Geologia Sudetica, 2004, 36: 53–66.

Late Carboniferous weathering and regolith at the Kudowa Trough, West Sudetes: palaeogeographic, palaeoclimatic and structural implications

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Key words: granite, saprolite, clay minerals, kaolinite, mixed-layer I/S, fault, tectonic block, Sudetes.

Abstract In the marginal part of the Kudowa Trough, on the border of Carboniferous granite and Permian (Saxonian) sediments, features typical for the profile of chemical weathering occurring in a regolith type sequence are described. Previously this border was interpreted as a tectonic fault. According to the authors, location of the initial cataclastic zone, followed by weathering of granite, is incidental. The extent of soil, its structural features and mineralogy are indicative of weathering in moderate-to-warm and humid climate conditions. Stratigraphic position of soil and its regional palaeogeographical and palaeoclimatic context make it possible to assume Late Westphalian (B and C, about 313–311 Ma) as the oldest, most likely beginning date of the weathering process. This opinion does not exclude the possibility of reactivation of weathering processes in Kudowa granite in the Early Cretaceous or even in the Triassic.

Manuscript received 28 October 2004, accepted 21 December 2004

INTRODUCTION

In 2001, after heavy rainfall in the Sudetes, numerous natural exposures appeared in road washaways formed by ephemeral streams. Several of those exposures, developed in the vicinity of Kudowa Zdrój, made it possible to document in detail some of poorly recognized areas of the NE border zone of the Kudowa Trough and crystalline rocks of the Kudowa Granitoid Massif (**KGM**) and its metamorphic cover (Fig. 1).

The Kudowa Trough forms a lowered, diamond-shaped block bounded by steep faults and covered by Cretaceous deposits. In the same sense, the name **Kreidescholle von Cudowa** was first used by Michael (1893) and later by other German geologists (e.g. Flegel, 1905; Rode, 1934) for this unit which is in turn part of a larger regional tectono-sedimentary unit, the Nachod Basin, filled with Permian and Cretaceous sediments. The Nachod Basin has a diamond shape with its edges/corners marked by Červeny Kostelec, Ždárek, Lewin Kłodzki and Nachod (Fig. 1).

At the intersection of the roads to Jakubowice and Karłów in Kudowa Górna (Figs. 2 and 3), a Kudowa granitoid-Permian deposit contact zone displaying structural features of a weathering profile equivalent to **regolith**, *sensu* Taylor & Eggleton (2001), was exposed on a distance of more than 50 m. It should be emphasized that on the 1:25000 geological map (Gierwielaniec & Radwański, 1955) a fault was interpreted in this area, which, according to some authors, has major regional significance, being a tectonic segment linking the Pořici-Hronov Fault Zone (**PHFZ**) in the west with the so called "Zieleniec Thrust" (**ZT**) in the south-east (e.g. Cymerman, 1996, 2004). While PHFZ is an old tectonic zone of Variscan foundation (cf. Franke & Żelaźniewicz, 2000), which was reactivated many a time, and it is well documented by mapping, the existence of the "Zieleniec Thrust" is based on the superposition of the metamorphic rocks above the Upper Cretaceous deposits observed in the vicinity of Zieleniec. However, this relationship was explained by Żelaźniewicz (1977a) as the reverse rejuvenation of the primary normal faults. It is also worth mentioning that the preliminary geophysical and map investigations carried around this zone (Kozdrój, 1997) indicate that the alleged Zieleniec thrust is rather a local feature, linked with gliding – perhaps gravitational – of relatively thin (100–200 m thick) blocks of metamorphic rocks.

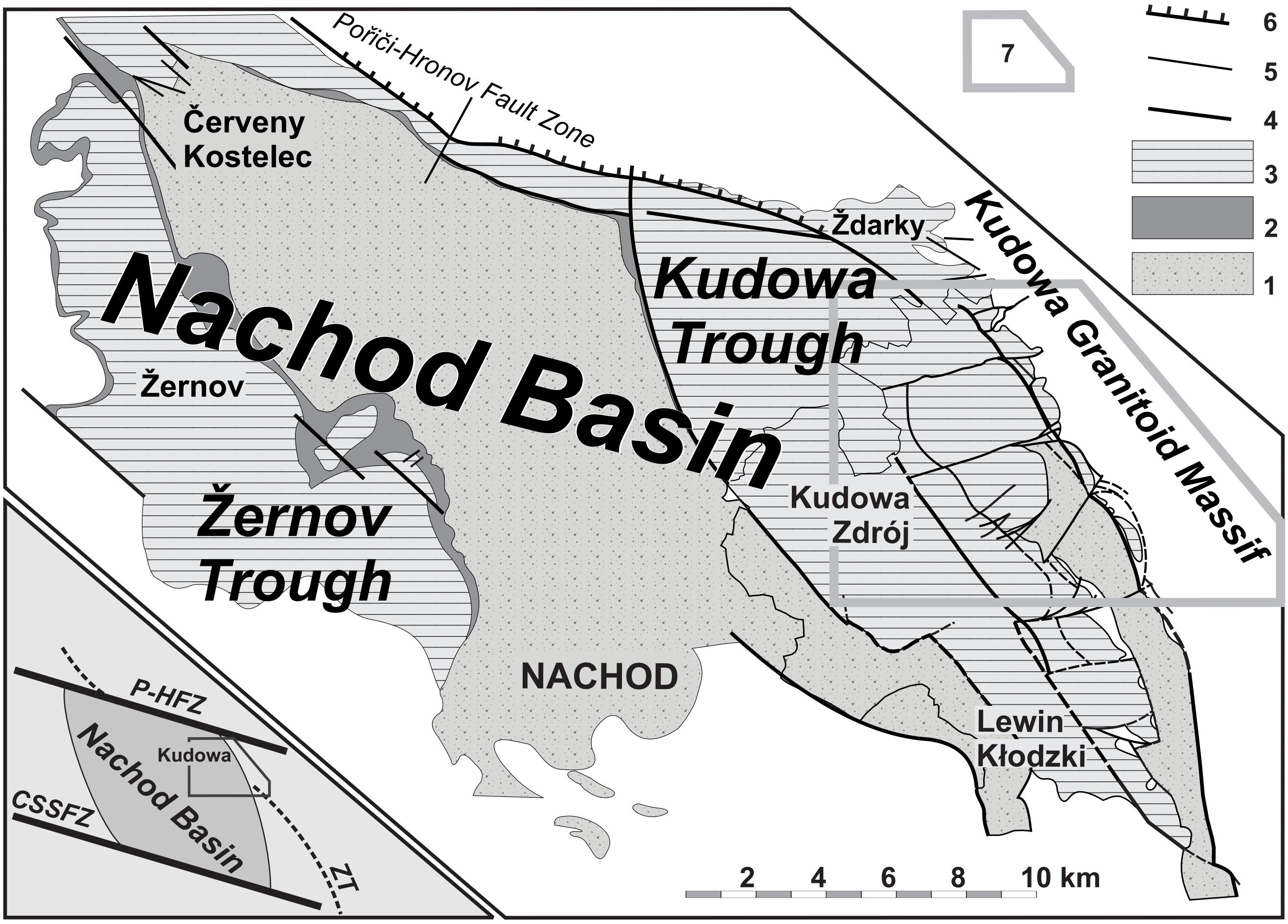

Fig. 1. Sketch map of the Nachod Basin. *1* – Permian (Rotliegendes) clastic deposits; *2* – Triassic (Bundsandstein) clastic deposits; *3* – Upper Cretaceous (Cenomanian–Touronian); *4* – major faults; *5* – subordinate faults; *6* – presumed inverse faults; *7* – the area shown in Fig. 2. Symbols: P-HFZ – Poříči-Hronov Fault Zone, CSSFZ – Česka Skalice – Spalona Fault Zone, ZT – Zieleniec Thrust.

This paper aims to document sedimentologically and mineralogically the regolith, to discuss implications on its age and the resultant implications for the evolution of the analysed area, which was thusfar thought to constitute a relatively young tectonic zone.

PETROGRAPHY AND RADIOMETRIC AGE OF THE KUDOWA GRANITE

The petrography of the Kudowa granite was described among others by Żelaźniewicz (1977b), who pointed to the presence of several feldspar and biotite generations, which formed at various stages of the magmatic and post-magmatic development of the intrusion. He also stressed a strong cataclasis (protoclasis) of the granite, originating during the cooling stage, and the related common presence of mica-feldspar-quartz aggregates. Furthermore, he noted the sporadic presence of chlorite and a sericite-kaolinite mass. Żelaźniewicz (1977b) showed that plagioclase predominates over K-feldspar in the mineral composition of the granite, and that the latter feldspar is red-coloured due to dispersed iron compounds.

