SUMMARY OF PROFESSIONAL ACHIEVEMENTS

1. Name and surname

Halina Pawelec

2. Education and scientific degrees

2002 – PhD in Earth Sciences (geography), Faculty of Earth Sciences, University of Silesia. PhD thesis "Periglacial morphogenesis of the southern part of the Ojców Plateau based on the analysis of structure of slope covers" prepared under supervision of Professor Zbigniew Śnieszko.

1983 – MSc in geography, speciality – paleogeography and lithology of Quaternary, Faculty of Earth Sciences, University of Silesia. Thesis "Fissure landforms left by ice sheet in the Głubczyce Plateau" prepared under supervision of Professor Józef Jersak.

3. Information about employment in research institutions to date

06.1984 – till now – at first assistant, at present assistant professor, University of Silesia, Faculty of Earth Sciences, Sosnowiec, 06.1986-10.1993 – parental leave.

08.1983 – 06.1984 – hydrologist, Research Department of the Institute of Meteorology and Water Management, Katowice

4. Designation of the scientific achievement required by the act of March 14, 2003 (article 16, paragraph 2) about scientific degrees and scientific title and degrees and title in the arts (Law Gazette No 65, item 595 with changes)

The achievement consists of five articles (***A5**-**A1**), which have been published after getting the PhD. The articles concerning the Cracow Upland (**A5** and **A4**) are the continuation of my studies conducted during the preparation of my PhD thesis, and contain their results supplemented with the results of my subsequent research. Based on them, new research problems were formulated and developed. In this summary I present these new results. Other articles, concerning the Miechów Upland and Holy Cross Mountains (**A3**, **A2**, **A1**), include only the results of investigations undertaken after the completion of my PhD thesis. All articles were published in journals listed in JCR – Web of Science (the list of scientific journals having impact factor). I am the only or first author of four papers (**A5, A4, A2, A1**) and second author of one paper (**A3**). My contribution to the preparation of individual articles is detailed in the annex 3 and confirmed by the statements of co-authors (annex 5).

*** A** – articles published in journals listed in *JCR*, **B** – articles published in other journals, **C** – articles published in conference proceedings. List of all articles is in the annex 3.

c) title of the achievement

„Sedimentological and paleoenvironmental interpretation of slope deposits in the southern Poland, based on macro- and microscopic studies"

b) author/authors, title of paper, year of publication, title of journal

A1, Pawelec H, Ludwikowska-Kędzia M. 2015. Macro- and micromorphologic interpretation of relict periglacial slope deposits from the Holy Cross Mountains, Poland. *Permafrost and Periglacial Processes.* Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/ppp.1864

$IF_{2014/2015}$ – 2.119, number of citations after WoS – 0, MNiSW score – 40

A2, Pawelec H, Drewnik M, Żyła M. 2015. Paleoenvironmental interpretation based on macro- and microstructure analysis of Pleistocene slope covers: A case study from the Miechów Upland, Poland. *Geomorphology* 232: 145-163.

$IF_{2014/2015}$ – 2.785, number of citations after WoS – 0, MNiSW score – 35

A3, Ludwikowska-Kędzia M, Pawelec H. 2014. Depositional environment of the glacigenic deposits from the Holy Cross Mountains (Poland) – interpretation based on macro- and microstructure analyses. *Geological Quarterly* 58 (4): 807-826.

IF_{2014} – 1.0, number of citations after WoS – 0, MNiSW score – 20

A4, Pawelec H. 2011. Periglacial evolution of slopes – Rock control versus climate factors (the Cracow Upland, Poland). *Geomorphology* 132: 139-152.

IF_{2011} – 2.52, number of citations after WoS – 7, MNiSW score – 35

A5, Pawelec H. 2006. Origin and palaeoclimatic significance of the Pleistocene slope covers in the Cracow Upland, southern Poland. *Geomorphology* 74: 50-69.

IF_{2006} – 1.698, number of citations after WoS – 12, MNiSW score – 35

Total IF of the scientific achievement – 10.122, total citations after WoS – 19,
total MNiSW score – 165

c) discussion on the scientific purpose of the aforementioned papers and the results achieved

Terrestrial slope deposits, occurring in the Cracow and Miechów Uplands and in the Holy Cross Mountains, were the object of my study. Main objectives of the research were as follows:

- sedimentological identification of slope deposits,
- paleoenvironmental/stratigraphic interpretation of periglacial slope covers, the answer to the following question,
- determination of the influence of geological structure and climate on the evolution of slopes in periglacial environment,
- determination of the usefulness of micromorphological method for interpretation of terrestrial slope deposits.

Sedimentological identification of slope deposits

Terrestrial slope environment is the least investigated depositional environment because it has not been the object of sedimentological research for many years. Previous investigations of slope processes focussed mainly on their geomorphological aspect, and concerned the relation between these processes and the relief of slopes as well as the forms of accumulation on footslopes (Varnes 1978, Klimaszewski 1981, Kirkby 1987). In those papers the terminology used for the description of deposits is inexact, often inconsistent, and based mostly on textural features, e.g. block cover, loamy-debris cover. General typology of terrestrial slope deposits, based on diagnostic lithologic features, has not been developed. In Poland the only attempt to classify slope deposits was made by Stochlak (1974) but he did not define clearly the textural-structural criteria for deposit classification. Progress of research in this field took place in the 1990s. Since then, many regional studies of terrestrial slope deposits, based on detailed sedimentological analysis, have been published, mostly by foreign authors (among others Bertran et al. 1997, Blikra, Nemec 1998, Migoń, Traczyk 1998, Nemec, Kazanci 1999, Texier, Meireles 2003, **B7**, **B6**).

Sedimentological analysis is especially important in the research on debris flows and solifluction because in geomorphological literature there are numerous inconsistencies in interpretation and classification of these processes. Debris flows are variously named (skin flows, mud flows, sand flows, earthflows, debris torrents, debris streams, debris avalanches*).* Sedimentological investigations indicate that mechanism of flow process in terrestrial environment is conditioned by grain-size distribution, saturation degree of displaced deposit, and slope inclination. The result of these investigations is the following classification of terrestrial debris flows: (i) cohesive flow, (ii) cohesionless flow, and (iii) grain flow (Lawson 1982, Lowe 1982, Eyles et al. 1988, van Steijn et al. 1995, Blikra, Nemec 1998, Nemec, Kazanci 1999). These kinds of debris flows are reflected in textural-structural features of deposits. In contrast, research is continued on establishing criteria for identification of solifluction processes (gelifluction and frost creep) (Ballantyne, Harris 1994, Matsuoka 2001). Interpretation of solifluction processes in modern periglacial areas is not in doubt while identification of relict deposits, occurring in the area of Pleistocene periglacial zone, is often dubious. However, the results of some investigations indicate that in the absence of macroscopic diagnostic features, solifluction deposits may be identified based on micromorphological analysis (Harris 1998, Bertran, Texier 1999, Van Vliet-Lanoë 2010).

The least-know process is landslide, i.e. the process of sediment redeposition along a slip plane. Former studies focussed on the classification of landslides depending on the relation between this plane and substratum structure. Very few articles dealt with sedimentological analysis of landslide deposits (Harris 1987, Skempton et al. 1991, Harris, Lewkowicz 1993a, b, Bertran, Texier 1999). Besides mass movements, an important redeposition process in terrestrial slope environment is overland flow (= slopewash, run-off, surface flow), which is defined as the down-slope displacement of deposit by water flowing as stream flow or sheet flow, accompanied by raindrop impact and splash. Sediments deposited as a result of this process (in Poland termed deluvia) have rarely been the subject of detailed sedimentological analysis (Dylik 1960, Rapp 1960, Lewkowicz 1988, Blikra, Nemec 1999, Mücher et al. 2010).

In general, the sedimentological research on terrestrial slope deposits is now at the stage of gathering their detailed textural-structural characteristics. These studies aim at determining of the unambiguous features identifying individual lithofacies and creating the uniform typology of deposits.

In the discussed articles (**A5**, **A3**, **A2**, **A1**) I report the results of detailed sedimentological analysis of slope deposits, which has been conducted in order to distinguish the mechanism of depositional processes and unambiguous lithological features identifying individual lithofacies. The studies were conducted in the Cracow Upland, Miechów Upland, and Holy Cross Mountains so the investigated deposits were formed under different paleoclimate conditions in the areas with different bedrock and relief of slopes. The studied Pleistocene relict deposits were mainly formed in slope periglacial environment (**A5**, **A2**, **A1**). Only in case of sediments deposited by debris flows I investigated debrites, previously termed flow tills (Boulton 1968), which were formed in the ice-proximal environment (**A3**). For a detailed identification of textural-structural features of the deposits in addition to macroscopic analysis I used micromorphological method. This is the first case of application of this method to the analysis of terrestrial slope deposits in Poland. In the world literature such studies are few.

Results

The results of my research contribute to the discussion on the identification of structures and lithofacies diagnostic of terrestrial slope deposits. I identified, based on sedimentological features studied in detail, the deposits formed by the following processes: (i) active-layer detachment, (ii) solifluction, (iii) debris flows – cohesive flow, cohesionless flow, grain flow, and (iv) low-energy and high-energy overland flows. Below I describe the main/diagnostic features of these deposits.

Solifluction deposits

Solifluction deposits are represented by two lithofacies with the following textural-structural features:

- coarse-grained, matrix-supported, massive diamictons with clayey-silty matrix, with flow folds and load cast structures. The clasts were aligned parallel to the slope with, as a rule, the ab planes parallel to the slope surface. Another secondary clast orientation was also identified, where the ab plane dipped in the opposite direction from that of the slope (**A5**, **A2**, **A1**). In the Cracow Upland these deposits contain limestone and flint clasts, and their matrix is mainly composed of loess material (**A5**). In the Miechów Upland the diamictons contain only weathered marl material (**A2**). In the Holy Cross Mountains the diamictons contain sandstone clasts, and their matrix is composed of weathered sandstone and claystone material, loess material and aeolian sand.
- silty-clayey deposits, laminated in places (**A2**). These deposits are composed of loess material.

Based on the above lithological features it is not possible to identify solifluction deposits because similar lithofacies are also formed as a result of other redeposition processes. All features of the described diamictons - bimodal texture, massive structure, flow folds, and load cast structures - are typical of cohesive flow deposits (van Steijn et al. 1995, Blikra, Nemec 1998, Nemec, Kazanci 1999) and solifluction deposits (Jahn 1975, Ballantyne, Harris 1994, **B7**). The orientation of clasts is analogous to imbrication in fluvial deposits. Such orientation is typical of deposition in the frontal zone of a solifluction lobe (Bertran 1993, Harris 1998, Bertran, Texier 1999) and also characterizes rapid stopping of debris-flow lobes (Blikra, Nemec 1998, Nemec, Kazanci 1999). Fine-grained, laminated deposits are formed both by solifluction and slopewash processes (Dylik 1960, Rapp 1960, Lewkowicz 1988, Van Vliet-Lanoë 1998, Blikra, Nemec 1999, Mücher et al. 2010).

Only micromorphological analysis established that the studied deposits were deposited as a result of solifluction. Solifluction is an exceptional slope process during which frost action and soil processes (mainly illuviation) are synchronized with a very slow down-slope movement of unconsolidated sediment (1 m a year at most, Matsuoka 2001). Deposition of the studied deposits as a result of solifluction was indicated by the coincident features formed by frost action and soil processes associated with mass movement (cf. Bertran 1993, Harris 1998) (Fig. 1). Banded microstructure is a record of combined effect of frost and soil processes (Fig. 2a, b). This microstructure develops when ice lenses form during freezing, and clay/silt subsequently accumulates on the top surfaces of peds and grains during thaw and illuviation processes

