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LITHOLOGICAL CONDITIONING OF LANDSLIDES AND CLIMATIC CHANGES WITH EXAMPLES FROM THE BESKIDY MTS., WESTERN CARPATHIANS, POLAND

ABSTRACT: WÓJCIK A., MROZEK T & GRANOSZEWSKI W., *Lithological conditioning of landslides and climatic changes with examples from the Beskidy Mts., Western Carpathians, Poland*. (IT ISSN 1724-4757, 2006).

The paper presents the results of geomorphological, geological and palynological investigations carried out in the area of Szymbark and Koszarawa, Beskid Niski and Beskid Żywiecki Mts., respectively (Western Carpathians, Poland). The examined sites, although located relatively far apart, represent the parts of the Polish Flysch Carpathians, where landslides affect the landscape pattern and cause damages to land resources, properties and people dwelling there.

This study is based on a comparative approach regarding the lithological setting (the same lithostratigraphic unit present in both sites), types of inventoried landslides and climatic triggers. The relation between particular rock complexes and climate control on landslide development is discussed. Lithologic and tectonic controls are very important in the Beskid Niski region, where distribution of landslides corresponds with a pattern of weak shales series and fault zones. In the Beskid Żywiecki region, the sequence of particular rock series, especially thin shales underlying massive sandstones, is more critical for mass movements. Landslides with complex style of activity predominate in these regions and, very likely, they contribute to slope transformation at present.

In particular, the investigations focused on the flow-like landslide form at Maślana Góra Mt. (Beskid Niski Mts.). This form is the outstanding feature due to its size. Moreover, it well illustrates the environmental changes that are related to wet climate, and exemplifies landscape sensitivity.

Organic sediments filling up two landslide depressions at Maślana Góra Mt. were ^{14}C dated and palinologically analysed. The older depression was formed at the transition of Subboreal to Subatlantic, that coincided with maximum distribution of *Abies alba* in the area. Time of formation of the younger depression, dated at ca. 1500 yrs BP, is related to the increase of fluvial activity in the Upper Vistula basin.

KEY WORDS: Landslides, Flysch, Pollen analysis, Holocene, the Carpathians.

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Questo lavoro presenta i risultati di studi geomorfologici, geologici e pollinici che sono stati condotti nelle aree di Szymbark e Koszarawa, rispettivamente nelle montagne di Beskid Niski e Beskid Żywiecki Mts. (Carpazi occidentali, Polonia). I siti che sono stati analizzati si trovano nei Carpazi della Polonia, dove numerosi fenomeni franosi si sviluppano in particolare nelle aree dove affiorano ammassi rocciosi flyschoidi, causando danni al territorio, alle attività e alla popolazione.

Lo studio si basa sull'analisi comparativa delle caratteristiche litologiche (le stesse unità litostratigrafiche affiorano nelle due aree), della tipologia delle frane rilevate e delle cause innescanti climatiche. Vengono trattate le relazioni tra specifici ammassi rocciosi e il controllo climatico nella evoluzione di fenomeni franosi. Il controllo della litologia e della tettonica sono molto importanti nella regione di Beskid Niski, dove la distribuzione dei corpi di frana corrisponde all'affioramento di unità argillitiche deboli e zone di faglia.

Nella regione di Beskid Żywiecki, la presenza di particolari sequenze litologiche, in modo particolare di argilliti fini che sovrastano arenarie compatte, è particolarmente critica per lo sviluppo di fenomeni franosi. In questa regione sono predominanti fenomeni franosi con stile di attività complesso, che anche attualmente contribuiscono alla evoluzione dei versanti.

In particolare, lo studio si è concentrato su una frana di colata nell'area di M. Maślana Góra (M. Beskid Niski). Questa forma è caratteristica, soprattutto per le sue dimensioni. Inoltre, fornisce importanti dati sui cambiamenti ambientali, in particolare quelli relative a climi umidi ed è un esempio di sensibilità del paesaggio.

I sedimenti ricchi di materia organica che riempiono due depressioni nel corpo di frana di Maślana Góra sono state datate con il ^{14}C e sottoposte ad analisi polliniche. La depressione più antica si è formata in corrispondenza della transizione tra Subboreale e Subatlantico, che coincide con la massima espansione di *Abies alba* nell'area. La seconda depressione, datata a circa 1500 anni BP, si è invece sviluppata in corrispondenza di una fase di intensa attività fluviale nell'alto bacino della Vistola.

TERMINI CHIAVE: Frane, Flysch, Analisi pollinica, Olocene, Carpazi.

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INTRODUCTION

Although the Polish Flysch Carpathians amount only to 6% of the country area, the region is very prone to landsliding as over 90% of all forms of mass movements recorded in Poland are concentrated here. The Carpathian landslides can be described, in majority, as rotational slumps and/or slides of rock-earth masses. Usually, they belong to slow mass movements, yet they bring about substantial damages to land resources, housing, transportation routes and infrastructure.