The Kudowa granite, occurring beneath the regolith, is usually a compact rock, inequigranular and medium-grained, red-brown coloured, and showing significant changes in its original structure. It consists of quartz, plagioclase, K-feldspar and biotite. This rock is distinctively cataclased, which is manifested by the reorganization of primary fabric, the fracturing of the feldspar and quartz grains, and the presence of fissures filled with fine-grained feldspar-quartz aggregates, often stained with iron compounds, within the feldspars and quartz. Accumulations of iron oxides and hydroxides, occupying interstitial positions, are common components of altered granites (Fig. 4a).

Under the microscope, an intense alteration of plagioclase and biotite, and less pronounced changes in K-feldspar grains, which lost their red colour in some places, can be seen. Plagioclase underwent an almost complete alteration into fine, flaky mica (Fig. 4b). Biotite was either altered into a brown, sporadically green phase, or was bleached (baueritized) with the release of iron that crystallized as opaque iron oxide aggregates (Fig. 4b).

The alteration of the main minerals of the granite described above might have occurred due to the imposition

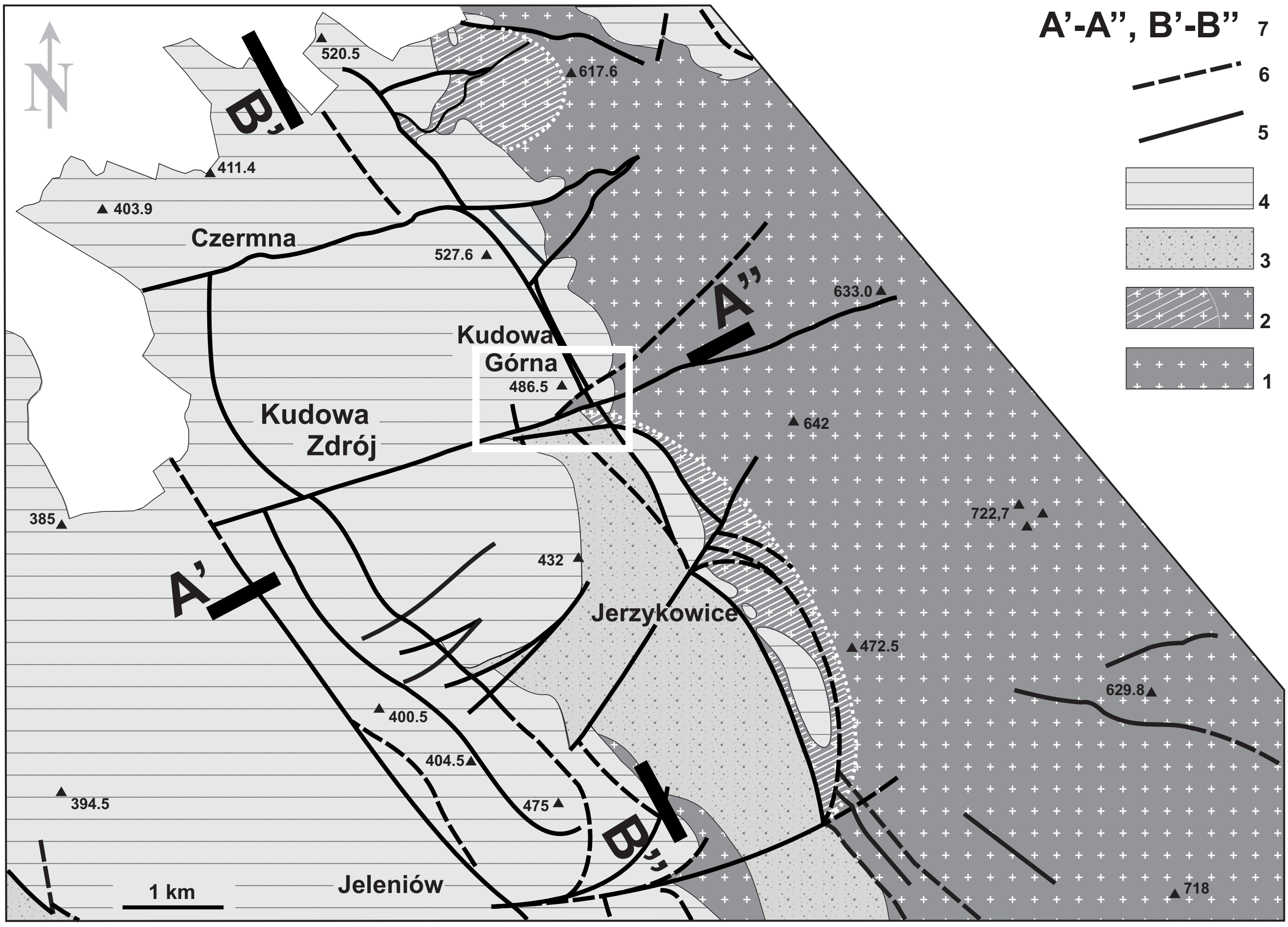

Fig. 2. Schematic geological map of the Kudowa Depression area in Poland. *1* – crystalline basement rocks (granitoids, amphibolites, schists); *2* – intensely weathered granitoids and soil covers; *3* – Permian (Rotliegendes) clastic deposits; *4* – Upper Cretaceous (Cenomanian–Touronian); *5* – documented faults; *6* – presumed faults; *7* – cross section lines (Fig. 5). The rectangle indicates the area shown on Fig. 3.

of post-magmatic processes related to the hydrothermal fluid migration, and/or to low-temperature solutions that were active during the cataclastic processes.

The granite altered in the above-described manner was the starting material for the formation of weathering covers, including such weathering profiles as the regolith from Kudowa Górna described later in this paper. Further alteration of the granite led to the fracturing of the rock and its fragmentation into smaller pieces ranging from a few centimetres to several dozens of centimetres in size, and then a granular disintegration and further chemical transformation of previously altered minerals, i.e. feldspars and biotite, as documented in the sample from Jerzykowice Wielkie (Fig. 4c).

It is justified to accept isotopic dating for the estimation of both the age of the intrusion and the age of the later mineral and tectonic transformation of the Kudowa granitoids, and for estimating the possible and probable onset of the exogenic processes which led to the further alteration of the Kudowa granitoids. The most reliable radiometric datings are presented below.

The oldest published radiometric determinations directly concerning the Kudowa granite are 301–312 Ma (the Rb/Sr method on biotite; Borucki, 1966) and 307–328 Ma (the K/Ar method, also on biotite; Przewłocki *et al.*, 1962). Domečka & Opletal (1974) performed K/Ar dating on amphibole and biotite on the gabbro-diorite and granodiorite

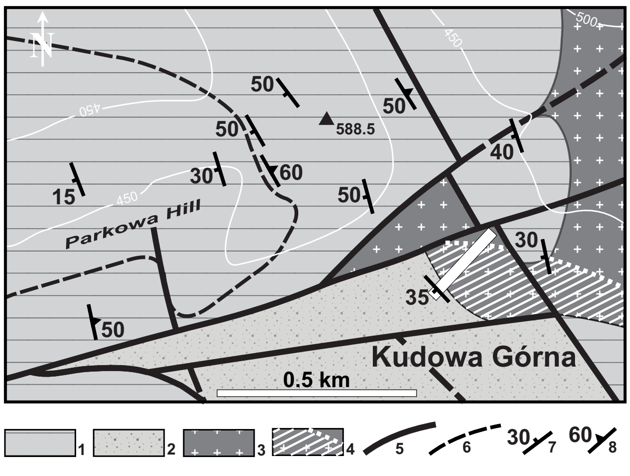

Fig. 3. Details of geological structure in the Kudowa Górna area. 1–6 – as on Fig. 2; 7 – strike and dip of bedding in Permian and Cretaceous deposits; 8 – strike and dip of spaced cleavage in Cretaceous deposits. White rectangle marks location of regolith profile in Kudowa Górna.