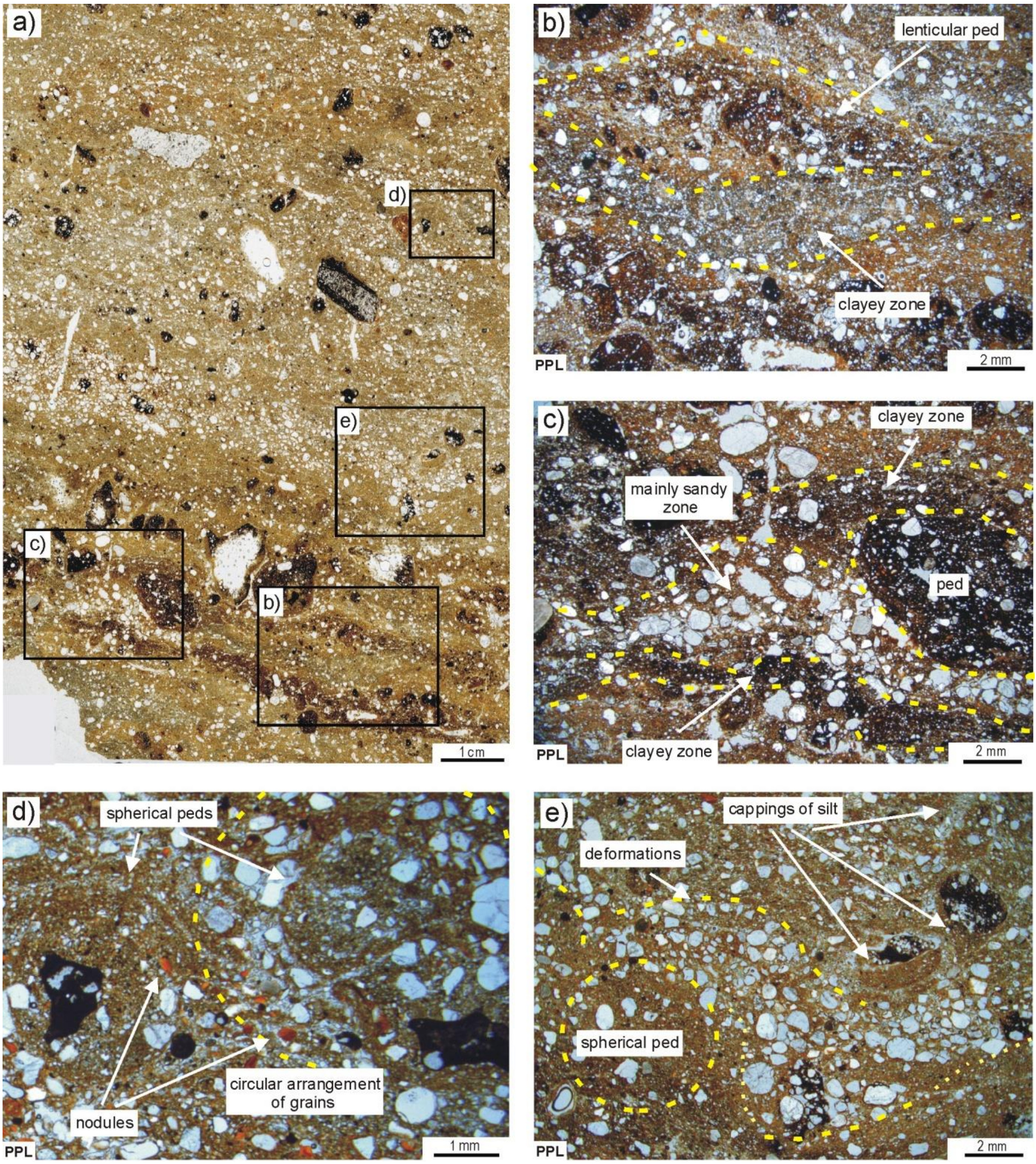


Fig. 1. Micromorphologic features of solifluction deposits: a) diamicton with a clayey matrix and complex structure (massive, banded, granular), b) banded microstructure with lenticular ped and zones composed mainly of clay, c) banded microstructure with a zone composed mainly of sand, d) granular microstructure with circular arrangement of grains around a soil aggregate, e) capping of silt on grain and ped surfaces, commonly to the side or bottom of the grain, visible plastic deformations in sediment, (after **A1**).

(Dumanski, Arnold 1966, Van Vliet-Lanoë, 1985, Harris 1998). Zones composed mainly of sand grains serve as a record of intense vertical translocation of fine particles and leaching of the deposit (Van-Vliet Lanoë 1976, Bertran, Texier 1999, Todisco, Bhiry 2008).

Moreover, the studied deposits reveal the features indicating rotation of peds and grains. These are: (i) granular microstructure, (ii) occurrence of fine-grained material deposited as result of illuviation on the side and bottom surfaces of grains. Iluviation without rotation results in the accumulation of this material as cappings on the upper surfaces of grains, (iii) circular arrangement of grains around peds that are termed „microcircles" in cryosol studies (Morozowa 1965, Van Vliet-Lanoë 1985, 2010, Todisco, Bhiry 2008), and „turbates" in the studies of glacial environment (van der Meer 1993, Phillips 2006). Rotation of grains/peds represents one of the mechanisms of solifluction (Harris, Ellis 1980, Van Vliet-Lanoë 1985, Bertran, Texier 1999). However, it cannot be excluded that the diamicton's formation was affected by repeated postdepositional wetting and drying or frost action (cf. Brewer 1964, Pawluk 1988, Van Vliet-Lanoë 1988). The orientation of elongated peds and grains arranged parallel to the slope indicates mass movement. The fragments of Fe/Mn oxide nodules and clay-ferruginous coatings, commonly formed in solifluction deposits by the destruction of soil features, and their displacement along the slope also provide evidence of mass movement (e.g. Van Vliet-Lanoë 1985, Kemp et al. 1998, Todisko, Bhiry 2008).

Solifluction is a complex process that consists of: (i) frost creep caused by freeze-thaw action and the growth and melt of ice lenses; and (ii) gelifluction, the downslope flow under conditions of high pore water content due to ground-ice melt and/or precipitation (e.g. Matsuoka 2001, Harris et al. 2008). Van Vliet-Lanoë (1985) attempted to distinguish these processes based on micromorphological analysis, suggesting that frost-creep is manifested by the presence of a banded microstructure and asymmetric aggregates with cappings of clay/silt, whereas gelifluction may be identified from the presence of silt coatings around grains/peds. Conversely, Bertran and Texier (1999) argued that frost-creep and gelifluction are closely associated. The relative importance of both processes depends particularly on: (i) granulometry – silt coatings around sand-sized grains, and (ii) the rate of particle rotation during mass movement, which is controlled by particle shape and the amount of displacement. Accordingly, I observed that rounded grains were coated with silt, whereas flattened grains and peds were only capped by silt on their upper surface. Both features occurred within a single thin section in this study. Bertran and Texier's (1999) conclusions support this interpretation that frost creep and gelifluction cannot be distinguished based on microscopic analysis.

Active-layer detachment deposits

Active-layer detachment deposits are represented by coarse-grained, matrix-supported diamicton (up to 2.5 m thick) consisting of packages/blocks (up to 50 cm thick) with massive structure. Under the blocks of diamicton, discontinuous layers (up to 10 cm thick) of sand occur. The clasts in the diamicton and sand layers are aligned parallel to the slope. The contact between the diamicton and underlying sand layers is generally erosional, and only in the lowest part of the deposits it is loaded, with the flame-shaped injection structures up to 30 cm high. Fractures and listric normal

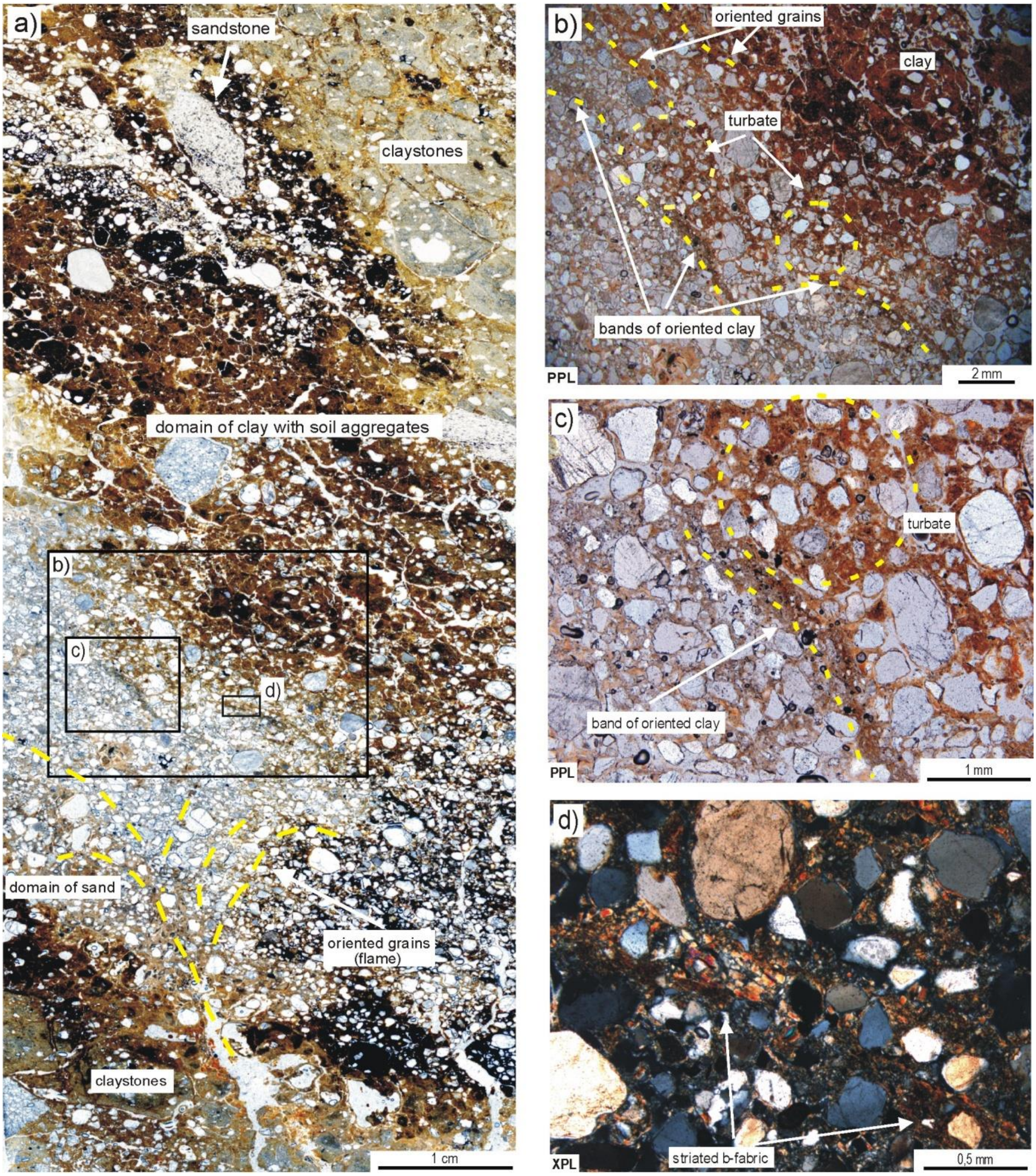


Fig. 2. Micromorphological features of the deposits representing slip plane of active-layer detachment. Main features are marked, (after **A1**).

faults occur in places in the top of sands (**A1**).

Deposition of diamicton as a result of shallow, translational slide (cf. Varnes 1978) is indicated by the presence of distinct sediment blocks, which are a record of short-distance transport in a relatively dry environment with no mixing of the materials. This interpretation is confirmed by the results of microscopic analysis of the sand layer occurring under the diamicton block, which indicate the occurrence of an individual shear zone/slip plane that is diagnostic of slide process. It is recorded by the occurrence of separate clay and sand domains. Microstructures typical of shear zone are observed at the contact between these domains (Fig. 2). These are deformation structures in the form of curvilinear bands of clay and bands composed of sand grains. Rotational structures of "turbate" type, where grains are arranged around a central coarser grain, are also observed (van der Meer 1997). These structures are accompanied by striated and granostriated plasmic fabric. Similar coincidence of microstructures was described by Skempton et al. (1991) and Harris and Lewkowicz (1993a) from the deposits representing slip plane of a landslide. Flame-shaped microinjections occurring in the bottom part of studied deposits suggest that the sediments underwent localized liquefaction. The presence of similar microstructures in shear zone was described by Harris and Lewkowicz (1993a) in landslide deposits. Such structures were also described from the basal zone of debris flow in glacial environment (Phillips 2006).

In the context of the above interpretation the erosional surface occurring between the diamicton and underlying sands may be identified as a main slip plane of landslide. The presence of brittle deformations (fractures, faults) in these sands indicates that the landslide developed in the top of permafrost. Unconsolidated and water-saturated sands occurred only in the lowest part of the landslide where injection structures were formed. Similar shallow landslides occurring in periglacial environment are termed active-layer detachments and sometimes skinflows (McRoberts, Morgenstern 1974) or active-layer glides (Mackay 1981). In this environment they commonly developed on gentle slopes with a minimum inclination of 5˚ (Lewkowicz 1990), at the base of thawing active layer over permafrost, under the conditions of high pore-water pressures (among others Harris, Lewkowicz 1993b, Lewkowicz, Harris 2005).

Debris-flow deposits

The investigated deposits were deposited as a result of: (i) cohesive flow, (ii) cohesionless flow, and (iii) grain flow. I documented the existence of cohesive flow and cohesionless flow deposits among glacigenic deposits occurring in the Holy Cross Mountains (**A3**). The studied grain-flow deposits were formed in periglacial environment in the Cracow Upland (**A5**).

