3* – organinė medžiaga, *4* – smėlis; vėlyvosios Plenivyslos (?): *5* – smėlis su aleuritu, *6* – velėna

~18.5 ka BP and deposition of Upper Plenivistulian alluvia. These facts imply that the ice wedges thawed – paradoxically – in the coldest period of the Vistulian.

In the study area, only a few wedges with the following features were found: with a very clear, undeformed outline, and V-shaped with a visible vertical lamination of infilling sand (Fig. 6). This characteristic suggests that these structures originated as wedges with primary sand infilling (Goździk, 1973; Kolstrup, 1986; Murton, 1996). The upper parts of the structures were eroded by the Upper Plenivistulian river. Sand wedges had been formed in a sandy-silt sediment accumulated after formation of an organic level dated to 24–36 ka BP. The content of wind-abraded grains (RM type) in this sediment was the highest in the whole profile of the Vistulian deposits and reached about 50 to 60% (Petera, 2002). Similarly, a high percentage of RM grains was recorded in the Upper Plenivistulian alluvia cutting and overlying levels with periglacial structures (Fig. 2). It is a very well known fact that in the Vistulian deposits the amount of wind-abraded grains increased and reached the maximum in the Upper Plenivistulian (e. g., Van Huissteden et al., 1986; Goździk, 1995, 2007; Manikowska, 1993; Kasse et al., 1995). During this extremely cold period when most of the surface had been devoid of plants and the climate became semi-arid, favourable conditions appeared for the formation of sand wedges (Goździk, 2007).

Ice fissures with the primary mineral infilling developed in the external part of the terrace in thin Plenivistulian and Wartanian deposits. Their length is about 1.5 m and the width a few centimeters (Fig. 7). In the lower part of the structures formed in till, small finger-like sand veins below and from the sides were visible. The same kind of structures occurred in the lower part of sand wedges (Fig. 6). They represented original elements of the frost wedge or a fissure (Harry, Goździk, 1988). Fissures formed from the level of thin pavement partly consisted of wind-abraded stones with the maximum diameter about 5 cm. The formation of the pavement was connected with the coldest period of the Vistulian. It was documented on uplands, in dry valleys and in sediments of river terraces (e. g., Klatkowa, 1965; Dylik, 1967; Kozarski, 1995; Turkowska, 1995).

CONCLUSIONS

The development of ice wedges and sand wedges obviously depends on climatic conditions. Alluvia accumulation in such a big river valley as the Warta valley favoured formation of ice wedges, especially syngenetic ones, and during the coldest and arider periods of the Upper Plenivistulian, in external parts of the valley, sand wedges developed.

The research carried out in the middle Warta valley showed that thawing of ice wedges could take place much earlier than during permafrost degradation due to the action of such local factor as the migration of the river and initiation of thermokrast processes, even in the coldest periods.

Syngenetic ice wedges developed in the timespan from the Lower Plenivistulian to the Upper Plenivistulian, while epigenetic wedges were formed during the transition from the Middle to the Upper Plenivistulian (older generation) and in the Upper Plenivistulian (younger generation). In the coldest and arider part of the Upper Plenivistulian, sand wedges appeared.

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KRIOGENINIŲ PLYŠIŲ FORMAVIMASIS VIDURIO VARTOS SLĖNIO NUOGULOSE (VIDURIO LENKIJA)

S a n t r a u k a

Atlikus tyrimus vidurio Vartos slėnyje nustatyta, kad ledo pleištų tirpimas gali prasidėti gerokai anksčiau nei permafrosto degradacija. Tai gali būti susiję su vietiniais veiksniais, tokiais kaip upės migracija ir termokarstinių procesų inicijavimas netgi šalčiausiais laikotarpiais.

Singenetiniai ledo pleištai formavosi nuo ankstyvosios iki vėlyvosios Plenivyslos, tuo tarpu epigenetinės formos susidarė pereinamuoju laikotarpiu tarp vidurinio ir vėlyvojo Plenivyslos etapo (vėlyvoji generacija) ir vėlyvajame Plenivyslos etape (jaunesnioji generacija). Šalčiausio ir sausiausio klimato laikotarpiu formavosi smėlio pleištai.

Raktažodžiai: kriogeniniai plyšiai, ledo ir smėlio pleištai, permafrosto degradacija