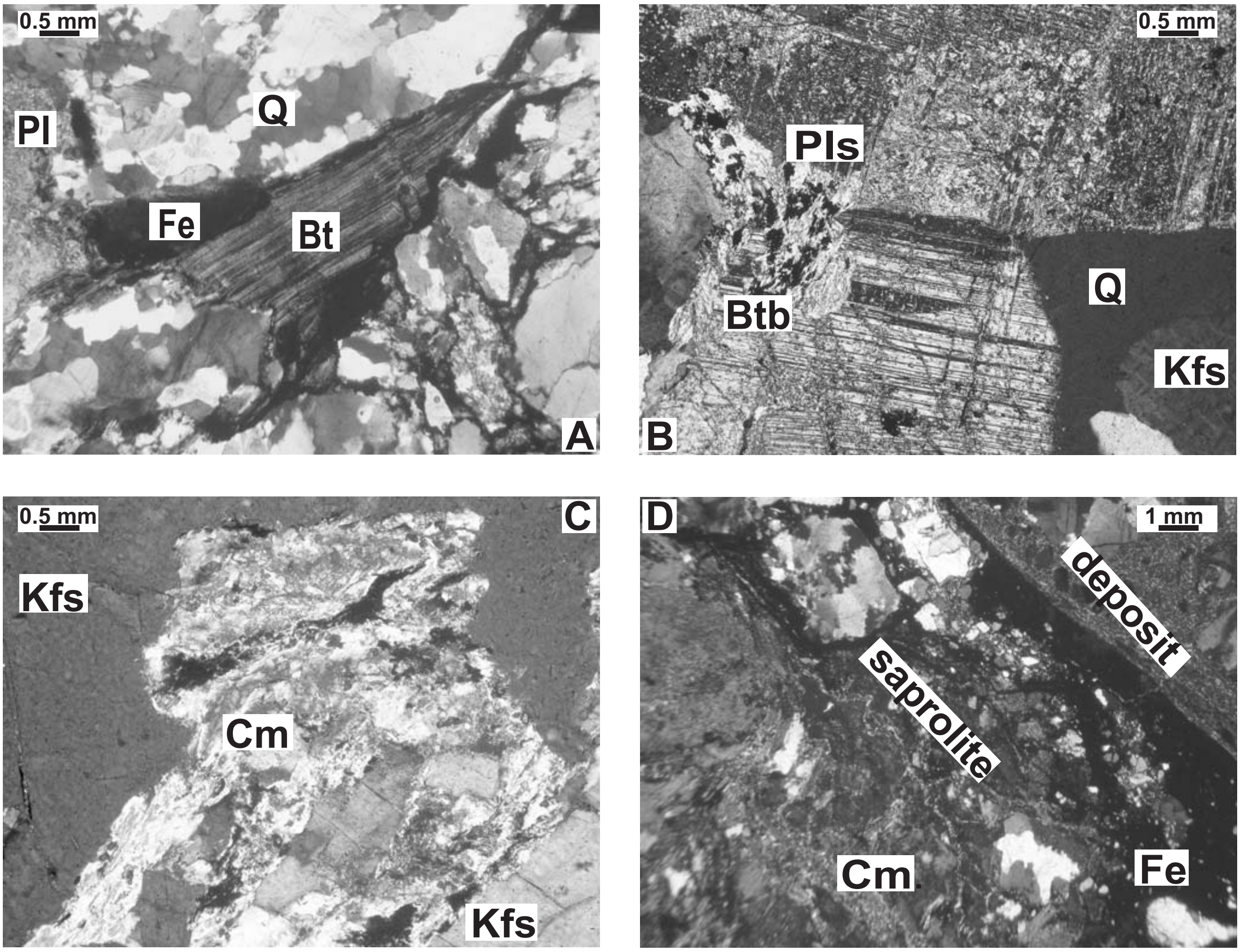

Fig. 4. Granite photomicrographs from Kudowa Górna locality (crossed nicols). **A** – cataclastic microstructure, **B** – post-magmatic alteration of plagioclase and biotite in granite from regolith, **C** – plagioclase- and biotite-derived clay mineral in weathered granitic corstone from regolith, **D** – muddy-clayey deposit filling a fissure in granitic saprolite. Symbols: Q – quartz, Pl – plagioclase, Kfs – K-feldspar, Bt – biotite, Fe – iron oxide released from biotite, Pls – strongly sericitized plagioclase, Btb – bleached (baueritized) biotite incrusted by opaque iron oxide/hydrooxide aggregate, Cm – clay aggregate.

(considered to be the equivalents of the Kudowa granite) from Novy Hrádek in the Czech Republic, yielding the following ages: 318–352 Ma, 327–361 Ma (gabbro-diorite) and 342–378 Ma (granodiorite).The most recent dating of the Kudowa granite yielded the whole rock Rb-Sr age of 331 ± 11 Ma (Bachliński, 2002).

REGOLITH FROM KUDOWA GÓRNA

PROFILE OF THE REGOLITH

The regolith has been exposed in the escarpment of the washed-away road leading to Jakubowice, at the Kudowa-Karłów and Kudowa-Jakubowice crossroads (Figs. 5 & 6). More than 25 m long the profile is composed of:

– weathered, though consolidated, Kudowa granite (Fig. 7a);

– fractured granite with fractures filled with fine-grained mudstone (Figs. 4d & 7b);

– a zone of disintegrated granite (Fig. 7c); and

– bedded Rotliegendes deposits (Fig. 7d).

The consolidated granite has pink colour and only some of the pseudomorphs after plagioclase are lighter in colour. The material filling the fissures in the granite is homogeneous and dark brown, and it completely fills the fissures, irrespective of their orientation and dimensions. The heave of the fissures is up to 4 cm. The disintegrated granite splits into angular granules of up to 2 cm in diameter when sampled. The Rotliegend deposits have distinct parallel- or cross-layering, and apart from the Kudowa granite, they contain numerous rock fragments (including amphibolites and quartz schists). These are dominantly conglomerates (95%) interlayered with sandstones (4.5%) and mudstones (0.5%). While the granite grains are angular to semi-angular in the conglomerates, the other rock grains, usually of finer-grained rock varieties, are rounded (after Powers, 1982). The layers are generally inclined toward 225°,

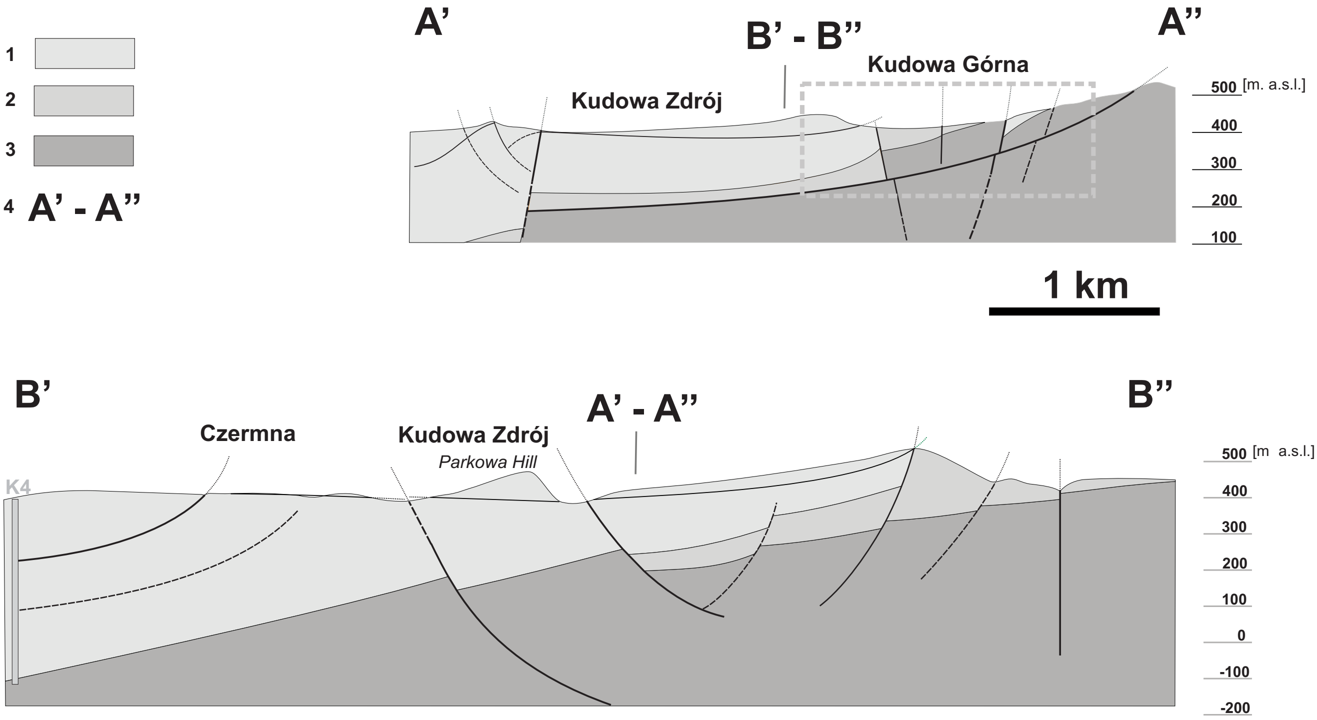

Fig. 5. Two cross sections showing the architecture of the Kudowa Trough. Location of the cross sections on Fig. 2. The rectangle on A' – A'' cross section indicates the location of the enlarged cross section shown on Fig. 3.