<u>Cohesive flow deposits</u> are represented by coarse-grained, massive, matrix-supported diamictons

with clayey matrix. In the distal part the diamicton occur in the form of lobes and flow folds. Longer axes of clasts are aligned with the direction of sediment movement. The contact with bedrock is depositional (**A3**). Microscopic analysis indicated the coincidence of the following structures (Fig. 3): „flow tail" – with clayey zones occurring on distal surfaces of grains, „marble-bed" – the deposit contains a number of spherical aggregates that behave like ball bearings (van der Meer 1993),

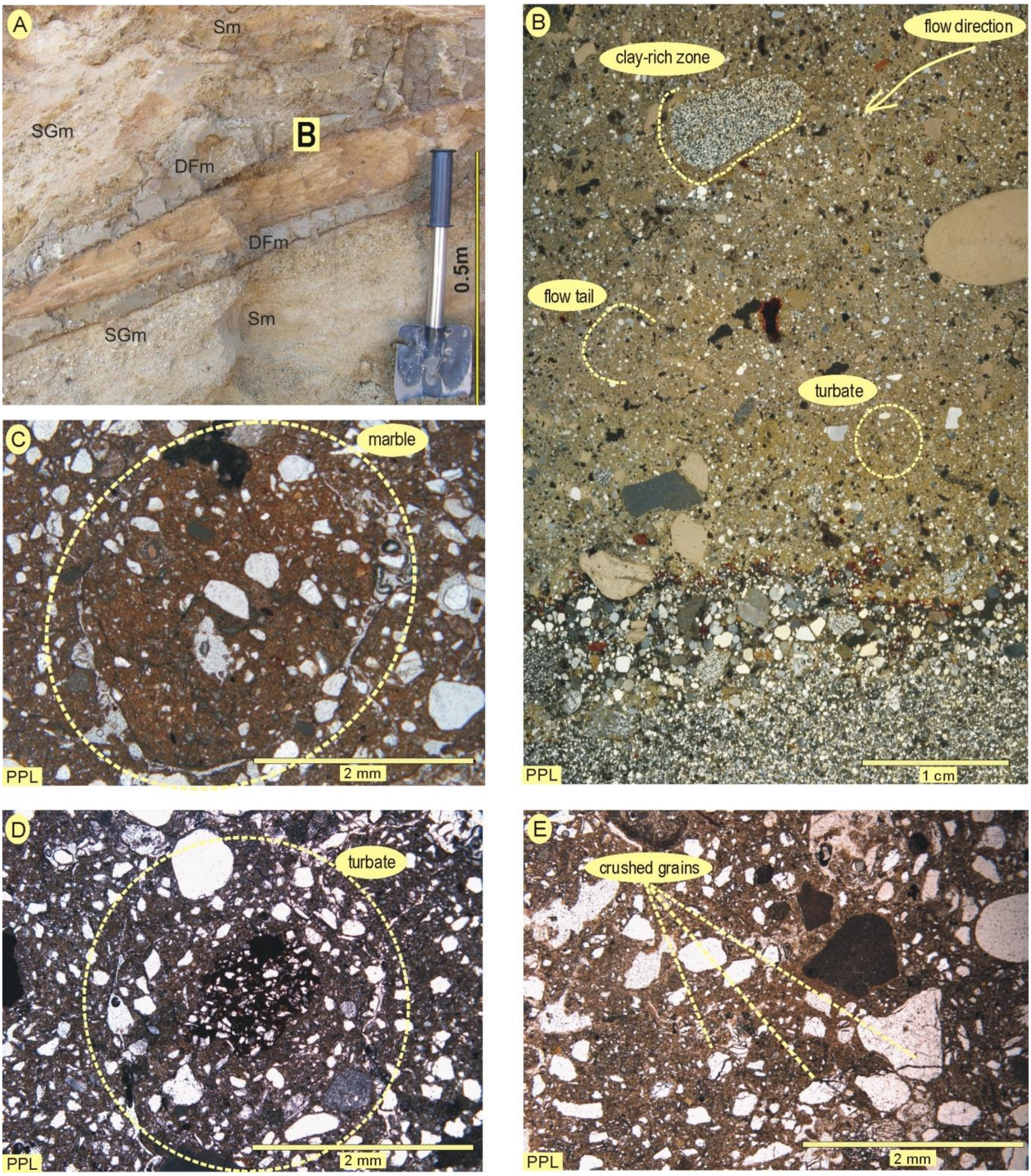


Fig. 3. Micromorphologic features of cohesive debris-flow deposit: A – sample location for microstructural research, B – diamicton with „flow tail" and "turbate" structures, and with the orientation of clasts parallel to the direction of flow, C – "marble-bed" structure, D – "turbate" structure, E – crushed in situ grains, (after **A3**).

"turbates", "grain clusters" with crushed grains in places. Distinct planar shear structures have not been found. Only indistinct lineation is visible in the matrix. Moreover, granostriated b-fabric is found in places. Long axes of coarser skeleton grains are similarly oriented parallel to the direction of sediment movement.

The conclusion that the studied deposits were formed as a result of cohesive flow was inferred from their macroscopic features – clayey matrix of the diamictons and the occurrence of lobes and flow folds (cf. Nemec, Steel 1984, Shultz 1984, Pierson 1985). It is also confirmed by depositional contact between the diamicton and the underlying deposits (Kasprzak, Kozarski 1984, Lachniet et al. 1999). Microscopic features of the diamicton also indicate a possibility that it was deposited by cohesive flow. All these features have been described from deposits of this type (Lachniet et al. 1999, 2001, Menzies, Zaniewski 2003, Phillips 2006), and marble-bed structure is considered diagnostic for clayey debris-flow deposits (Menzies, Zaniewski 2003).

The results of microscopic analysis contribute to the discussion on the deposits of glacial environment, which concerns diagnostic significance of individual microscopic features. It turns out that all the microscopic features described in the studied deposits may also characterize till formed in submarginal zone during seasonal changes of climate conditioning postdepostional transformation of till by frost action and processes associated with pore water (cf. Hiemstra, van der Meer 1997, Hiemstra 2001, Hiemstra, Rijsdijk 2003, Evans, Hiemstra 2005).

<u>Cohesionless flow deposits</u> are represented by coarse-grained, matrix-supported diamictons (the largest clasts occur in the bottom part of the diamicton) with sandy-clayey matrix and most commonly massive structure. In places, these are discontinuous silty layers, up to 2 cm thick, parallel to the inclined basal surface of the diamicton. Orientation of clasts is parallel to the direction of sediment movement. Only in the distal part there is also found vertical orientation. The contact with the underlying deposits is loaded (**A3**). Microscopic analysis indicates that the diamicton's matrix is composed mainly of silt, and the content of clay is low. The deposit is characterized by a low degree of homogenization – it consists of the clast-supported domains composed exclusively of sand and silt, and silty-clayey domains (Fig. 4). Matrix lineation and grain lineation structures are found. Structures of „turbate" type occur in the clayey zones. The deposit is characterized by high microporosity and undifferentiated plasmic fabric.

Deposition of the diamicton by cohesionless flow (transitional between cohesive flow and grain flow) is indicated by a low content of clay and massive structure (cf. Eyles 1979, Nemec, Steel 1984, Zieliński, van Loon 1996, Dasgupta 2003). The occurrence of laminae within the massive diamicton is not of depositional nature. These are deformation structures formed as a result of shearing and laminar flow (cf. Postma et al. 1983). The concentration of coarse clasts in the basal part of the diamicton may be related to shearing processes at the base of flow (cf. Nemec, Steel 1984). Clasts' orientation parallel to the direction of flow is typical of similar flows

(Blikra, Nemec 1998) while their vertical orientation may be explained by “sinking” of clasts in the fine-grained material during deposition of water-saturated sediment (Ruszczyńska-Szenajch 1998).

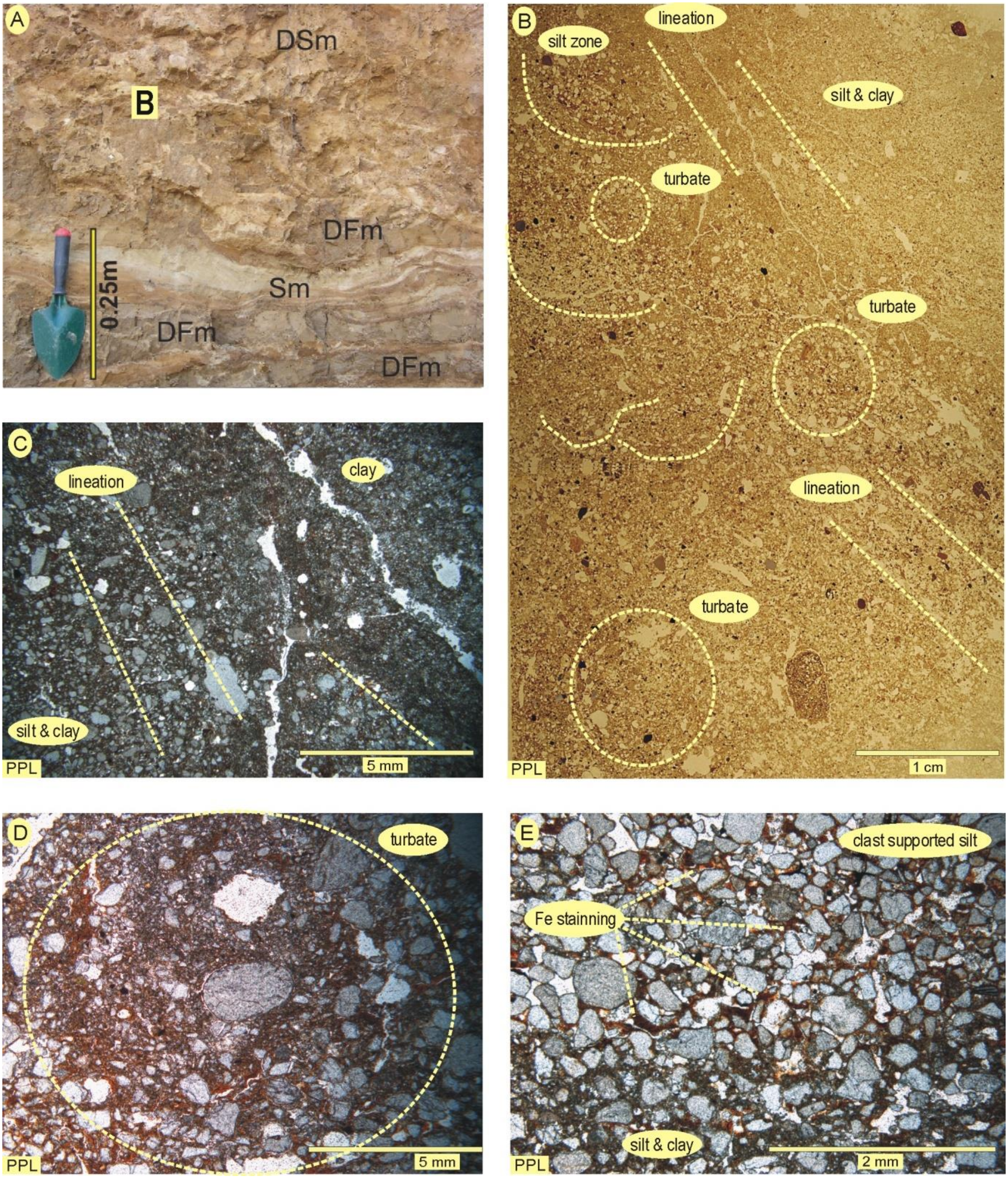


Fig. 4. Microscopic features of cohesionless flow deposits: A – sample location for microstructural research, B – diamicton consisting of sandy-silty and silty-clayey domains. Deformation structures of matrix and grain lineation type, and “turbates”, C – lineation of grains at the contact of deposit domains, D – “turbate” structure in the zone of silt with clayey matrix; E – silty/sandy zone with packing voids, which contain precipitated iron and manganese compounds, (after **A3**).

Microscopic analysis confirmed that the studied sediment was deposited by cohesionless flow. It is indicated by the degree of deposit homogenization – the occurrence of domains separated by lineations (cf. Menzies, Zaniewski 2003). The "turbate" microstructures are a record of turbulent flow occurring in places (Lachniet et al. 2001, Phillips 2006). Water-saturation of flow is also indicated by high porosity of the deposit and its undifferentiated plasmic fabric (cf. Kilfeather et al. 2008).

Grain-flow deposits are represented by homogenous, massive, clast-supported diamicton with coarse-grained limestone clasts ranging from 2 to 15 cm, and with loess matrix. The beds are up to 1.2 m thick. The clasts are oriented parallel to the slope inclination. The contact with the underlying deposits is erosional in places. These dimictons form intercalations within the loess in the foot zone of a steep slope (**A5**).

Deposition by thin grain flows is indicated by clast-supported framework and homogenous texture of diamictons (cf. Lowe 1976, Nemec, Steel 1984, Postma 1986, Blikra, Nemec 1998). Such flows represent typical redeposition process, which develops within cohesionless material on steep slopes (Kotarba, Strömquist 1984, Blikra, Nemec 1998).

Overland flow deposits – deluvia

Overland flow deposits are represented by two lithofacies with the following textural-structural features:

- fine-grained, silty-clayey or sandy-clayey deposits containing thin layers (up to 2 cm thick) of debris material or single clasts (up to 15 cm in diameter) in places. The deposits are massive or laminated (horizontally or wavy), and occur over an erosional surface (**A5**, **A2**, **A1**). In the Cracow and Miechów Uplands they are loess deluvia up to 6 m thick (**A5**, **A2**);
- coarse-grained massive diamicton (up to 1.5 m thick) that consisted of angular sandstone clasts and a silty-sandy matrix. The diamicton exhibited normal grading, with a coarse-grained, clast-supported deposit near its base (clasts up to 25 cm long), fining upwards into matrix-supported diamicton (clasts up to 10 cm long). The long axes of clasts were oriented randomly. Its base was marked by an undulating erosional surface. This diamicton was previously related to solifluction (Klatka 1962, Filonowicz 1969).

Identification of fine-grained deluvia is not always possible based on macroscopic investigations. The main features that distinguish loess deluvia from loess are the occurrence of lamination and erosional contact with the underlying deposits. However, they are not always macroscopically visible. They may be also blurred by pedogenetic processes. Moreover, as mentioned above, fine-grained, laminated deposits may be also formed as a result of solifluction.