Changes in the landscape depend on geological setting, geomorphological processes and climatic changes (Brunsden, 2001; Harvey, 2001; Usher, 2001). Mass movements exemplify well a coupling between the interplay of these processes and the resultant landscape. The mass movement driven significant changes in the relief of the Carpathian regions led to a specific landform pattern called «landslide landscape» (Starkel, 1972).

These relict landforms, inherited from the different environmental conditions of the Late Pleistocene and Holocene, are sometimes difficult to recognise, yet they set preparatory conditions for currently acting controls which, in turn, reshape differently sensitive landscapes.

The focus is on the two study areas located in the Polish Western Carpathians (fig. 1). A marginal zone of the Beskid Niski Mts., in the vicinity of Szymbark (fig. 1A), is characterised by active mass movements. The detail studies concentrated on the catchment of Bystrzanka and Biczyska streams (17.5 km^2), where 348 landslides of various sizes, occupying ca. 30% of slope area, have been recognized. This region has been subject of interest since the beginning of the 20th century. One of the first landslides characterised in detail is the one that re-activated at the southern slopes of Maślana Góra Mt. (fig. 1A) at the beginning of the former century and named after Sawicki (1917). Other landslides of this region have been examined by Kotarba (1970, 1986). The strong relationship between rainfall and dynamics of colluvium masses is pointed out by Sawicki (1917), Gil (1994, 1996), Gil & Kotarba (1977), Gil & Starkel (1979), Thiel (1989), Rączkowski & Mrozek (2002), Starkel (1996, 2003). A feedback between the landslide development and the Ropa river activity has been studied by Dauksza & Kotarba (1973). The only landslide in Szymbark region, which has been ^{14}C and palynologically dated until now, is reported by Gil & *alii* (1974).

For the purpose of comparison, the results of the investigations performed in the region with similar geological structure, namely the Koszarawa drainage basin, Beskid Żywiecki Mts., in the western section of the Carpathians (fig. 1B), have been used. In the Koszarawa catchment (245 km^2) the total of 475 registered landslides occupies ca. 16% of the slope area.

The problem of landslide conditioning and climate changes as the controls that drive landscape changes are the objectives of this paper.

METHODS

In both regions the inventory of landslides has been performed based on field surveying, analyses of air photographs and archive materials. Morphometric parameters of the landslides originate from the geomorphological and geological mapping. The landslides identified in both the regions are landslides with complex style of activity (complex landslides) and debris/earth flows (fig. 1A, fig. 1B), according to Cruden & Varnes (1996) classification. As a number of boreholes and available cores were limited, rock series, their arrangement and thickness have been also assessed inferring from natural outcrops and erosional incisions of the streams.