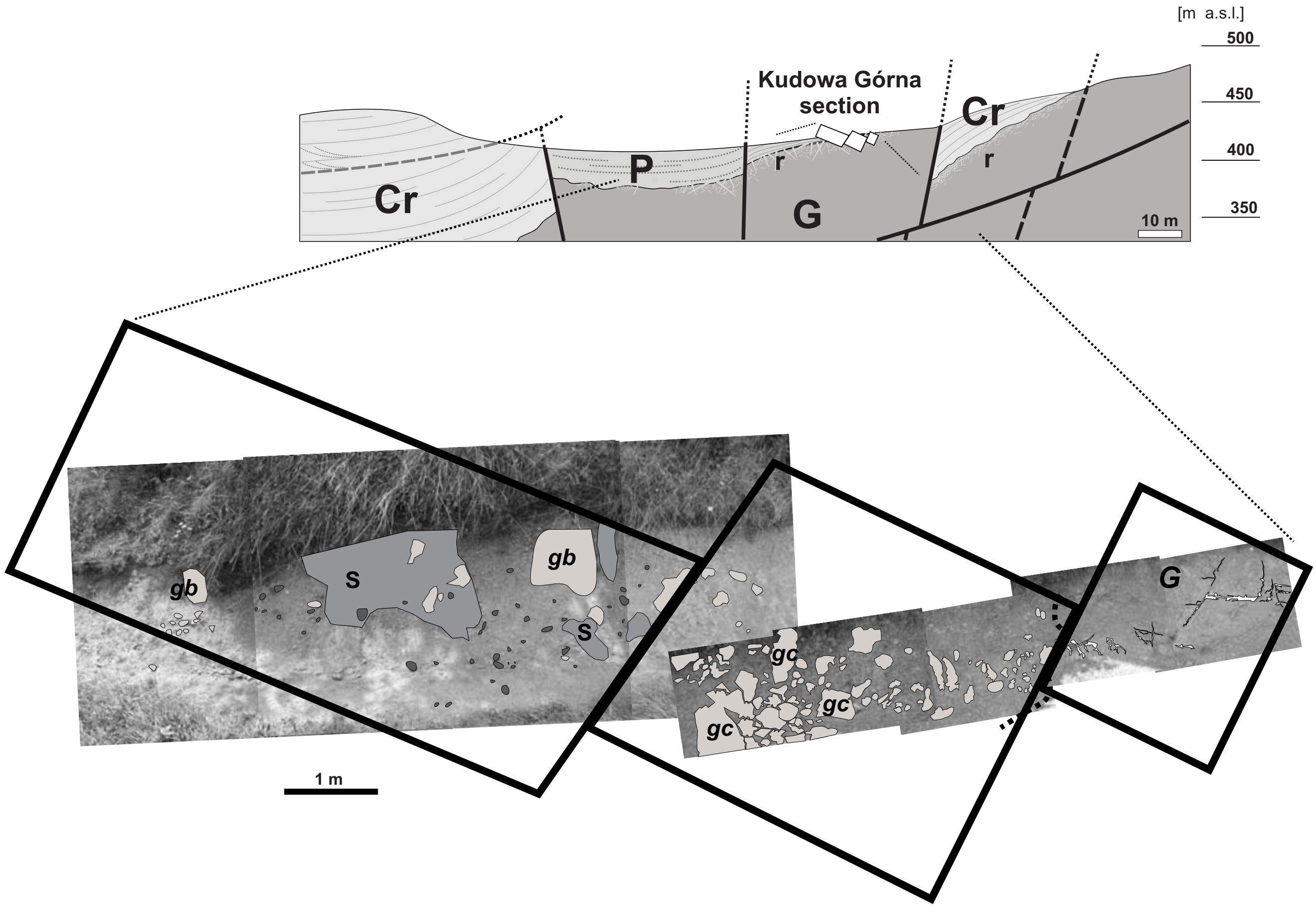

Fig. 6. The upper part of the regolith profile from Kudowa Górna and its location on a general cross section. G – granite, P – Permian (Rotliegendes), Cr – Upper Cretaceous (Cenomanian–Touronian), r – regolith, gc – granitic cornstones, gb – granitic clasts, s – saprolite.

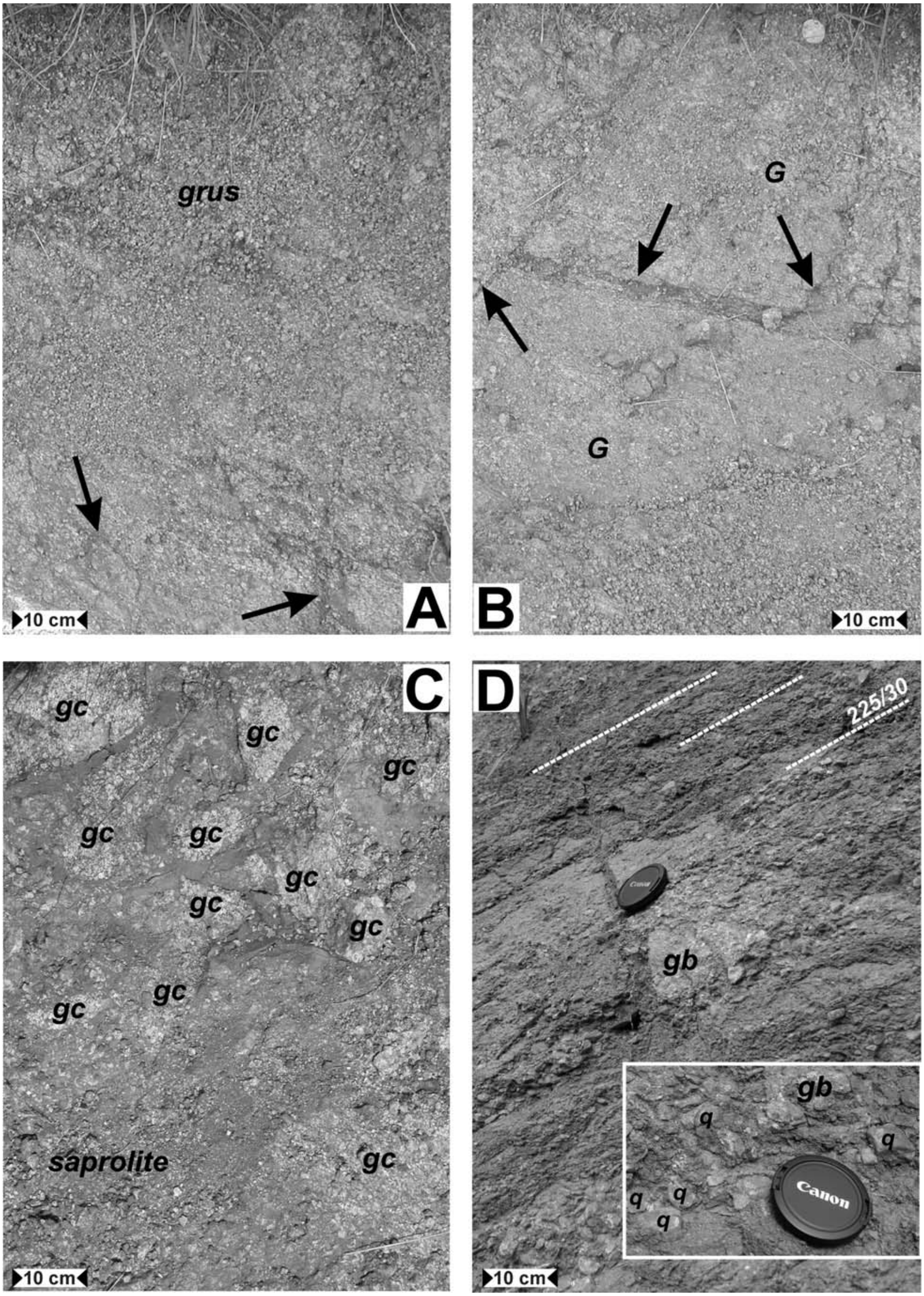

Fig. 7. Facies types in the profile from Kudowa Górna. Disintegrated weathered granite: **A** – grus, **B** – fractured weathered granite (G). Arrows indicate fissures filled with brown-red mudstones. **C** – saprolite with granitic cornstones (gc), **D** – Rotliegendes pebbly sandstones containing rounded granitic (gb) and quartz (q) clasts. Dashed line indicates bedding.