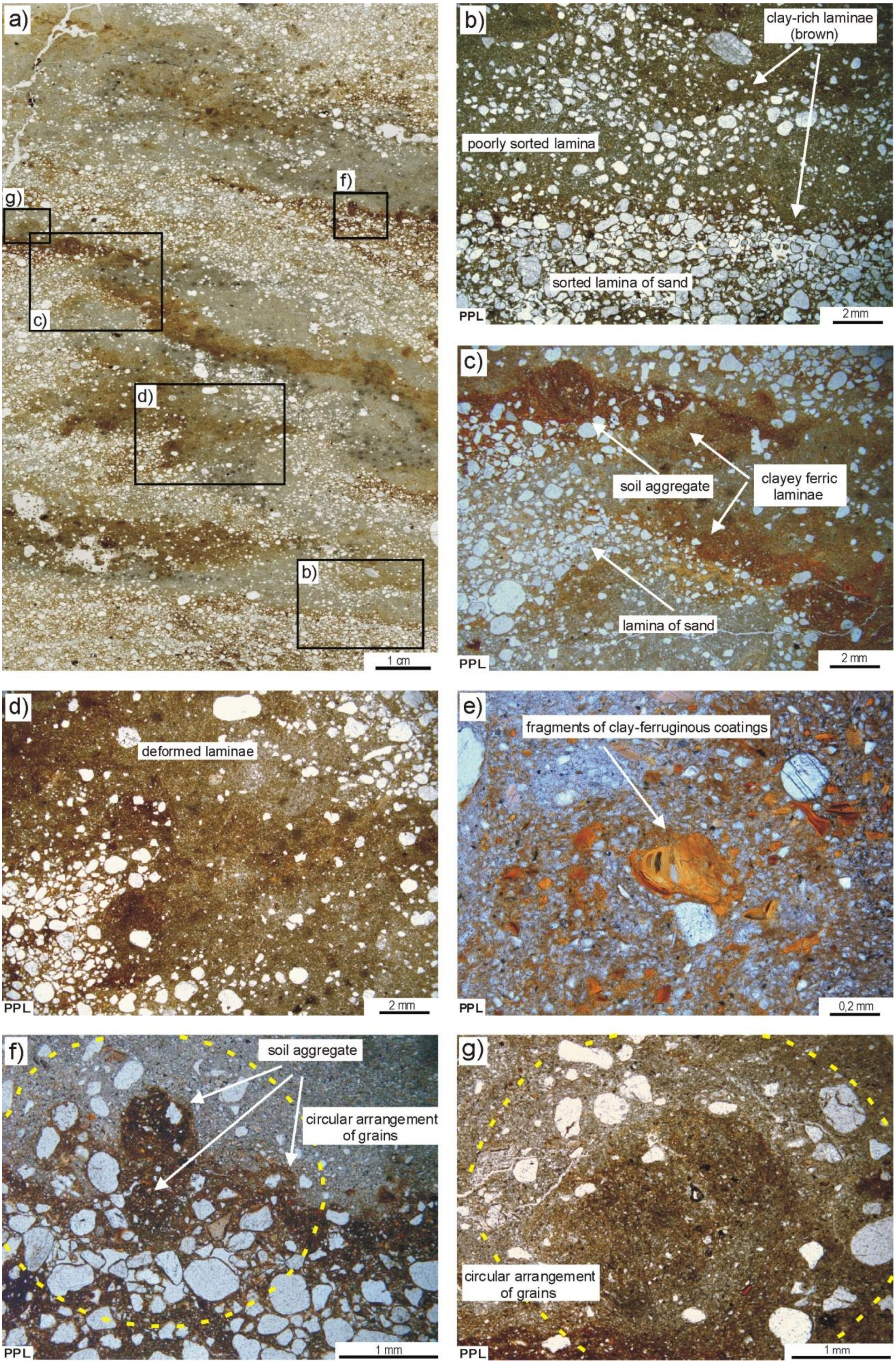


Fig. 5. Micromorphologic features of low energy overland flow deposit. Pertinent features are labelled, (after **A1**).

Therefore, in the papers **A2** and **A1** I identified deluvia based on micromorphological analysis. In the paper **A1** the object of the research was macroscopically massive deposit occurring as deformed layers (up to 8 cm thick) and overlying the above described diamicton (related to active-layer detachment).

Microscopic analysis indicate its deposition due to overland flow. Lamination and varying degrees of sorting suggest this process – these were sandy laminae, clayey laminae, and poorly

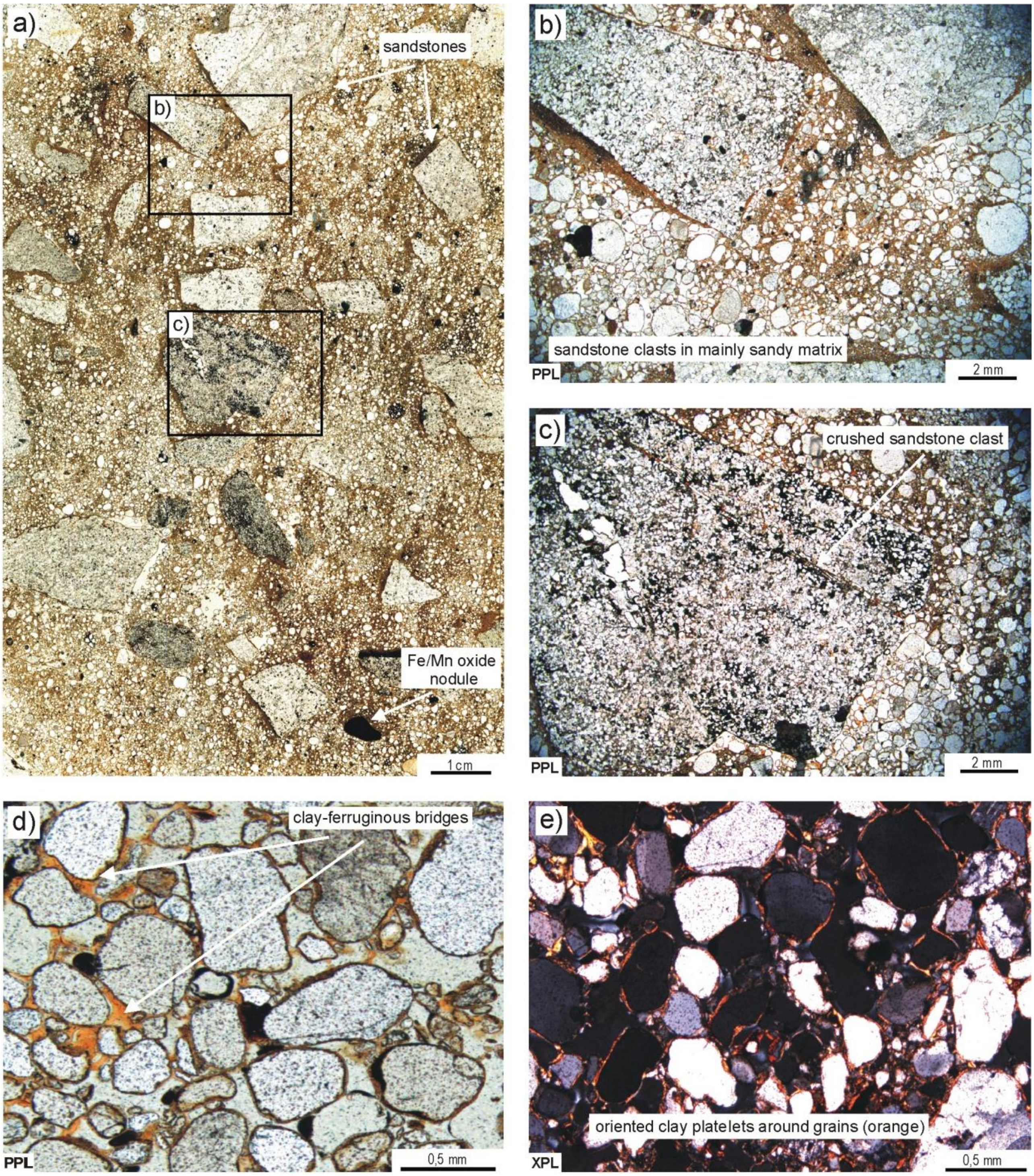


Fig. 6. Micromorphologic features of high energy overland flow deposit. Pertinent features are labelled, (after **A1**).

sorted diamicton laminae (Fig. 5a, b) (cf. Mücher, De Ploey 1977, Bertran, Texier 1999). According represent rapid accumulation of sediment. The occurrence of granostriated plasmic fabric and “turbate” structures around the peds indicates rotational movement associated with turbulent flow to Mücher and De Ploey (1977), sorted and loosely packed parts of a deposit are formed during flow without splash, whereas massive zones form due to flow combined with raindrop impact leading to the displacement of material. Bertran and Texier (1999) suggested that sorted deposits (cf. Menzies, Zaniewski 2003, Phillips 2006). Laboratory experiments indicate that overland flow may be turbulent (Mücher, De Ploey 1977). Laminae rich in iron oxides that contain fragments of coatings, organic matter, and rounded peds (Fig. 5c, e, f) serve as a record of soil horizon erosion (cf. Mücher et al. 198, A2). Deformation structures such as folds and attenuated and boudinaged laminae (Fig. 5a, c, d) may be related to the postdepositional deformation of the deposit resulting from subsidence and compaction, which was also visible at the macroscale.

I also carried out the microscopic analysis of matrix of coarse-grained diamicton related to overland flow. This analysis indicated the occurrence of homogeneous deposit, composed of gravel-sized sandstone clasts and a mostly sandy quartz matrix, and lacked a significant fines fraction (Fig. 6a to e). Some clasts were crushed (Fig. 6c). The deposit was massive and lacked a dominant orientation of clasts and/or deformation structures. Clayey-ferruginous bridges were found between some sand grains (Fig. 6d), and granostriated b-fabric was also apparent around some particles (Fig. 6e).

The coarse-grained fraction, sorting, massive structure, and random orientation of clasts and grains observed at both macroscale and microscale indicate deposition by high-energy overland flow (cf. Rapp 1960, Strömqvist 1983, Blikra, Nemec 1998). Bertran and Texier (1994, 1999) described a similar microfacies for a colluvial fan in the French Alps and linked it with deposition by hyperconcentrated flow (Lowe 1982)**.** Normal grading, visible at the macroscale, indicates rapid deposition from suspension under conditions of decreasing flow energy. The occurrence of clayey-ferruginous bridges may be related to postdepositional, illuvial processes. Similar, but silty bridges or irregular coatings around skeleton grains are associated with the translocation of particles by percolating water when surface runoff loses momentum (Texier, Meireles 2003). Granostriated b-fabric may be the result of postdepositional processes linked with changes in water content in the deposit (cf. Brewer 1964) or with frost action (cf. Pawluk 1988).

Paleoenvironmental/stratigraphic interpretation of periglacial slope covers

Paleoenvironmental/stratigraphic interpretation of periglacial slope deposits in many regions is an unresolved research issue. This problem is especially important for the investigations of periglacial deposits occurring on the slopes of mountains and uplands in the northern and central Europe where they are often the only record of Pleistocene. The research methods commonly applied to

Quaternary sediments are rarely useful for the analysis of slope deposits. One of the main reasons is the lack of organic material in slope deposits that allows dating. Moreover, the lateral lithological variations present in slope covers commonly prevent identification of marker horizons, so that lithostratigraphic correlation is very difficult. This diversity results from the following numerous factors influencing the course of slope processes: geological structure of bedrock and associated lithology of slope covers, slope inclination, climate, and vegetation cover. Paleoenvironmental/stratigraphic interpretation of periglacial slope covers is based on the analysis of climatic conditions under which slope processes develop, and their succession in the context of other determinants. The possibility of a reliable climate reconstruction on the basis of the succession of slope deposits is still under discussion. It has been suggested that slope deposits are so closely related to the local conditions that they cannot be used as an input for climatic interpretations (van Steijn et al. 1995), but other researchers state that sedimentological analysis may indeed be a basis for palaeoclimatic reconstructions (Bertran et al. 1994, González Dìez et al. 1996, Matthews et al. 1997)

In the articles concerning Cracow Upland (**A5**) and Miechów Upland (**A2**) I made an attempt at lithostratigraphic correlation of slope covers. In these regions the slope deposits are accompanied by loess, the occurrence of which played an important role in these studies. Moreover, information about stratigraphy of the slope cover in the Miechów Upland (**A2**) can be inferred from the fossil soils and horizons of cryogenic structures occurring in the studied profile.

Results

The results of my research proved that sedimentological analysis of slope covers can be the basis for regional paleoenvironmental/stratigraphic reconstruction. In the Cracow Upland the investigated slope covers were formed in the Upper Vistulian, in the period of accumulation of the youngest loess and later. The succession of the studied deposits reflects the following climatic development (Fig. 7):

- a cold, humid climate, permafrost origin, initial phase of loess deposition, formation of weathered debris, scree, low-density debris flows (grain flows), solifluction and/or dense debris flow (cohesive debris flow),
- an extremely cold and dry continental climate, continuous permafrost; main phase of loess accumulation followed by erosion,
- a cold, humid climate, initial phase of permafrost decline, deposition of scree, low-density debris flows (grain flows) solifluction and/or dense debris flows (cohesive flow). These deposits underwent extensive erosion immediately after their accumulation (hiatus);
- a humid climate; main phase of permafrost decline; formation of washed loess.

Based on the investigations carried out in the Cracow Upland, I studied the role of morphological factor in the formation of slope deposits. The results indicated that depending on the slope relief, under the same climate conditions (cold and humid climate during permafrost growth and decay), the following different types of slope deposits were formed (Fig. 7):

- foot of rock walls – scree
- steep slopes – low-density debris flows (grain flows),
- gentle slopes – solifluction and/or dense debris flow (cohesive debris flow).

The synchronous coexistence of rockfall, solifluction, high- and low-density mass flows suggests that all these gravitational processes were controlled by climatic and morphological factors, both in the same degree. Slopewash developed in the whole area, irrespective of the slope relief, in the very humid environment associated with intensive thaw of permafrost at the end of Vistulian.