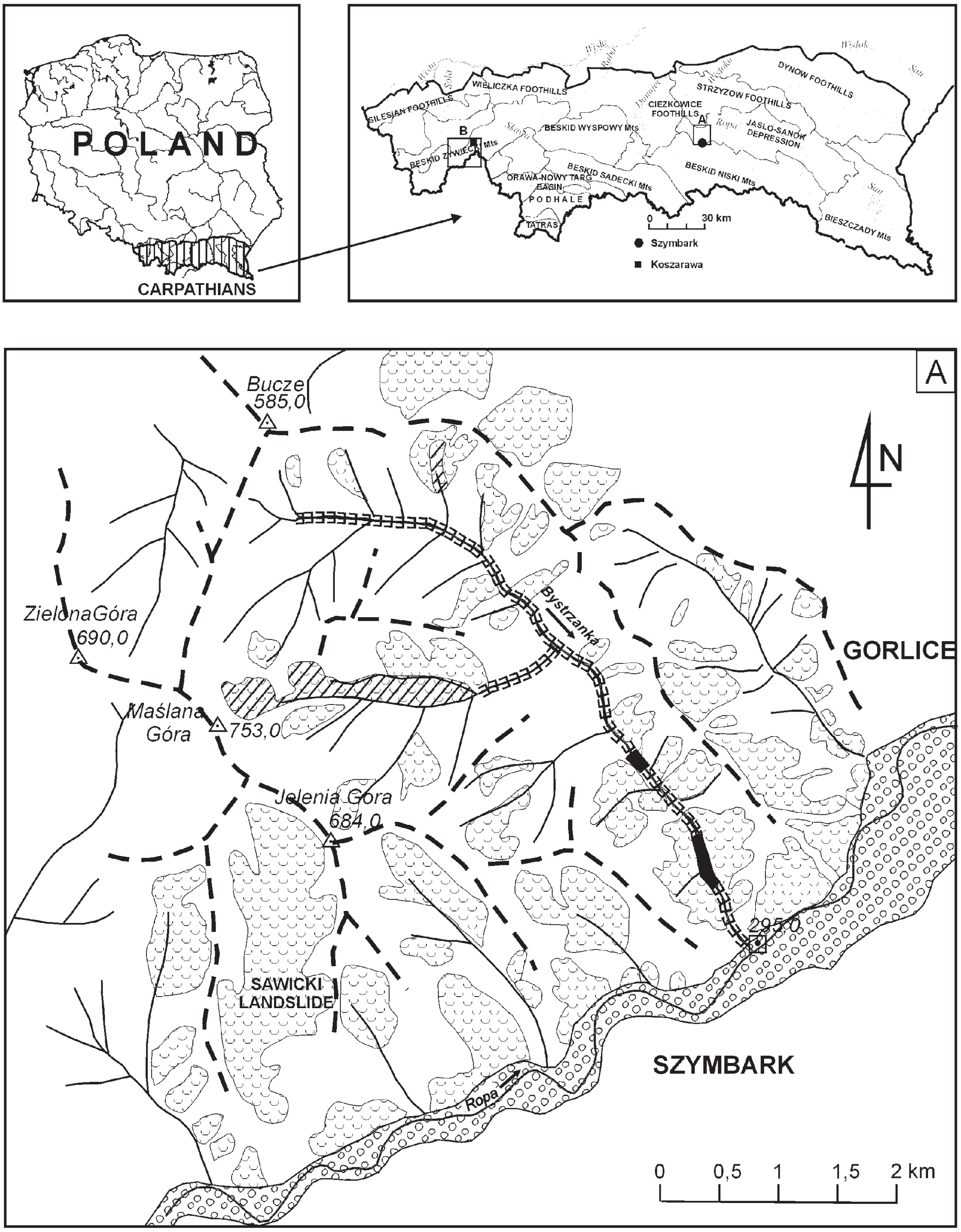
Pollen analysis and AMS ^{14}C datings served to assess the age of landslides and climatic changes. Two sediment cores were taken using «Eijkelkamp» peat sampler. Preparation of the samples (1 cm^3) for pollen analysis followed the standard method (Faegri & Iversen, 1989). Separation of minerogenic particles was performed by means of dense-media separation method ($ZnCl_2$; 1.88 g/cm^3) according to Nakagawa & *alii* (1998). To estimate pollen concentration in sediments, *Lycopodium* tablets were added to each sample prior to maceration (Stockmarr, 1971). The pollen diagrams were plotted using POLPAL program (Walanus & Nalepka, 1999). The basic sum used for percentage calculations consisted of pollen of terrestrial plants. Proportions of local element pollen and spores were calculated in relation to this sum.

AMS radiocarbon datings were carried out mainly on plant macrofossils and were performed at the Radiocarbon Laboratory in Poznań. The conventional ages were calibrated with OxCal v3.9 (Bronk Ramsey, 2001).

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The two study areas are composed of rocks known as the Carpathian flysch, comprising sandstones interbedded with conglomerates, mudstones, siltstones and shales, deposited by turbidity currents in a deep-water marine environment. The rocks are locally accompanied by marls or limestones of turbidity origin as well. Based on the mutual relation between the sandstone and shale rock series the following flysch types are distinguished: the «sandstone flysch» where sandstones predominate over the shales, «normal flysch» where sandstone and shale contents are alike, and the «shale flysch» with predominating shales (Bober & Zabuski, 1993).

The flysch rocks occurring in the two studied areas span in age from the Cretaceous to the Palaeogene. In general, they belong to the same lithostratigraphic unit, built of similarly developed rock series. However, the outcrops of the particular rock series occupy different surface areas in both the studied regions.



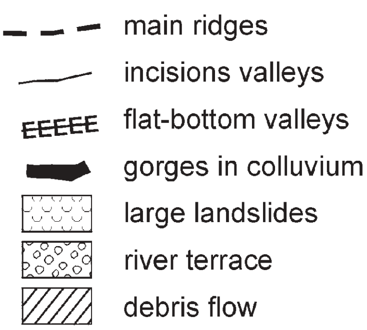


FIG. 1 - Study areas. A - Landslides in the region of Szymbark, the Beskid Niski Mts.