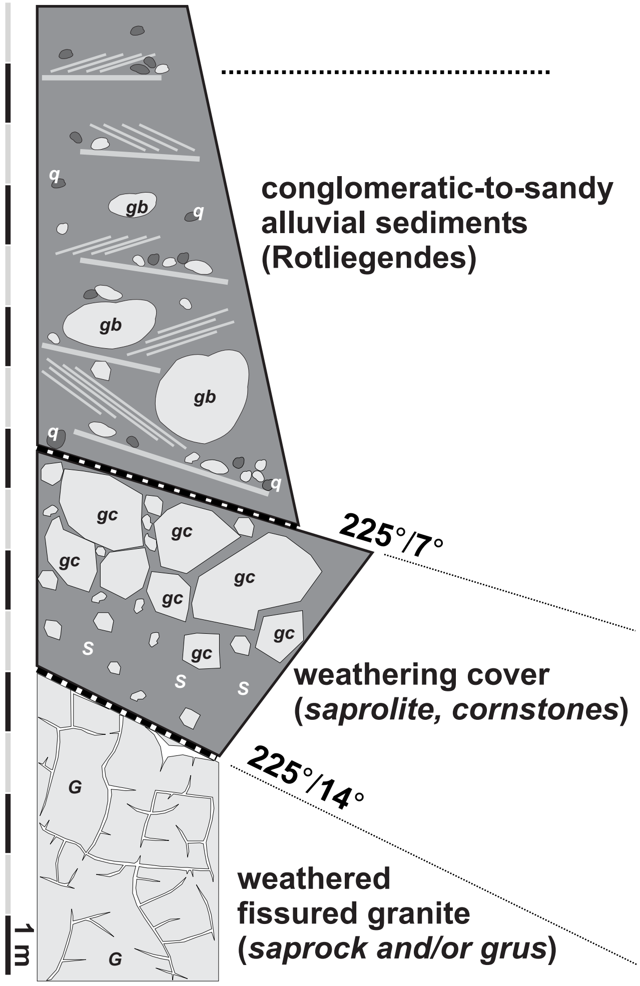

Fig. 8. The profile of the regolith and Rotliegendes deposits from Kudowa Górna (rotated, vertical scale in metres). G – weathered granite, gc – granitic cornstones, GB – granitic pebbles, q – quartz.

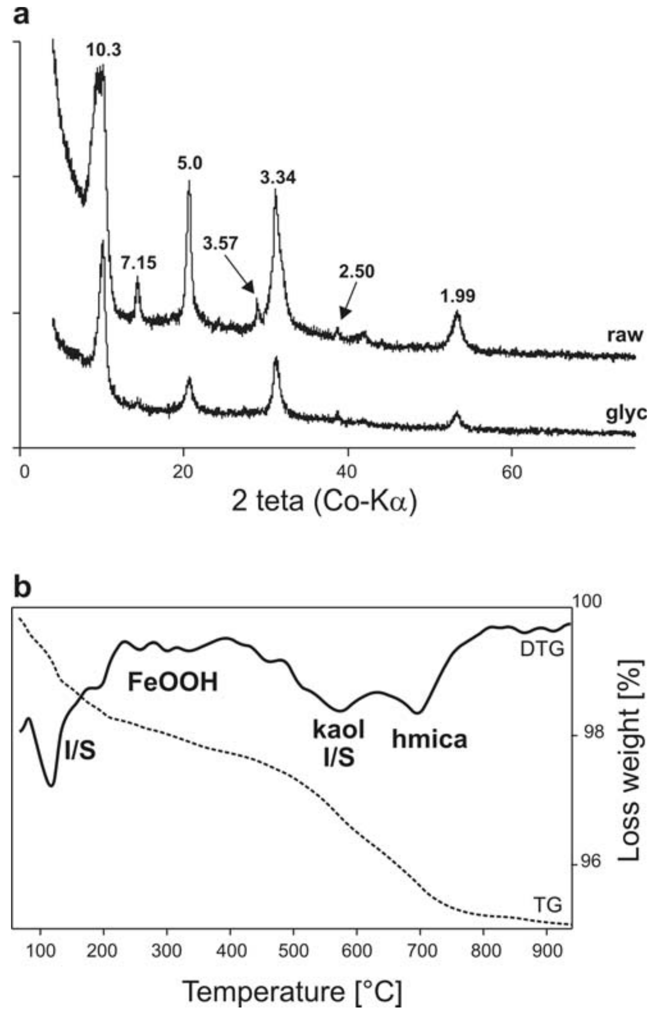

Fig. 9. The XRD (a) and thermal DTG and TG (b) plots of the regolith (Kudowa Górna profile, fraction > 5 μm); abbreviations: a – raw = raw sample, glyc = after glycol; b – FeOOH = Fe oxide/hydroxide, I/S = illite/smectite, hmica = hydromica, kaol = kaolinite.

having a dip of 30°. The calculated true thickness of the profile is approximately 16 m (Fig. 8).

No features indicative of the presence of a fault surface were observed anywhere in the exposed profile. The boundary between the consolidated and unconsolidated granite is irregular and gradual. Its general orientation after the rotation of the beds to a horizontal position is 225/14 (Fig. 8). The base of the Rotliegendes deposits can be assessed using textural criterion: it is marked by the occurrence of material other than granitic and by an increase in grain roundness. The orientation of the base of the Rotliegendes, after the rotation of the profile, is estimated to be 225/7 (Fig. 8).

MINERALOGY OF THE REGOLITH

Beginning from the lower part of the section, the granite that occurs at the base of the regolith shows a characteristic purple-brown colour. It is compact and, despite strong fracturing, rather weakly chemically altered. K-feldspars are not altered, and the biotite also shows no evidence of any chemical alteration. XRD and thermal analyses indicate the presence of kaolinite and mixed-layer I/S type mineral (Fig. 9). Such an altered granite formed at the level of more weathered rock (**saprock** *sensu* Velde, 1991) than the **saprolite** *sensu* Delvigne (1998) and Velde (*op. cit.*).

The higher part of the regolith from Kudowa Górna (Fig. 8) developed in the granite as a typical saprolite (*sensu* Delvigne, *op. cit.*, and Velde, *op. cit.*) or **grus** *sensu* Migoń & Lidmar-Bergstrom (2001). It predominantly consists of quartz-K-feldspar aggregates and microaggregates, often surrounded by thin layers of post-biotite and post-plagioclase fine platy minerals. There is no unaltered plagioclase in the aggregates.

However, XRD analyses of the saprolite indicate a more varied mineral composition with a distinctive predominance of a 10.3 Å mineral (illite-montmorillonite) and 7 Å structure of kaolinite (Fig. 10a).

The thermal analyses (see DTG and TG plots on Fig. 10b) indicate the presence of mineral phases undergoing dehydration at temperatures of 140°C, and dehydroxylation at 350° and 540°–570°, 650°–670°C. These analyses provide evidence of the presence of several clay minerals,

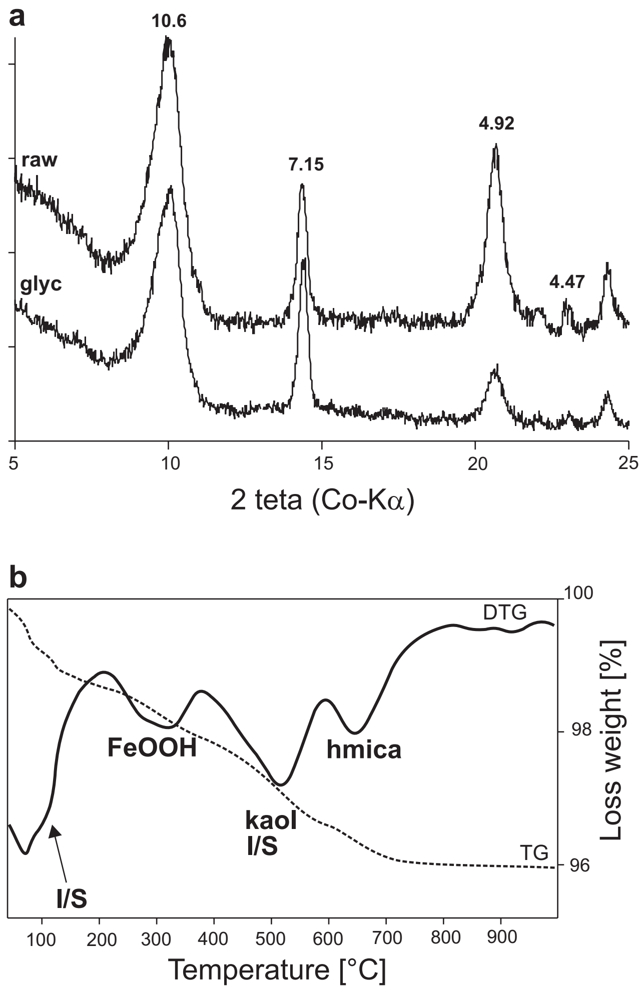

Fig. 10. The XRD (**a**) and thermal DTG and TG (**b**) plots of the saprolite (Kudowa Górna profile, fraction >5 μm); abbreviations as in Fig. 9.