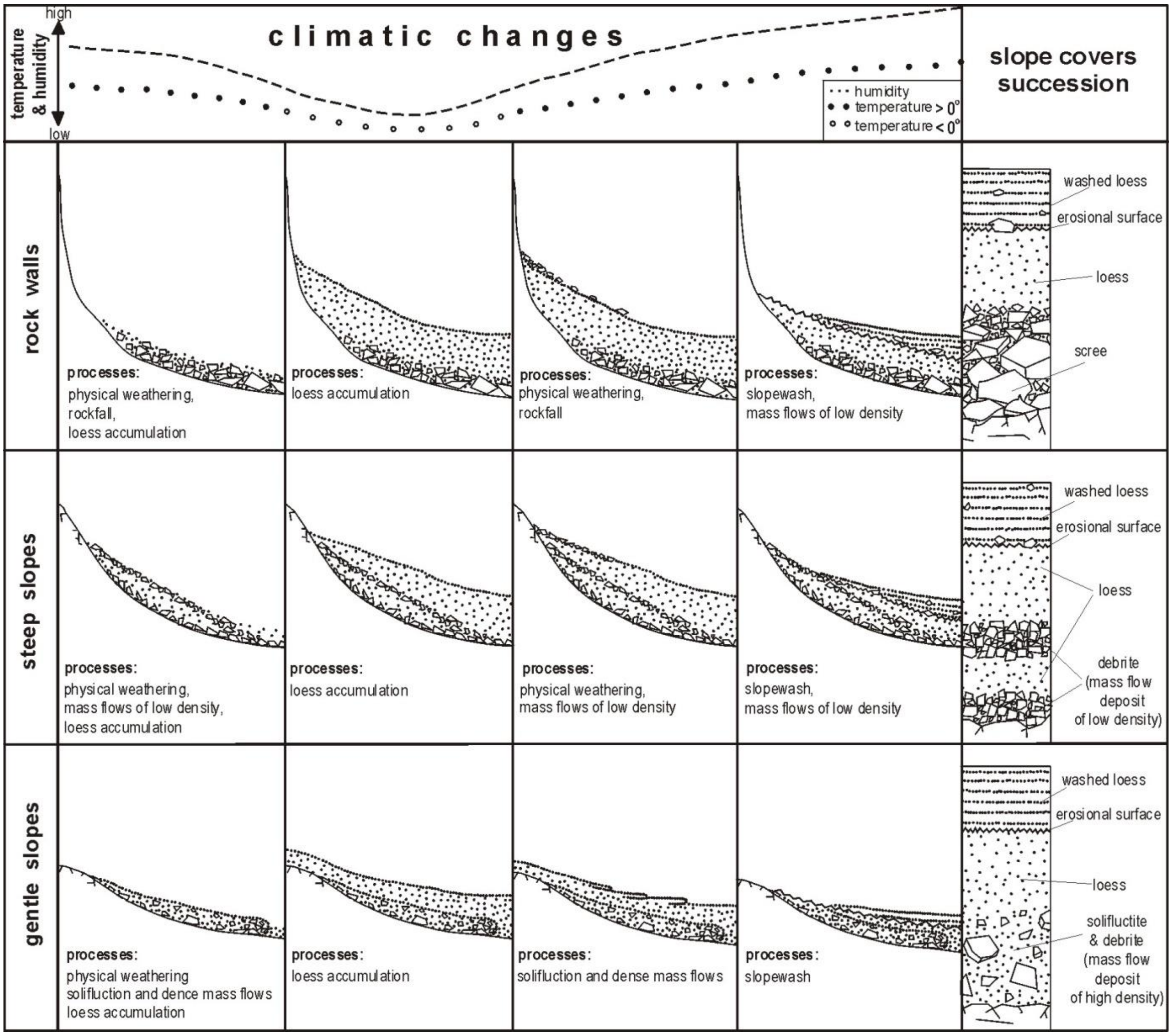
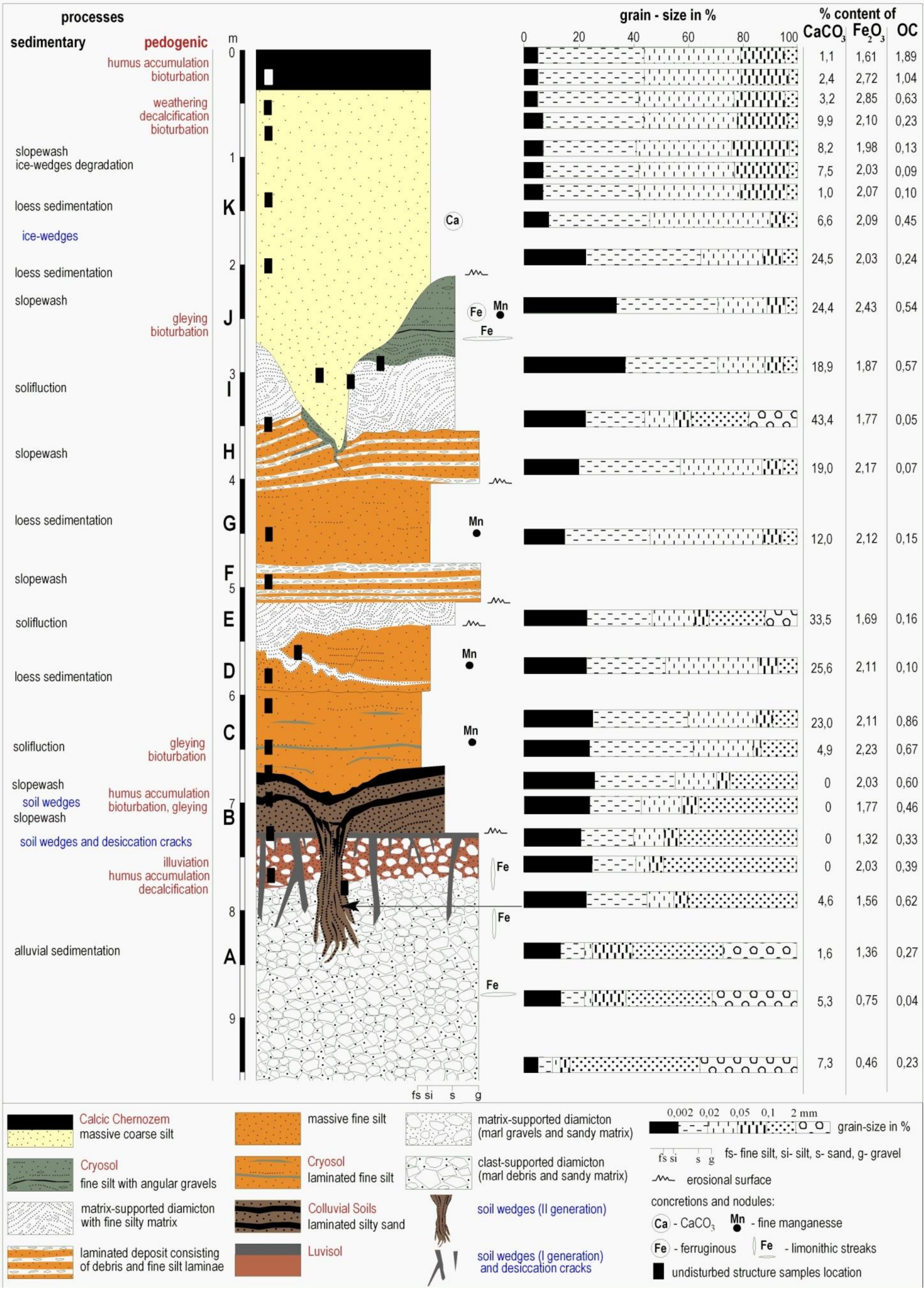


Fig. 7. Climate changes interpreted from the periglacial slope covers succession in relation to slope morphology, (after **A5**).

In the Miechów Upland the object of study was a rare profile, located on the slope of a valley, in which slope deposits coexisted with fluvial deposits, loess, fossil soils and cryogenic structures (**A2**) (Fig. 8). Based on the results of detailed macro- and microscopic investigations of the deposits, cryogenic structures and soils (soils were analysed by the co-authors - Marek Drewnik and Marcin Żyła), I determined the sequence of paleoenvironmental change, which was then compared with dated loess profiles located in Poland (Jersak 1973, Maruszczak 1986, 1991, Jary 2009, Jary, Ciszek 2013) and especially the Odonów reference profile for central Poland (among others Jersak et al. 1992, Dwucet, Śnieszko 1996). In addition, since the area of the research lies in the central part of the northern European loess belt, the results of the research were also compared with stratigraphic schemes published for loess in Western Europe (cf. Huijzer, Isarin 1997, Haesaerts, Mestdagh 2000, Antoine et al. 2001, Guiter et al. 2003) as well as Ukraine and Russia (Bogutsky 1986, Morozova, Nechajew 1997, Haesaerts, Mestdagh 2000, Bogutsky, Łanczont 2007, Jary 2009, Jary, Ciszek 2013). This comparison indicated that the sequence of paleoenvironmental change described in this paper corresponds that published in the research literature for the European loess belt and including the period from the Eemian interglacial to the Holocene. The study described in this paper confirms that investigations based on a detailed analysis of environmental conditions of the genesis of sediments, soils and deformation structures are a source of data for paleoenvironmental/stratigraphic interpretation.

The most important horizon in the interpretation is the distinct decalcified horizon with a well-developed Luvisol that occurs at the top of marl gravels (Fig. 8. Unit A) and evidences long-lasting stabilization of relief and intensive weathering accelerating soil-formation processes. It may be deduced that the horizon represents an interglacial warm period. This period is correlated with the Eemian interglacial during which forest soils (Luvisol, lessivè), common in Europe from the Atlantic Ocean to Central Russia, had formed on the loess bed (e.g. Bogutsky 1986, Morozova, Nechajew 1997, Vandenberghe et al. 1998, Haesaerts, Mestdagh 2000, Guiter et al. 2003, Bogutsky, Łanczont 2007). The soil has been also documented for the Miechów loess lobe by numerous researchers (e.g. Jersak 1973, Maruszczak 1991, Jersak et al. 1992, Dwucet, Śnieszko 1996, Mroczek 2008). Deposition of marl gravel not containing organic material at the start of soil development may be associated with a cold period preceding the Eemian, which favoured the development of braided rivers (cf. Vandenberghe 1993, 2001, Zieliński, Goździk 2001, Zieliński 2007). The above interpretation is confirmed by the sequence of crack structures cutting the Luvisol and the deposits above the soil in the profile. Small cracks cutting the top layer are dehydration-type and soil wedges larger than these cracks (I generation) were formed in the conditions of cold climate during the Early Weichselian. Both types of structures occur at similar positions in numerous profiles across the uplands of southern Poland (Jersak 1973, Maruszczak 1986, Waga 1987, Jersak et al. 1992, Jary 2009, Jary, Ciszek 2013). Soil wedges are commonly found at the same positions in Ukraine and Russia — Torchin cryogenic stage phase “a”



$CaCO_3$	Fe_2O_3	OC
1,1	1,61	1,89
2,4	2,72	1,04
3,2	2,85	0,63
9,9	2,10	0,23
8,2	1,98	0,13
7,5	2,03	0,09
1,0	2,07	0,10
6,6	2,09	0,45
24,5	2,03	0,24
24,4	2,43	0,54
18,9	1,87	0,57
43,4	1,77	0,05
19,0	2,17	0,07
12,0	2,12	0,15
33,5	1,69	0,16
25,6	2,11	0,10
23,0	2,11	0,86
4,9	2,23	0,67
0	2,03	0,60
0	1,77	0,46
0	1,32	0,33
0	2,03	0,39
4,6	1,56	0,62
1,6	1,36	0,27
5,3	0,75	0,04
7,3	0,46	0,23

Fig. 8. The sequence of sedimentary, pedogenic and frost processes determined at the Niedźwiedź site (Miechów Upland), (after **A2**).

— Bogutsky (1986), Smoleńsk cryogenic stage phase “a” — Morozova and Nechajew (1997). Structures resulting from drying (desiccation cracks) (Grande Pile, Les Echets and Velay) were the most common in Western Europe during the Early Weichselian (Early Vistulian) (Herning/Melisey I stadial) (e.g. Haesaerts, Mestdagh 2000). Unit B documents the later part of the Early Weichselian and is a record of the sequence of the following processes: (i) redeposition due to washout, (ii) soil processes (Colluvial Soil), and (iii) development of soil wedges (II phase).

Unit C was formed by the loess material redeposited as a result of slopewash. The base part of the deposit was later transformed by soil processes (Cryosol). Unit C is a record of the beginning of the Lower Pleniglacial, in which the Weichselian loess accumulation had occurred (Younger loess IIa in Poland, Khotylevo loess in Russia, Loess 4b in Ukraine). In Poland, this loess horizon is described as an argillaceous deposit transformed by soil processes and formed with the involvement of slope processes (Jersak 1973, Maruszczak 1986, Jersak et al. 1992, Jary 2009, Jary, Ciszek 2013). These loess features are explained by slow sedimentation on a humid bed. Loess sedimentation was also very limited in that period in Western Europe (e.g. Antoine et al. 2001) and slope processes were most frequently developing in the top part of older deposits (Van Vliet-Lanoë 1985). Subsequent units (D – G) document further sedimentation of loess (Units D and G). These were phases of loess sedimentation interrupted by periods of accelerated slope processes, i.e. solifluction (E) and slopewash (F). Characteristics of European loess generally suggests a cooling of the climate and the development of permafrost (Vandenberghe et al. 1998). However, it has also documented that short phases of a warmer climate had occurred in that period of time (Guiter et al. 2003), which favoured the development of slope processes.