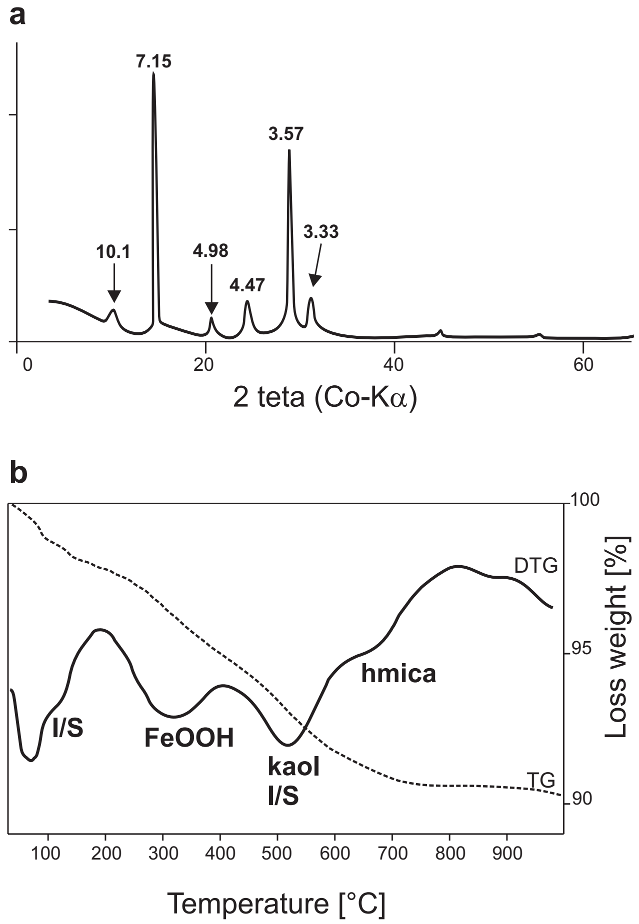

Fig. 11. The XRD and thermal DTG and TG (b) plots of the regolith (Jerzykowice Wielkie near Kudowa Górna, fraction >5 μm); abbreviations as in Fig. 9.

e.g. hydromica, illite-montmorillonite, and kaolinite as the secondary minerals. The TG plots show the dominant content of kaolinite in the clayey fraction.

The composition of the matrix in the Rotliegendes deposits is similar to the composition of the granitic weathering cover lying below – quartz and hydromica predominate. A difference appears in a distinctively greater kaolinite content.

OTHER OCCURRENCES OF REGOLITH

In the northern and north-eastern part of the Kudowa Trough, the Kudowa granite occurring on the surface or underneath Permian or Cretaceous deposits is weathered. Apart from the exposure in Kudowa Górna, the Kudowa granite is most strongly weathered in the zone extending from Pstrążna through Czermna to the area east of Jerzykowice Wielkie (Fig. 2).

A poorly weathered purple-brown or grey granite occurs at Jerzykowice Wielkie. Following the reasoning of Delvigne (1998), this granite could be considered a weathered rock where unmodified structural and textural features were preserved and which shows poorly visible small chemical changes of the main minerals on the macroscopic scale. Its K-feldspar remains unaltered, while its plagioclase is bleached in places. Its biotite plates change into fine-grained flaky aggregates without luster. XRD and thermal analyses show elevated kaolinite contents compared to the saprock/saprolite level from Kudowa Górna (Fig. 11).

The above features make it possible to classify this rock as one altered in an early stage of chemical weathering. Changes of this type are typical of the lower (deeper) part of the weathering profile. However, though it is from the upper level, and is more thoroughly altered compared to the weathered granite from Kudowa Górna. It cannot be ruled out that the higher kaolinite content indicates weathering in conditions different from those documented by the section from Kudowa Górna, despite the structural and textural features of this rock not distinguishing it in any specific way.

A granite with unmodified primary structure and texture occurs at Czermna. Its K-feldspar is unaltered but its plagioclase shows slight alteration. Similarly, its biotite

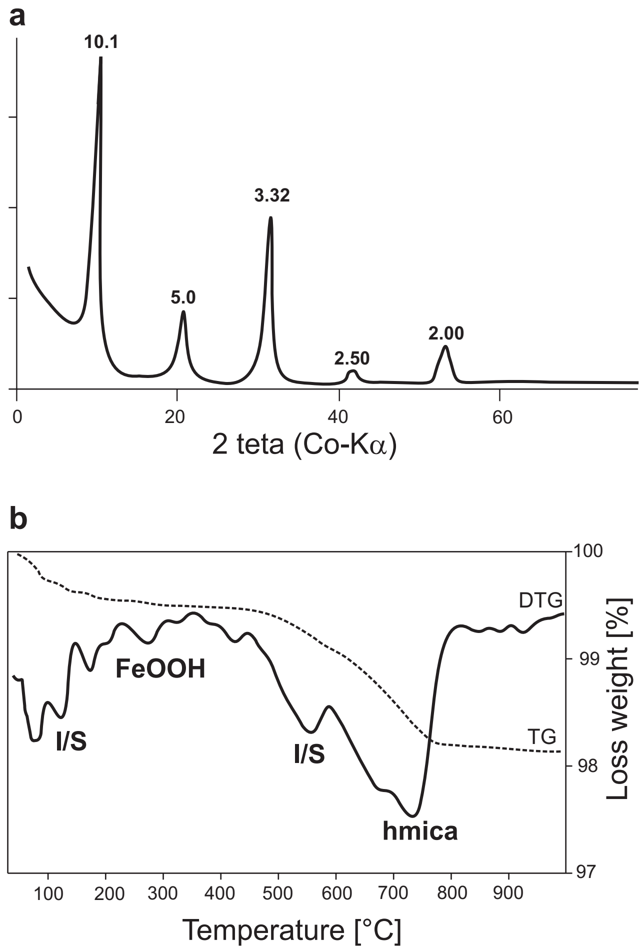

Fig. 12. The XRD and thermal DTG and TG (b) plots of the regolith (Czermna, fraction >5 μm); abbreviations as in Fig. 9.

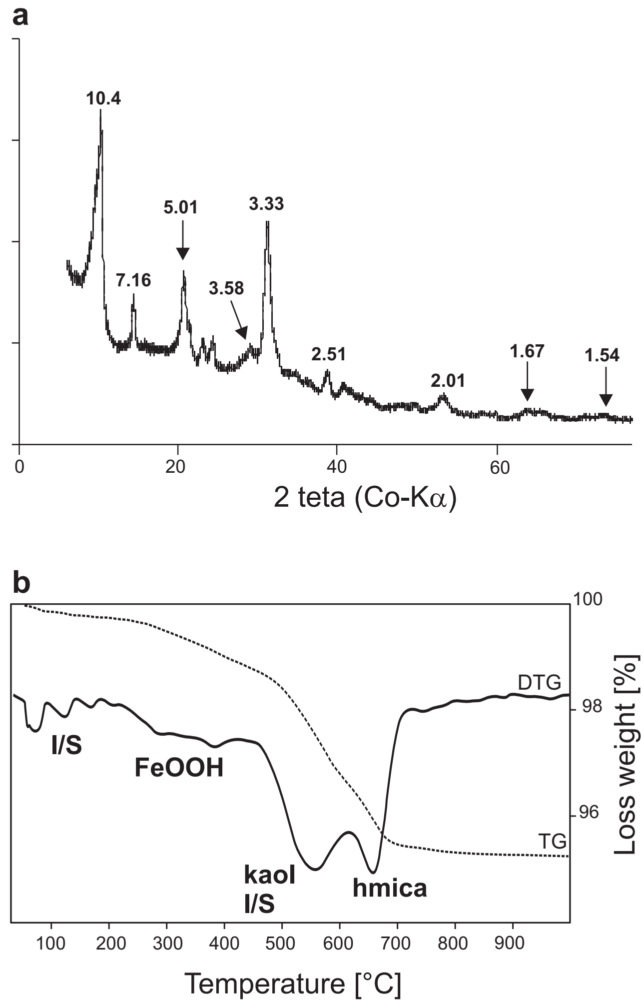

Fig. 13 The XRD and thermal DTG and TG (b) plots of Carboniferous sediment (Pstrążna, fraction >5 μm); abbreviations as in Fig. 9.

changed colour to dark green and lost its luster. XRD and thermal analyses indicate the presence of hydromicaceous minerals (Fig. 12). Therefore, it is a poorly weathered granite from the level adjacent to saprolite. Saprolite, or rather alterite *sensu* Delvigne (1998), should show disaggregation of rock but with the preservation of the primary granite fabric.

SEDIMENTARY OVERLAY ABOVE SOILS

THE CARBONIFEROUS

The oldest non-metamorphosed and palaeontologically evidenced deposits directly overlying the Kudowa granitoids or their metamorphic mantle occur in Ždárky (Czech Republic) near the border with Poland. These are variably-grained clastic deposits containing coal interlayers, which at the beginning of the 20th century were referred to as the Žaclerskie Beds of Westphalian age (***Schatzlarer Schichten*** *sensu* Petrascheck (1905, 1922, 1923) and Berg (1925) or ***žacléřské vrstvy*** *sensu* Nemejc (1933) and Hynie (1949). Gierwielaniec (1965), based on the lithological similarity to deposits occurring in Poland in the vicinity of Pstrążna and north of Jakubowice and Darnków, also classified them as Westphalian.

The age of those deposits was narrowed down in subsequent studies (Nemejc, 1953, 1958; Tásler *et al.*, 1979). In a review work by Tásler *et al.* (1979), the authors divided the Westphalian into ***žacléřské vrstvy*** in the vicinity of Ždárky-Pstrążna and ***petrovické vrstvy*** north of Hronov, and called them Westphalian B and C, respectively.