Units H, I, and J record hindered loess accumulation, with frequent redeposition from slopewash (Unit H) and solifluction (Unit I). The soil of Cryosol type (Unit J) developed on a bed built of solifluction deposits. Following the initiation of soil processes, redeposition processes, which were conditioned by summer thawing of the ground, became active. The complex divides two Vistulian loess horizons in the profile and corresponds to the soil horizon usually described for European loess and correlated with Hengelo interstadial. This is the Komorniki palaeosol complex in Poland (Jersak et al. 1992), the Dubno soil in Ukraine (Bogutsky 1986, Bogutsky, Łanczont 2007), and the Bryansk soil in Russia (Morozova, Nechajew 1997). It is a soil type that corresponds with subarctic soils in Western Europe (Vandenberghe et al. 1998). Slope processes in the horizon have been documented in Poland for numerous loess profiles (e.g. Kozłowski, Sobczyk 1987, Alexandrowicz 1995, Dwucet, Śnieszko 1996, **B5**).

Unit K represents the youngest loess horizon. Pseudomorphosis following ice-wedges corresponds to the cryogenic horizon commonly occurring across Europe and Russia (e.g. Vandenberghe et al. 1998, Murton, Kolstrup 2003, Jary 2009, Jary, Ciszek 2013). At that time, permafrost was present virtually throughout Europe. Surface erosion, which appears at the top of the structures, is the result of thermokarst processes connected with the thawing of the permafrost and rapid development of the process of slopewash during the Late Glacial (e.g. Kozarski 1993). A Calcic Chernozem (Siltic) soil formed in the top part of the loess as a result of Holocene soil-forming processes.

The results of the presented research are a contribution to the discussion on lithostratigraphic interpretation of periglacial slope covers occurring in loess areas. The presented interpretation was based in part on the regularities found in loess deposits the lithostratigraphy of which based mainly on the vertical succession of horizons of loess and fossil soils. Loess horizons serve as a record of phases of cold and dry climate leading to intensive aeolian dust sedimentation (glacials/stadials). Fossil soil horizons mark periods of warm climate, featuring weaker aeolian processes and the emergence of plant communities. Depending on the exact type and degree of soil development, this can be an interglacial, interstadial or short period of warming and stabilization of slopes in a periglacial environment (cf. Catt 1991, Konecka-Betley 1994, Huijzer, Isarin 1997, Kemp 1999, Fedoroff et al. 2010).

In the presented investigations the conclusions on stratigraphy were also drawn from the analysis of cryogenic structures – ice wedge casts and soil wedges. Paleoclimatic significance of cryogenic structures is under discussion because their formation was influenced not only by air temperature but also by other factors conditioning the development of ground ice, such as lithology of substratum, relief and aspect of slopes, occurrence of snow cover, power and direction of wind (Dylik 1966, Black 1969, Romanovskij 1973, Karte 1983, Van Vliet-Lanoë 1985, Murton, Kolstrup 2003). However, the analysis of cryogenic structures in the studied profile and the common occurrence of cryogenic horizons in a similar stratigraphic position in the European loess belt indicates their significance in paleoenvironmental/stratigraphic interpretation. Ice wedge casts serve as a record of periods of frigid continental climate occurring in permafrost conditions (glacial/stadials). Soil wedge structures indicate a period of cold, seasonally frigid climate.

Moreover, sediments deposited as a result of slope processes are important for the presented interpretation. Slope deposits are an underestimated source of data for interpretation of loess covers. They serve as a record of moisture in the environment, which accelerates the development of slope processes. Such deposits are usually a record of transitional climate phases - melting of the permafrost (glacial or stadial/interglacial or interstadial) and its aggradation (interglacial or interstadial/glacial or stadial) (**A5**, **A4**). Transitional climate phases are difficult to discern in loess profiles found on flat summit surfaces. Erosion surfaces and hiatuses serve as the only record of these phases and this record is difficult to identify in such loess deposits. The presented investigations indicated that the lower parts of slopes, where redeposited sediments often co-occur with aeolian sediments and horizons of fossil soils, are especially helpful in the understanding of the evolution of the loess cover. This study documents the development of slope processes during the following transitional phases:

- between the Eemian interglacial and the period of sedimentation in the lower Weichselian loess horizon,

- between the period of sedimentation in the lower Weichselian loess horizon and the period of development of interstadial soil,
- between the period of development of interstadial soil and the period of sedimentation of the upper Weichselian loess horizon,
- between the period of sedimentation of the upper Weichselian loess horizon and the Holocene.

Studies of slope deposits not only allow us to draw conclusions concerning the existence of paleoclimate phases favouring the development of slope processes, but also allow the identification of more detailed characteristics of climate features (especially the degree of humidity of the environment). Solifluction usually develop in a cold climate, where thawing of the top of perennial permafrost occurs (Benedict 1976, Ballantyne, Harris 1994, Matsuoka 2001, **A5**, **A4**). Slopewash deposits serve as a record of a humid environment enabling slopewash. In a periglacial environment, the development of these processes is determined by rapid melting of the active layer atop the permafrost table (e.g. Dylik 1969, Jersak et al. 1992, **A5**, **A4**).

The report on the downloads of my article (**A2**), sent by the Elsevier publisher (Fig. 9), indicates that my research on paleoenvironmental/stratigraphic interpretation of slope covers has aroused interest.

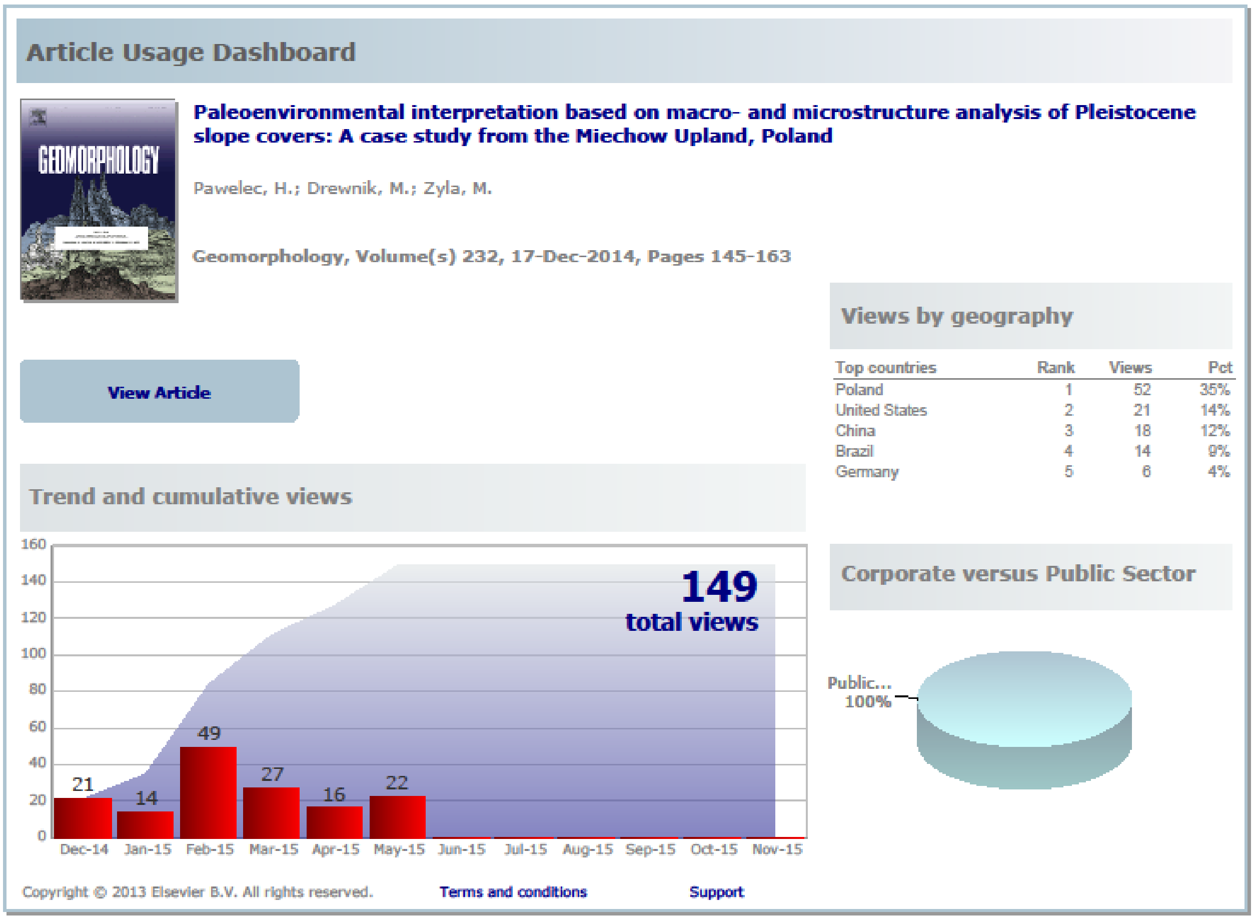


Fig. 9. The report on the downloads of the article **A2** sent by the Elsevier publisher.

Influence of geological structure and climate on the evolution of slopes in periglacial environment

Periglacial environment is the place of intensive development of denudation processes caused by the combined action of frost weathering and slope processes, which are stimulated by the existence of permafrost with active layer that seasonally thaws (Peltier 1950, Palmer, Neilson 1962, Demek 1969). The determination of the development trends of slope relief in this environment is a disputable problem. This issue affects the question that is fundamental to geomorphology: „Does geologic structure or climate control the evolution of slopes?" Research on slope denudation has proved a direct correlation between the slope relief and geological background. Structural geomorphology stresses rock control in relief development (Yatsu 1962, Twidale, Lageat 1994, André, 1996). In contrast, the influence of climate is not so obvious, and has been evaluated at different levels. The role of climate used to be overestimated in climatic geomorphology, emphasizing the influence of climate on morphological processes. This research trend is especially well known from the concept of morphoclimatic zones (Büdel 1960, Tricart, Cailleux 1965). These rock-control and climate-control aspects are also visible in studies on periglacial phenomena. The periglacial "cycle of erosion" (Peltier 1950) is grounded in climatic geomorphology theories. Numerous papers have considered the problems of denudation processes in polar climate. The relationships between slope exposure, influence of climate and denudation were also a common interest of geomorphologists. Asymmetry of valley slopes is recognised as an indicator of periglacial climate (Poser 1948, Tricart 1952). The origin of monadnocks used to be substantiated by denudation processes developed in a periglacial environment (Palmer, Neilson 1962, Scourse 1987). The monadnocks on slopes used to be interpreted as the result of cryoplanation terraces (Cairnes 1912, Boch, Krasnov 1943, Demek 1969). The characteristic convex shape of slope profiles is defined as typical of periglacial areas — the result of solifluction (Büdel 1960, Souchez 1966).

However, there are also studies that undermine the dominant role of climate in the development of slope relief in periglacial areas. It has been proved that the subaerial exposure of slopes does not have to be the only reason for valley slope asymmetry. Lithology and tectonics of basement rocks as well as fluvial processes can be more important factors in the development of asymmetry (Kennedy, Melton 1967, Washburn 1973). The genesis of cryoplanation terraces raised doubts also. Numerous investigations prove the significance of rock control and the terraces are rather interpreted as lithologic and/or structural benches than the result of cryoplanation (Washburn 1985, Traczyk, Migoń 2003, Grab et al. 2004, Hall, André 2010). The existence of stepped slopes as well as concave–convex slopes are common in periglacial environments, nevertheless the concave slope - free faced or debris slope assemblage is also present (Jahn

1947, 1968, 1975, Rapp 1960, Dylik 1969, Lewkowicz 1988, French 2007). Generally, slope development in periglacial environments is influenced by the lithology of the underlying rocks and the geological processes involved. Slopes evolve through the combined action of mass movement and running water and not through "unique" periglacial processes (French 2007). Therefore, extensive analysis, taking into consideration both the geological background and climate changes, should be the basis for geomorphological reconstructions of slopes (see, among others, Van Vliet-Lanoë et al. 2000, André 2009, Knight, Harrison 2009).

In the article **A4** I answer the question: *„Did geological structure or climate control the periglacial morphogenesis of slopes in the Cracow Upland?"* This work is the continuation of my investigations conducted in this area. I could undertake this problem owing to the fact that I used the results of previous investigations supplemented with new observations. The previous investigations resulted in the sedimentological identification and lithostratigraphic interpretation of slope deposits (**B7**, **B5**, **A5**). In the article **A4** I focus on the analysis of distribution of these deposits in relation to slope relief. My research covered the main relief forms of the Cracow Upland: (i) river valleys of asymmetric slopes; (ii) undulating plateaus with gentle convex–concave slopes, towering with monadnocks with steep, often vertical slopes; and (iii) tectonic edges of various height, the majority of which are fault-line scarps (locally gentle and locally steep). In the present contribution, the relation between the slope shape and geology of the substratum (lithology and tectonic structure) is presented. Climatic conditions of slope development are discussed as well, especially the relations between shape of slopes against their exposure, relations between slope shapes and types of denudation processes controlled by climatic factors.