On the synthetic lithotectonic profile of the Polish part of the Intrasudetic Basin (Nemec *et al.*, 1979), equivalent deposits under the topmost part of the Žacleř Formation were classified Westphalian B; the authors classified the overlying deposits of the Glinik Formation Westphalian C, and did not distinguish Westphalian D in the proposed profile. In studies dedicated to palaeogeographical reconstructions of the Intrasudetic Basin (e.g. Mastalerz *et al.*, 1993; Bossowski & Ihnatowicz, 1994a, b), these deposits were interpreted as the upper part of the Žacleř Formation (Westphalian B-C). One can conclude that the most probable time span in which the oldest non-metamorphosed deposits directly overlying the Kudowa granite or its mantle rocks were formed was between 308 and 313 Ma.

It must be emphasized that pebbles of intensely weathered granite first occur in the top of an over 60-m thick series of deposits (***dolsko-ždárecke vrstvy***) in which they constitute a characteristic horizon of "granite-quartz conglomerate" (*hronovske slepence*, according to Czech authors), which was called "*okruchowiec*" by Gierwielaniec (1965). Underneath, pebbles of metamorphic rocks and quartz are dominant in the conglomerates. Therefore, the onset of the direct weathering of the granitic basement must have occurred closer to the upper limits of the sedimentation time span, i.e. about 308 Ma.

Additionally, it must be emphasized that the Westphalian deposits do not show evidence of any epigenetic transformation (no altered mica or feldspar, the presence of carbonaceous flora remnants), and that they lie directly over unweathered basement rocks – mica schists (in the vicinity of Pstrążna) or amphibolites and partial granite (the area north of Jakubowice and Darnków) (compare: Żelaźniewicz, 1977b) (see mineralogical data at the end of the chapter). This means that if any weathering soil was created in those places, it had to happen before 308 Ma or perhaps even before 313 Ma, as indicated by some well-evidenced occurrences of ***dolsko-ždárecke vrstvy*** (Westphalian B) that directly overlie "palaeo-, residual- or re-deposited soils over crystalline basement" (p. 36, Tásler *et al.*, 1979).

There is much evidence to indicate that such a soil cover could have formed over a rising and subsequently denudated massif related to the intrusion of the Kudowa granite. Part of the Žacleř Formation (Westphalian B according to Nemec *et al.* (1979), Westphalian A-B according to Tásler *et al.* (1979)) forms an upwards grain-fining sequence (Nemec *et al.*, 1979). The sequence additionally shows an increase in the degree of stratigraphic condensation up the profile (Tásler *et al.*, 1979; Bossowski & Ihnatowicz, 1994). These are typical features of cyclothems related to denudational cycles of landscape development. In the terminal phase of these cycles, if the climatic and hydrogeological conditions are favourable, residual soil covers may develop (compare Taylor & Eggleton, 2001).

Assuming such a scheme of evolution for the area in question, the probable onset of the rise (or period of rise) should be deemed as synchronous with the beginning of development of the Žacleř Formation megacycle, which took place at the termination of Westphalian A, i.e. 313–315 Ma. This was a period in which the sedimentation of the ***lampertické vrstvy*** accompanied the denudation of the risen massif (Tásler *et al.*, 1979). The development of the soil cover and its erosion coincided with a period of sedimentation of the ***dolsko-ždárecke vrstvy***, i.e. between 308 and 313 Ma. From about 311 Ma, the erosion was more intense; the development of the topmost part of the Žacleř Formation (***petrovické vrstvy***, according to Tásler *et al.*, 1979) was its effect, and a new denudation-depositional cycle was thus initiated.

PETROGRAPHY OF THE CARBONIFEROUS DEPOSITS FROM PSTRĄŻNA

Sample 1. It consists of quartz conglomerate of beige-grey colour, strongly lithified, with a mineral composition distinctively akin to granite. The rock shows features of a very poorly sorted material. The main components are quartz grains ranging from 5 to 30 millimetres in size. Fine mica flakes and white clayey cement are clearly distinguished in the matrix. XRD and thermal phase analyses (Fig. 13) definitely stress the presence of a clay mineral from the mica, I/S and kaolinite group.

Sample 2. This is a fine grained, purple-brown coloured sandstone. The mineral composition is akin to a granitic material (quartz, feldspars, biotite, haematite). Fine biotite plates show significant changes manifested by the loss of luster and colour change from black to dark green. In the light of phase analyses, this sample contains chlorite, hydromica and a small amount of kaolinite.

Sample 3. It is a light grey conglomerate with a brown pigment, poorly sorted, largely composed of very poorly rounded quartz grains ranging from a few to 20 millimetres in diameter. The colour of the rock is purple-brown in another part. The fine-grained matrix contains, among others, quartz and feldspars, and there is not too much cement. XRD and thermal analyses show the presence of a micaceous mineral and rather significant content of kaolinite. It is a sedimentary rock which could have originated due to the redeposition of a granitic saprolite similar to that described from the vicinities of Kudowa Górna, Jerzykowice Wielkie and Czermna (compare Fig. 10, 11 and 12).

Sample 4. It consists of fine-grained and equigranular quartz sandstone containing a hydromica and kaolinite in the position of a cement. The material for this rock could have but did not have to originate from a granitic saprolite.

THE PERMIAN

The Permian deposits in the area of the Kudowa Trough, by comparison to the area of the Intrasudetic Basin, are classified under the upper part of the Rotliegend – the Saxonian (Petrascheck, 1934; Dziedzic, 1957; Gierwielaniec, 1965). Their textural and structural features, and the presence of distinct horizons enriched in calcium carbonate (caliche), make it possible to correlate them with the uppermost part of the Lower Permian found in the vicinity of Radków, i.e. with the Conglomerate from Wambierzyce (see Śliwiński, 1984). As for the age of those deposits, it is only possible to say that they are younger than 268 Ma. The thickness of Permian deposits in the area of the Kudowa Trough does not exceed 2000 m.

It should be pointed out that Gierwielaniec (1965) already indicated that the deposits regarded as Rotliegendes represent two facial varieties. One, which has a broader extent, is represented by coarse-grained conglomerates and sandstones of pinkish to brown colour, layered, and consisting dominantly of feldspar and granite (40–50%), quartz (up to 30%) and clasts of metamorphic rocks (up to 30%). The other lithological type occurs locally between Kudowa Górna and Dańczów, and it consists of angular clasts of the Kudowa granite and mica schists and additionally "the pebbles are lithified with a rich clay-kaoline cement, locally impregnated with iron hydroxides" (Gierwielaniec, 1965). The latter description is analogous to the above-described part of the regolith profile from Kudowa Górna.

THE CRETACEOUS

The Cretaceous within the Kudowa Trough fills a tectonic depression of the same name, and occurs in patches around the Trough's margins (Fig. 2). The age of the oldest Cretaceous deposits has not been precisely determined. Originally classified under the Middle Cenomanian (Michael, 1893; Gierwielaniec, 1965) conglomerate and calcareous sandstone from Kudowa, the shell conglomerate and siliceous-calcareous sandstone from Jakubowice appear to have a limited extent, grading sideward into glauconite sandstones containing *Actinocamax Plenus* (Upper Cenomanian) and upward into sandstones and mudstones with *I. labiatus* (Lower Touronian). The main portion of the deposits in the area of the Kudowa Trough is made up of calcareous mudstones of the Middle Touronian (*I. lamarcki*), the thickness of which is almost 500 m in the deepest part of the depression. Thus, it can be assumed that the Cretaceous deposits are not older than ca. 98 Ma.

In the area in question, one of the oldest counterparts of the Upper Cenomanian, always occurs directly upon the Kudowa granite. The lowermost deposits almost always contain intensely weathered constituents of the basement, particularly clasts of granite and kaolinitized feldspar (see Gierwielaniec, 1956; Gierwielaniec & Turnau-Morawska, 1965). In places where the intensity of weathering was weaker, the deposits usually contain more calcareous cement.

THE AGE OF THE SOILS: DISCUSSION

Soils developed from crystalline rocks of the Kudowa Granitoid Massif either outcrop directly on the surface (e.g. in the area of Jakubowice) or occur under deposits of different age, which was evidenced both in boreholes and via geological surveying (Fig. 1). In the vicinity of Czermna and east of Jerzykowice Wielkie, granitic soils occur under Cretaceous deposits (Upper Cretaceous, Cenomanian). In Kudowa Górna and Jerzykowice Wielkie, they are overlain by the topmost Rotliegendes deposits (Lower Permian, Saxonian). In Pstrążna and north of Jakubowice and Darnków, soils over amphibolites occur underneath the Žacleř Formation (Upper Carboniferous, Westphalian B-C). In each case, the soils can be classified under one or several zones typical of a regolith profile *sensu* Taylor & Eggleton (2001).