Results

The results of the analysis presented here showed that in the area studied, periglacial morphogenesis of slopes was mainly conditioned by the geology of the substratum, which is in agreement with the general view of significant influence of rock control in slope development (Yatsu 1962, Twidale, Lageat 1994, André 1996, French 2007). The following relations between the geology of the substratum and slope relief have been determined:

- asymmetric slopes of the valley are conditioned by the isoclinal, in relation to their run, distribution of bedding in the Upper Jurassic limestone - steep slopes developed in the bedding fronts, and gentle slopes on bedding surfaces. Moreover, changes in limestone facies influenced the development of slope relief. Vertical rocky walls and slope monadnocks are built of organogenic limestones which are very resistant to weathering. Gentle slopes developed on bedded limestones. The presence of joints causes these rocks to be less resistant. The differentiation in resistance of these two types of limestone was also influenced by the density of joints - being larger in bedded limestones;

- periglacial morphogenesis of undulated plateaus with monadnocks was conditioned by the range of underground karst, which developed during the Paleogene and Neogene. Karst processes resulted in differentiation of the limestone into less weathered "cores" (cf. Linton 1955) and intensively weathered parts. Pleistocene denudation processes caused transformation of these "cores" into modern monadnocks and development of undulating relief on the plateau. Development of both underground karst and periglacial denudation processes was stimulated by variable resistance of Jurassic limestones. Monadnocks are built of resistant massive limestone, whereas undulating plateaus developed on less resistant bedded limestone;
- flat and gently inclined plateaus developed on the substratum of almost horizontal beds of less resistant bedded limestone; and
- periglacial morphogenesis of the northern edge of Krzeszowice Graben was conditioned by variable heights of fault scarps, which was caused by tectonics - the occurrence of hinge faults and neotectonic movements. High scarps were degraded, and steep rocky slopes developed there. In the area of low scarps, accumulation processes dominated. These scarps became builtup by sediment cover, and gentle slopes developed there.

The following types of slopes have been documented in the Cracow Upland: (i) concave (free-face), (ii) concave–convex, (iii) regularly inclined (rectilinear), and (iv) convex (Table 1). The variety of slope shapes definitely conflict with the model of slope development in periglacial environments (Peltier 1950, Büdel 1960). The existence of different slope relief was conditioned mainly by primary slope inclination, geology, i.e. tectonics and the architecture of the Jurassic limestones sedimentary facies (Table 1). The primary slope inclination determined the denudation

Table 1. Types of slope shapes against geology of the substratum and predominated process of genesis, (after **A4**).

Slope shape	Type of relief	Geology of the substratum	Slope inclination	Major processes
Concave (free-face)	Eastern valley slopes	Inclined, bedded limestone - fronts of beds, locally massive limestone	Steep slopes	Frost weathering, rockfall, debris flows
	Hilltop monadnocks	Massive limestone		
	Fault-line scarps	High uplifted fault-line scarps		
Convex-concave	Undulated plateaus	Different limestone facies- bedded and massive	Gentle slopes	Frost weathering, solifluction, slopewash, debris flows
	Fault-line scarps	Low uplifted fault-scarps		
Regularly inclined (rectilinear)	Western valley slopes	Inclined, bedded limestone - surfaces of beds		
	Gentle inclined plateaus			
Convex	Lover part of western valley slopes	Deluvial cover		River bottom erosion

processes. Rocky, steep slopes were shaped by frost weathering, rock falls and gravity flows (mostly grain flows). These processes caused the stepping backwards and formation of the concave slope profile. Solifluction supported by rainwash and fluidized debris flows dominated on gentle slopes, which resulted in convex–concave (on the differentiated limestone facies and within low fault scarps) or regularly inclined shape (on the gently inclined, bedded limestones). The convex slope is documented in places covered by deluvium as a result of river bottom erosion.

The relation between the climatic exposition of slopes and slope inclination is not determined. However, climate stimulated the type and intensity of denudation. Intensive development of frost weathering and slope processes occurred in transitional phases - the increase or decay of permafrost in conditions of cold and humid climate. On the other hand, during a phase of very frosty and dry climate when permafrost occurred, frost weathering and slope processes decayed. In this period, loess sedimentation was a dominant process. The presented results allow the conclusion that analysis of slope deposits can be used as the basis for further, deep palaeogeographic/stratigraphic interpretation (cf. Bertran et al. 1994, Nemec, Kazanci 1999; **A5, A2**).

Apart from geology and climate, the presence of deposit cover also influenced the intensity of limestone degradation, i.e. the slope cover protected the substratum against the weathering. Intensive degradation of Jurassic substratum took place during increasing permafrost, when the thickness of slope mantles was small. On the other hand, in the phase of permafrost decay, slope processes occurred mainly in the roof of loess cover and earlier developed slope deposits, and so did not reach the Jurassic substratum. In general, redeposition processes (solifluction, mass flows, washing) on the slopes in the area studied predominated over accumulation processes (frost weathering, rockfall, loess sedimentation) during the Pleistocene. This resulted in intensive denudation of the Jurassic substratum.

The use of micromorphological method for interpretation of terrestrial slope deposits

Micromorphological method is rarely used in sedimentological investigations of the Quaternary deposits. Since the 1990s it has been used for the analysis of glacigenic deposits, mainly tills (among others van der Merr 1993, Carr 2004, Menzies 2000, Hiemstra 2001, Ruszczyńska-Szenajch et al. 2003, Phillips et al. 2007, B1), and sporadically also debris-flow deposits formed in the ice-proximal environment (Lachniet et al. 1999, 2001, Phillips 2006, **A3**). Micromorphological sedimentological investigations of slope deposits are rare and usually limited to one type of deposit. The only attempt to compare the micromorphology of different types of deposits was made by Bertran and Texier (1999). Solifluction deposits were quite often analysed under microscope. However, these analyses concerned mainly soil processes, and rarely focussed on the mechanism of slope process (Harris, Ellis 1980, Harris 1998, Van Vliet-Lanoë 1985, 2010, Bertran 1993, Bertran, Texier 1999). The micromorphology of deposits formed as a result of active-layer detachment has only been described by Harris, Lewkowicz (1993a) and by Skempton et al. (1991). Additionally, the deposits formed by a shallow landslide were described by Bertran, Texier (1999). Debris flow deposits were studied by Harris (1998) and Menzies and Zaniewski (2003). The first micromorphological investigations of overland flow deposits concerned loess translocated by water (Mücher et al. 1972, 1981, 2010, Mücher, De Ploey 1977). Deposits derived from weathered cover on different rocks and soils were studied by Bertran, Texier (1994, 1999) and

Texier, Meireles (2003). Bertran and Texier (1999) express doubts about the possibility of using the micromorphological method for sedimentological identification of relict slope deposits because sedimentation microstructures in these deposits may be destroyed by post-sedimentation pedogenesis and frost processes associated with the development of ground ice. Researchers recommend further studies in order to collect micromorphological descriptions of different types of slope deposits.

The reason why I decided to use micromorphological method in my research were the difficulties in interpreting slope deposits based on macroscopic investigations. Macroscopic identification of processes based on sedimentological analysis of relict slope cover can be problematic because different processes can yield similar lithofacies. For example, massive coarse-grained diamictons can form on gentle slopes as a result of: (i) solifluction, (ii) active-layer detachment, iii) debris flows, and (iv) overland flow (e.g. Ballantyne, Harris 1994, Blikra, Nemec 1998, Traczyk, Migoń 2003, **A5**, **A3**, **A2**, **A1**). This problem appeared also in my previous studies, in which I could not distinguish the solifluction deposit from the cohesive flow deposit (**A5**). I have come to the conclusion that micromorphology may provide important information on redeposition processes in the absence of unambiguous macroscopic indicators. Therefore, in the further work I extended the list of used methods to include the micromorphological analysis (**A3**, **A2**, **A1**).

Results

The presented studies (cf. the chapter *„Sedimentological identification of slope deposits"*) indicate that micromorphological method is an important research tool in the interpretation of terrestrial slope deposits. The microscopic analysis clarified our understanding of the sediment texture and structure. This method played a decisive role in the identification of relict active-layer detachment deposits because it allowed to distinguish the existence of slip planes that are diagnostic for slide process (**A1**). It was particularly important in analyzing fine-grained deposits with a macroscopically massive structure, produced by low-energy overland flow (**A2**, **A1**). It also allowed the identification of solifluction deposits, based on the coincidence of features indicating synchronous development of frost and pedogenetic processes with slow mass movement (**A2**, **A1**).

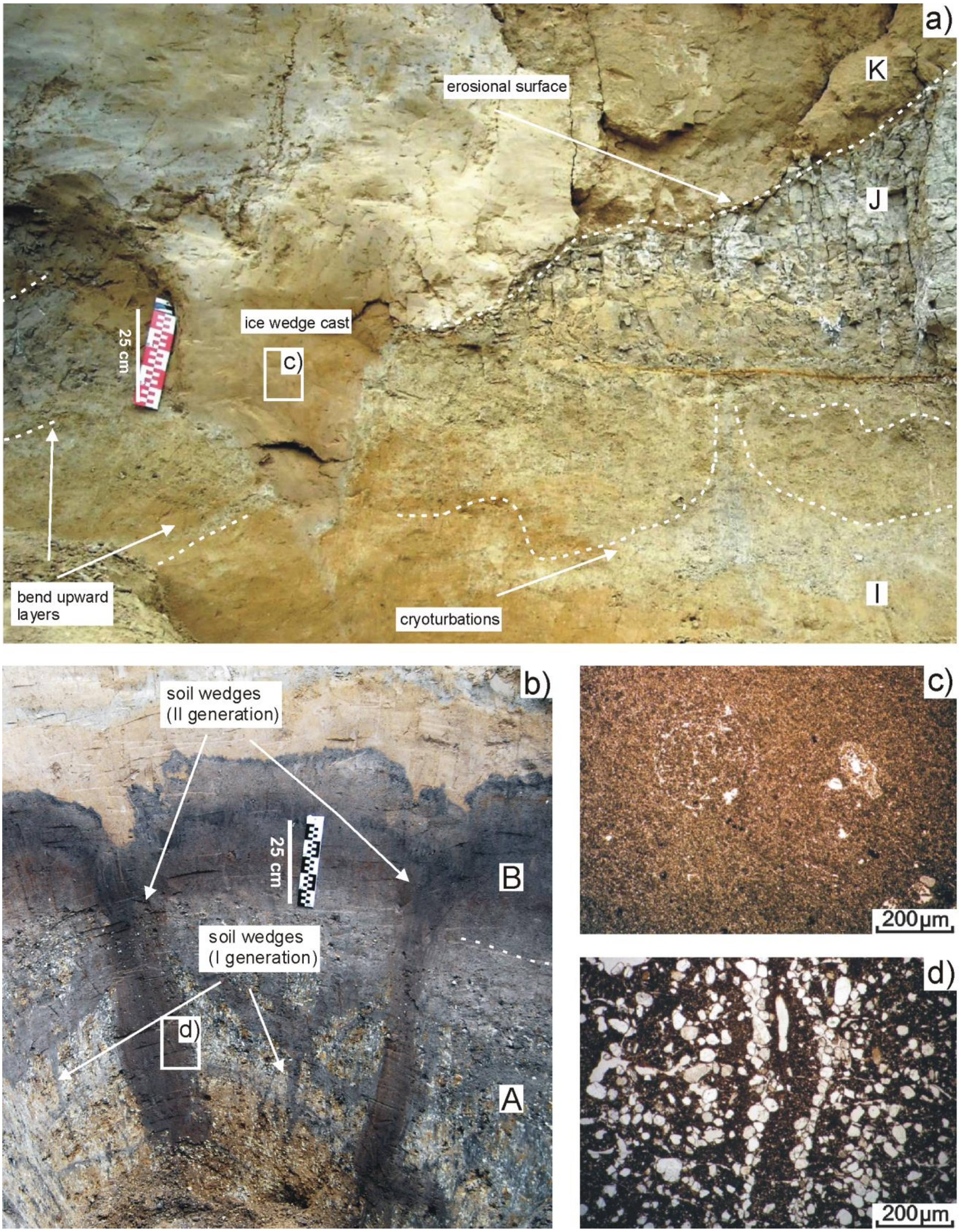


Fig. 10. Frost fissures and the orientation of their infillings (based on microscopic analysis): a) ice wedge cast (Units I, J, K), b) soil wedges (Units A, B), c) random orientation of the material filling the ice wedge cast (visible crystals of calcite), d) vertical orientation of the material filling the soil wedges, (after **A2**).

As I mentioned above, the micromorphological descriptions of terrestrial slope deposits are rare, making it impossible to conduct a comparative study (cf. Bertran, Texier 1999). The presented investigations allowed to describe micromorphological features of the deposits formed as a result of the following processes: (i) active-layer detachment, (ii) solifluction, (iii) debris flows (cohesive and cohesionless), and (iv) low-energy and high-energy overland flows (**A3**, **A2**, **A1**). The pioneering idea was to use the micromorphological method in the investigations of frost fissures – ice wedge casts and soil wedges (**A2**). So far it was not used in the investigations of these structures. Microscopic analysis allowed the study of diagnostic for interpretation but macroscopically invisible orientation of the material filling these structures. In soil wedges, this is a vertical linear distribution of patterns. On the other hand, the material filling ice wedge casts possesses a mostly massive structure (Fig. 10) (cf. Black 1969, Goździk 1973, Karte 1983, Murton, Kolstrup 2003).

The results of presented studies allowed the discussion concerning the methodology of micromorphological analysis of slope deposits. I have indicated that the presence of individual sediment features does not have diagnostic value in determining depositional mechanisms, whereas, the combination of features is helpful. Researchers studying the origin of glacial features have reached this conclusion (van der Meer 1997, Lachniet et al. 2001, Hiemstra, Rijsdijk 2003, Carr 2004, Phillips 2006). Moreover, the results of my studies allowed to respond to doubts about the possibility of using microscopic analysis for interpretation of relict slope deposits because of their transformation by post-sedimentation pedogenesis and frost processes (cf. Bertran, Texier 1999). An important result of my research is the designation of microscopic diagnostic features that are the basis for sedimentological interpretation of these deposits, and additional features that only support this interpretation (because they may be formed both as a result of depositional and postdepositional processes) (**A1**) (Table 2). I have indicated that the degree of deposit

Table 2. Diagnostic and additional features of relict slope deposits, (after **A1**).

deposition processes	sample	content of		diagnostic features of deposit				additional features of deposit	
		water	clay	homogenization	texture	sedimentary structure	fabric	deformation structures	b-fabric
active-layer detachment (individual slip plane)	1			absence	domains of clay domains of sand clasts, grains	breccia-type erosional surfaces shear zones	parallel to the slope	fissures, faults injections, turbates	undifferentiated, striated granostriated
solifluction	3			low	diamicton with clayey matrix	banded	elongated clasts and lenticular peds oriented parallel to the slope	folds, attenuation boudinage injections, turbates	undifferentiated granostriated
overland flow of low energy	2			average	graded laminae of sand, clay and sandy/silty clay	lamination	laminae oriented parallel to the basement slope	folds, attenuation boudinage, turbates	undifferentiated granostriated
overland flow of high energy	4			high	diamicton with silty/sandy matrix	massive	random	absence	undifferentiated granostriated

homogenization, texture, sedimentary structure, and fabric can be used to interpret relict slope deposits (Table 2). The same key characteristics are used in macroscopic analysis of such deposits. Additional features including plasmic fabric, deformation microstructures are of secondary importance in interpreting slope deposits. These features are considered to be diagnostic in the investigations of tills. However, in relict deposits, depositional or postdepositional processes (frost action, moisture changes, subsidence and compaction) may control these features.

For example, granostriated b-fabric and "turbate" structures were found in almost all deposits examined, whereas "turbates" were absent from deposits formed by high-energy overland flow. Both features record grain rotation conditioned by shearing of the matrix (van der Meer 1993). Stress-induced grain rotation may result from diverse processes. Granostriated b-fabric may form due to: (i) wetting and drying of clayey deposits (Brewer 1964), (ii) repeated freeze-thaw cycles in poorly drained deposits (Pawluk 1988), (iii) solifluction displacements (e.g. Harris, Ellis 1980, Van Vliet-Lanoë 1988), (iv) slide-type displacements (Harris, Lewkowicz 1993a, Bertran, Texier 1999), (v) debris flows (Menzies, Zaniewski 2003, van der Meer et al. 2011, Phillips 2006), and (vi) subglacial deformation in tills (van der Meer 1993). Therefore, it appears that the occurrence of granostriated b-fabric in solifluction deposits may be the result of mass movement, postdepositional cryogenic processes, or wetting and drying. "Turbate" microstructures were identified for the first time in tills, and indicate ductile conditions within a deforming till bed (van der Meer 1993, Hiemstra, Rijsdijk 2003). It was later determined that they also occur in debris-flow deposits (Lachniet et al. 1999, 2001, Menzies, Zaniewski 2003, Phillips 2006). Structures similar to "turbates" termed "microcircles" have also been found in cryosols, and attributed to the reorientation of grains by frost action (Morozowa 1965, Van Vliet-Lanoë 1985, 2010, Todisco, Bhiry 2008).

Microporosity is a key diagnostic feature in the investigations of tills. This is especially true when voids follow the general structural pattern of the deposit (e.g. Kilfeather et al. 2008). My studies indicate that in relict deposits, microporosity is the most unstable deposit feature. Postdepositional microporosity may disappear due to compaction and illuvial processes, and may increase due to frost action and moisture changes. Moreover, microporosity type is affected by particle-size distribution and grain shape, which result from mineral/petrographic composition (cf. Stoops et al. 2010).

The importance of my research for identification of morphological features of periglacial slope deposits and their interpretation has been confirmed by the reviews of my article **A1** (annex 6), which have been written by the authorities in the field of microscopic analysis of deposits. Dr Emrys Phillips (British Geological Survey) wrote: *"I think that this paper will make a significant contribution to our understanding of the micromorphology of periglacial/slope deposits".* Dr Simon Carr (Centre for Micromorphology, School of Geography, QMUL) wrote: *"This manuscript offers* *therefore a comprehensive and detailed explanation of the processes and mechanisms of solifluction, active-layer detachment and high-energy overland flow within periglacial environments, and the sediment textures and structures that will arise from these processes. As such, this paper should be essential reading for anyone studying the microscopic scale analysis of periglacial slope deposits."*

Summary

In my opinion the results of my research, published in five paper forming the scientific achievement entitled *„Sedimentological and paleoenvironmental interpretation of slope deposits in the southern Poland, based on macro- and microscopic studies"*, are an important contribution to the development of investigations aimed at interpreting terrestrial slope environment. These results provided new data on all of the defined research objectives, i.e.: (i) sedimentological identification of slope deposits, (ii) paleoenvironmental/stratigraphic interpretation of periglacial slope covers, (iii) determination of the influence of geological structure and climate on the evolution of slopes in periglacial environment, (iv) determination of the usefulness of micromorphological method for interpretation of terrestrial slope deposits.

The results of sedimentological investigations contribute to the discussion on the identification of structures and lithofacies diagnostic of terrestrial slope deposits. I identified and described in detail macro- and microfacies of the deposits formed by the following processes: (i) active-layer detachment, (ii) solifluction, (iii) debris flows – cohesive flow, cohesionless flow, grain flow, and (iv) low-energy and high-energy overland flows. An additional result of my research was the detailed macro- and microscopic description and interpretation of cryogenic structures – ice wedge casts and soil wedges.

The results of paleoenvironmental interpretation of periglacial slope covers proved that sedimentological analysis can be the basis for regional paleoenvironmental/stratigraphic reconstruction. In the Cracow Upland the investigated slope covers were formed in the Upper Vistulian, in the period of accumulation of the youngest loess and later. The sequence of paleoenvironmental conditions determined at the Niedźwiedź site in the Miechów Upland included the period from the Eemian interglacial to the Holocene. Moreover, I studied the role of morphological factor in the formation of slope deposits. The synchronous development of rockfall, grain flows, solifluction and/or cohesive flows indicates that all these processes were controlled by slope relief and climate (cold and humid), both in the same degree. Slopewash developed in the whole area, irrespective of the slope relief, in the very humid environment associated with intensive thaw of permafrost. The results of investigations are a contribution to the discussion on the lithostratigraphic interpretation of loess covers. They confirmed the significance of cryogenic structures and indicated an important role of slope deposits for this interpretation. Slope deposits

are an underestimated source of data in the studies of loess covers. Such deposits are usually a record of transitional climate phases - melting of the permafrost (glacial or stadial/interglacial or interstadial) and its aggradation (interglacial or interstadial/glacial or stadial). Transitional climate phases are difficult to discern in loess profiles found on flat summit surfaces. Erosion surfaces and hiatuses serve as the only record of these phases and this record is difficult to identify in such loess deposits. The presented investigations indicated that the lower parts of slopes, where redeposited sediments often co-occur with aeolian sediments, horizons of fossil soils, and cryogenic structures are especially helpful in the understanding of the evolution of the loess cover.

The investigations aimed at determining of the influence of geological structure and climate on periglacial morphogenesis of slopes in the Cracow Upland indicated that slope relief was mainly conditioned by the geology of the substratum – facial diversity of Jurassic limestones, tectonics and the existence of karst forms. Geological structure and associated primary slope inclination conditioned the type of slope process and development of slope shape. Steep, rocky walls stepped backwards as a result of rock falls and grain flows, and concave slope were formed. Solifluction and/or cohesive flows and overland flows developed on gentle slopes, which resulted in convex–concave (on the differentiated limestone facies and within low fault scarps) or regularly inclined shape (on the gently inclined, bedded limestones). The convex slope, formed as a result of river bottom erosion, was documented on valley slopes built of deluvia. The relation between the climatic exposition of slopes and slope inclination was not determined. However, climate stimulated the intensity of denudation, which was high under cold and humid climate conditions.

An important aspect of the presented research is evaluation of applicability of micromorphological method. It turned out that this method is an important research tool in the interpretation of terrestrial slope deposits, and it allows full understanding of the sediment texture and structure. The identification of depositional process in some of these deposits – active-layer detachment, solifluction, and fine-grained deluvial deposits – would be not possible without microscopic analysis. The presented research is the first case of application of this method to the analysis of terrestrial slope deposits in Poland. In the world literature such studies are few. Moreover, I am the first who have applied microscopic analysis in the investigations of cryogenic macrostructures. I do not know example of its application in a similar study.

The results of presented studies allowed the discussion concerning the methodology of micromorphological analysis of slope deposits. I have indicated that the presence of individual sediment features does not have diagnostic value in determining depositional mechanisms, whereas, the combination of features is helpful. I respond also to doubts about the possibility of using microscopic analysis for interpretation of relict slope deposits because of their transformation by post-sedimentation pedogenesis and frost processes (cf. Bertran, Texier 1999). An important result of my research is the designation of microscopic diagnostic features that are the basis for sedimentological interpretation of deposits (the degree of deposit homogenization, texture, sedimentary structure, and fabric), and additional features (deformation structures, plasmic fabric, microporosity) that only support this interpretation. These additional features, which are considered to be diagnostic in the investigations of tills, in relict deposits may be formed both as a result of depositional and postdepositional processes.

References

All items of cited literature are published in the references of individual articles (**A1** – **A5**) forming the scientific achievement (annex 4).

5. Description of other scientific achievements

Glacigenic forms and deposits were the object of my first research interests. My magisterial thesis concerned the interpretation of fissure glacifluvial landforms in the Głubczyce Plateau, based on detailed analysis of deposits. I presented the results of this study at the conference (**C16**). My doctoral thesis concerned periglacial slope covers occurring in the Ojców Plateau, and the obtained results I presented in several papers. In article **B9** I included the lithogenetic classification of the studied covers. The following periglacial slope covers have been distinguished and described: weathered debris, scree deposit, deposit of low-dense mass flow, deposit of solifluction and/or of dense mass flows, slope loess, deluvial loess. This classification met with a discussion on the part of Stochlak (2005) so I wrote a polemical article (**B7**). The article **B5** contains the results of investigations concerning the stratigraphy of slope covers in the southern part of the Ojców Plateau. My conclusions on the stratigraphy of these covers were drawn from the sedimentological analysis and results of determination of weathering degree of deposits – based on chemical analyses ($CaCO_3$, Fe_2O_3, C_{org} contents) and analysis of composition of clay mineral assemblage (by X-ray diffraction). I compared the results of these investigations with the stratigraphy of deposits from the Nietoperzowa Cave (Madeyska-Niklewska 1969, Madeyska 1977). My studies indicated that the karstic residual clays preserved in places were formed in the Upper Pliocene/Early Pleistocene. Glacigenic residua can be related to the San Glacial, and periglacial slope deposits represent the period form the end of the Warta Glacial to the end of the Vistulian Glacial. The articles **B8**, **B4**, **B3** contain the partial results of my investigations concerning periglacial morphogenesis of the Ojców Plateau. In the paper B3 I presented a new view on the origin and age of hilltop monadnocks. The results of my investigations indicated that the previously published theories (Klimaszewski 1958, Polichtówna 1962, Pokorny 1963, Felisiak 1992, Rutkowski 1996, Alexandrowicz, Alexandrowicz 2004) underestimated the significance of Pleistocene morphogenesis for the formation of hilltop monadnocks in the Ojców Plateau. Based on the analysis of slope deposits and estimation of Pleistocene surface degradation, I concluded that these monadnocks were formed mainly as a result of Pleistocene denudation processes. These processes developed in the substratum transformed by underground karst processes, which were active during the Palaeogene and almost whole Neogene (Gradziński 1962, Dżułyński et al. 1966, Alexandrowicz 1969, Felisiak 1992, Rutkowski 1996). Relict forms of that karst are found in the walls of modnadnocks (Tyc 2009).

Currently, my research focuses on the identification of deposits based on micromorphological analysis. I see the possibility of applying this method for interpretation of deposits representing different depositional environments. The obtained to date results of my research on terrestrial slope deposits are included in the presented above scientific achievement. I also conducted micromorphological analysis of glacial deposits, which resulted in the identification subglacial tills and detailed description of their depositional environment (**B1**). Recently I have studied cover deposits near Kunów, in the Mesozoic marginal zone of the Holy Cross Mountains. I conducted a detailed macro- and microscopic analysis of slope deposits of various types (among other things, interesting debrites formed as a result of cohesive and cohesionless flows) and loess occurring in this area. Based on the obtained results of the study, I am able to present a palaeoenvironmental/stratigraphic reconstruction (article in preparation). I also participate in the investigations concerning deposits of fluvial environment, which are led by Professor Ireneusz Malik. These fine-grained, macroscopically massive deposits occur on a floodplain. My studies, based on micromorphological analysis, are intended to distinguish fluvial deposits from overland flow deposits. The obtained results are interesting (article in preparation). In the near future I plan to study the slope deposits occurring in the area of Flysch Carpathians and Jeseniki. I have already done field reconnaissance, and I prepare the application for funding the research project to the National Science Centre. Generally, my research is aimed to develop a detailed classification of terrestrial slope deposits, based on the reconstructed mechanisms of transport and deposition of these deposits as well as their clear macro- and microscopic lithological features identifying individual lithofacies.

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