Had it been certain that the soils constitute relics of a solid soil cover developed over the whole area synchronously, the age interpretation for individual occurrences would have been relatively straightforward. The upper age limit would have been determined by the oldest unweathered deposits which overlie the soil, and the lower age limit would have been bound by the age of the source rock for the soil. The above results clearly show that soils which are not overlain by deposits could have formed at any time after the development of the source rock; thus, in order to univocally establish their age, one should refer to other implications or to radiometric age.

As for the weathered granite overlain by unweathered Cretaceous deposits (Czermna, vicinity of Jerzykowice Wielkie), it is known that the soil cannot be younger than 95 Ma because this is the approximate age of the so-called calcareous sandstones of Upper Cenomanian age, which mark the beginning of the transgressive profile of the Cretaceous almost in the whole area of the Kudowa Trough. The uneven boundary and poor roundness of the material constituting the calcareous sandstone may indicate both relatively fast inundation of the ground surface and remarkable lithification of soils which covered the area. It must be pointed out that before the development of the Kudowa Trough in the Quaternary (*cf.* Don & Wojewoda, 2005), Cretaceous deposits formed continuous cover in this region. Thus, at present, in every place where the soils grade sideward from underneath Cretaceous deposits to soils outcropping directly on the surface, pre-Cretaceous is the most likely age of their formation.

The issue of the age of the weathered granite overlain by Rotliegendes deposits in Kudowa Górna and Jerzykowice Wielkie is more complicated, primarily because the Rotliegendes deposits display effects of intense weathering, and therefore it is possible that the basement weathered together with the overlying deposits, after the sediment deposition. In that situation, the uppermost age of the soil is bounded by the non-weathered Cretaceous deposits occurring above the Rotliegendes. However, in such a case, the record of the weathering processes in the basement and the sedimentary cover should be the same. What is more, hydrogeological and climatic conditions favouring this particular type of weathering should potentially occur in the period between the deposition of the Rotliegendes and the Cretaceous transgression.

In every place where non-weathered deposits of Upper Carboniferous age occur above crystalline rocks' soil, we can conclude with certainty that the soil is older than those deposits and younger than the rocks from which it developed. Summing up, the "undoubted" events can be put into the following order:

– the intrusion of the Kudowa granite (342–320 Ma)

– the rise and denudation (erosion) of the metamorphic mantle of the Kudowa Massif (before 313 Ma) (Westphalian A)

– chemical weathering, the erosion of soils and sedimentation (313–311 Ma) (Westphalian B-C)

– the erosion of soils and of the basement, physical weathering, and sedimentation (299–268 Ma) (Saxonian)

– the erosion of soils and of the basement, sedimentation (98–85 (?) Ma) (Cenomanian–Santonian).

Less convincingly evidenced events, although probable because of the regional context, include chemical weathering of outcropping Sudetic rocks, which occurred prior to the marine transgression in the Late Cenomanian, but after the deposition of the Rotliegendes. This time span equals nearly 200 Ma (268–98 Ma) and includes periods favouring chemical weathering. The conditions prevailing over the area of the Sudetes in the Saxonian, i.e. a dry climate, high insolation, intense physical weathering and the short-lasting, ephemeral deposition of sediments (see Lützner, 1988; Wojewoda & Mastalerz, 1989) rule out deep chemical weathering at that time. However, at time of the marine transgression, a major part of the present day Sudetes had to be relatively level and covered with residual kaolin soils, including soils developed over Permian and Triassic deposits (Żuk, 2002). This is evidenced by features including the rapidity of the transgression, the almost identical profiles of the Cenomanian, and the lack of any littoral facies of this age in the Sudetes (see Wojewoda, 1997; Don & Wojewoda, 2005). It is additionally evidenced by the lithology of the younger deposits – the sandstone-clay megacyclothems of the Touronian and Coniacian must have formed from analogous material which was available on the land surrounding the Cretaceous basin (Wojewoda, 1986, 1997 and 2003). This opinion is also shared by other researchers studying the Cretaceous in the Sudetes and in the neighbouring areas (e.g. Skoček & Valečka, 1983; Störr, 1983).

The early Cretaceous (documented by kaolin soils in the Bohemian Massif) but also the Late Jurassic (documented by kaolin soils and *terra rossa* type soils in Moravia) should be considered as the most probable period of soil cover formation in the Sudetes. Also, conditions favouring deep chemical weathering prevailed at these latitudes in the Triassic, which is perfectly documented by the kaolin soils of that age in Scandinavia. An extensive summary of the occurrence and characteristics of soils of different ages in Europe is presented in papers by Migoń & Lidmar-Bergström (2001, 2002).

SUMMARY AND CONCLUSIONS

All the specimens described in this paper sampled from soils, i.e. from the regolith in Kudowa Górna and from the basement of the Cretaceous in Jerzykowice Wielkie and Czermna, represent altered Kudowa granite. The affinity is demonstrated by mineral composition and by advanced cataclasis.

Every analysed sample of the granite displays a similar degree of mineral alteration under weathering conditions. Assuming the division of the weathering profile according to Delvigne (1998), they constitute granitic soil, fractured, yet preserving original structure and texture, in which some of the fissures are filled with secondary clastic material (e.g. the sample from Jerzykowice Wielkie). The density of the fracturing could not be high at the time of their development, as no intense chemical alteration is visible in the fragments of the weathered granite. It is not possible to rule out that the observed consolidation of the soil is the effect of later lithification of the rock, which previously, during weathering, reached a saprolite stage, being a material in a state of disaggregation *sensu* Delvigne (1998), despite the fact that the degree of alteration of particular constituents could not have differed much from its present day form. It should be pointed out that similar observations were made by Żuk (2002), who pointed to secondary lithification of the saprolite profile on the Różana Pass, which had developed on Triassic sandstones directly under Cretaceous deposit cover.

The alteration of primary components appears as illitization and kaolinitization of plagioclase and alteration of biotite, reaching into the hydromica and I/S (10.3 Å) formation stage. Such phenomena are observed in weathering profiles originating in conditions of a limited water supply into the rock and a lack of organic components in the solutions penetrating the rock (not very low pH) (e.g. Wilson, 2004). In turn, the presence of kaolinite may indicate a more intense alteration developed locally in plagioclase. This process could have taken place during another, later stage of weathering.

The sedimentary rocks from the Carboniferous of Pstrążna also show similarities to the mineral composition of the Kudowa granite. This similarity is marked by the presence of red-coloured K-feldspar, plagioclase and biotite which, together with quartz, are also the main components of the granite. This is also evidenced by the similarity of the mineral composition in the conglomeratic lithologies, including the presence of hydromica, and the presence of biotite plates, locally altered into iron hydroxides, in the sandstone. A characteristic feature is the common presence of haematite, found both in the K-feldspar in the granitoid, and staining the weathered granite and deposits that overlie it.

The reconstruction of conditions in which the described soils over the Kudowa granite developed can not be univocal. Assuming that the studied material represents the whole profile of a regolith, it should be concluded that they could have formed in a moderate, not very humid climate, with limited vegetation (Velde, 1991). Such conditions could prevail in the transitional period between the Carboniferous and the Permian.

However, assuming that we can see only a part of the original profile of the weathering cover, which was previously much thicker, it is possible to accept with high probability that we may be dealing only with the lowermost section, which gradually passes downward into unweathered granite. In this case, it can be inferred that such a weathering cover could have developed in a humid and warm climate, such as that which prevailed in the Upper Carboniferous (see Górecka-Nowak, 1995, 2002).

Although the soil in Kudowa Górna occurs above the strongly tectonically engaged granite (cataclasite), the transition between granite, soil and Rotliegendes deposits is gradual and under no circumstances can it be regarded as a tectonic fault boundary. Such a transition rather implies that the soils overlie faults of Carboniferous age (or older), some of which were later reactivated. The reactivation of faults accompanying the sedimentation of the Permian deposits or those beneath the Cretaceous deposit cover is demonstrated only by flexural deflection and steepening of layers (e.g. Czermna-Dańczów Flexure *sensu* Gierwielaniec, 1965).

Our data shows that the Kudowa section of the northern tectonic border of the Kudowa Trough was not significantly reactivated between the Late Carboniferous and the Late Cretaceous. It means that the studied border cannot constitute the segment which would join the Pořici-Hronov Fault Zone in the west with the so-called Zieleniec Thrust in the south-east (see Fig. 1). The interpretation assuming the continuation of the PHFZ to ZT (Cymerman, 1996, 2004) is thus not confirmed, which also casts doubts on the real existence of the alleged "Zieleniec Thrust" that has not been observed by other authors.

Acknowledgments

The authors are grateful to Prof. Piotr Migoń (Wrocław University), Prof. Andrzej Wiewióra (a reviewer), Prof. Andrzej Żelaźniewicz (Polish Academy of Sciences) and Prof. Ryszard Kryza (Wrocław University) for kind remarks and comments which helped in preparation and improvement of this paper.

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