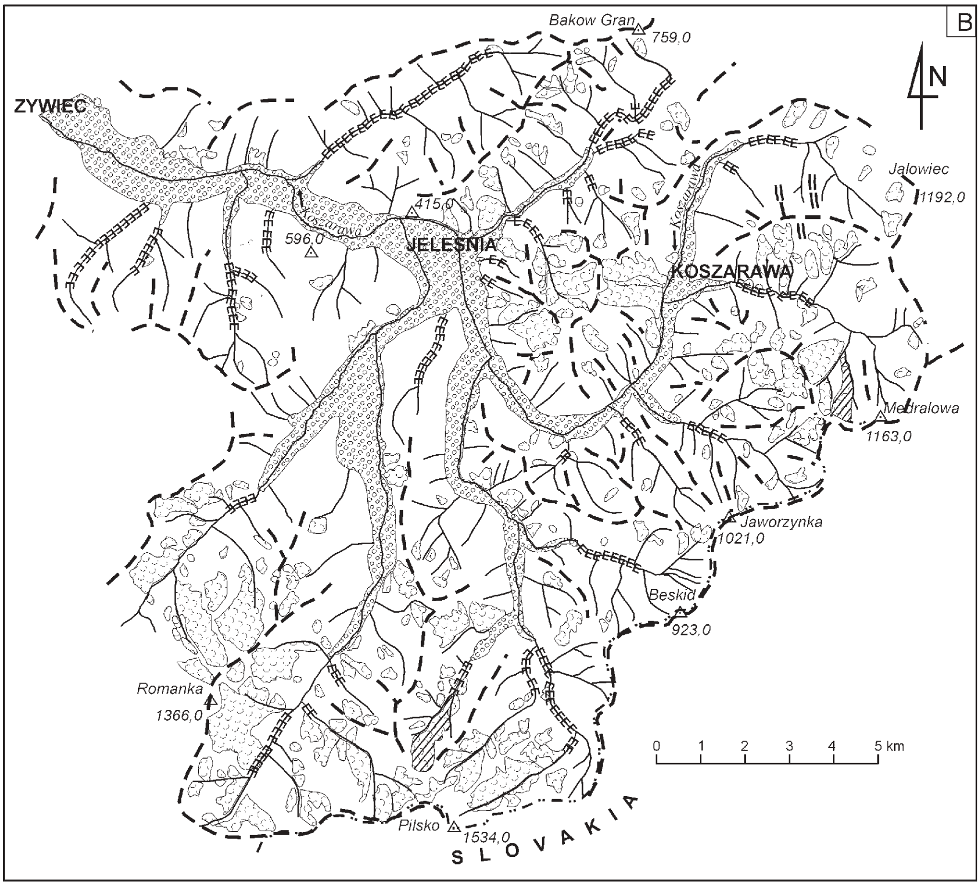


FIG. 1 - Study areas. B - Landslides in the Koszarawa drainage basin, the Beskid Żywiecki Mts.

The major rock series are as follows (fig. 2):

[A] Magura unit:

i *Inoceramian beds* (Senonian-Palaeocene), where sandstones and shales are in similar proportion forming the «normal flysch». In the region of Szymbark they occupy the largest area. In Koszarawa region, the lower face of the Inoceramian beds, is underlain by *variegated shales of Cebula* and *sandstones of Szczawina*, which are lacking in the region of Szymbark.

ii *Sandstones of Jaworzynka, Krzyżowa and Mutne,* forming thicker intercalations, are distinguished at the top of the Inoceramian beds in Koszarawa region where they are considered as separate rock members. On the other hand, in Szymbark region, they cannot be recognized, but thick sandstones occurring near the top of the Inoceramian beds are their counterparts.

iii *Variegated shales* (Palaeocene-Eocene) form clayey-shale flysch and occur above the Inoceramian Beds. In this member the lower and upper variegated shales are separated by Ciężkowice sandstones (Świdziński 1973; Kopciowski, in press).

iv *Ciężkowice sandstones* comprise massive sandstones and conglomerates interbedded with thin inserts of shales, including the variegated ones. They represent more resistant sandstone flysch.

v *Pasierbiec sandstones, hieroglyphic beds and Łącko marls*, often referred to as transitional beds, occur above the variegated shales, and are confined to the region of Koszarawa. They form the so called normal flysch.

vi *Sub-Magura shales* form thick clayey shales series; among which thin-bedded (ca. 10 cm) sandstones may occur. They are similarly developed in both the regions.

vii *Magura sandstones* (sandstone flysch), the youngest rock series, comprising mainly massive sandstones separated by thin layers of shales. They amount to almost 70% in the upper part of the profile.

[B] Silesian unit:

i *Krosno beds* are developed as grey marly shales with infrequent sandstone intercalations. The beds can form here normal and shale flysch.

The flysch sediments of the Carpathians, as a consequence of intense Palaeogene-Neogene orogeny, were folded, and then detached from the underlying bedrock to form several uprooted nappes. The Carpathian nappes are all thrust upon each other and are themselves overthrust in a northerly direction onto the Miocene sediments of the Carpathian foredeep. The Magura nappe is the innermost unit of the Outer Carpathians and its northern part rests

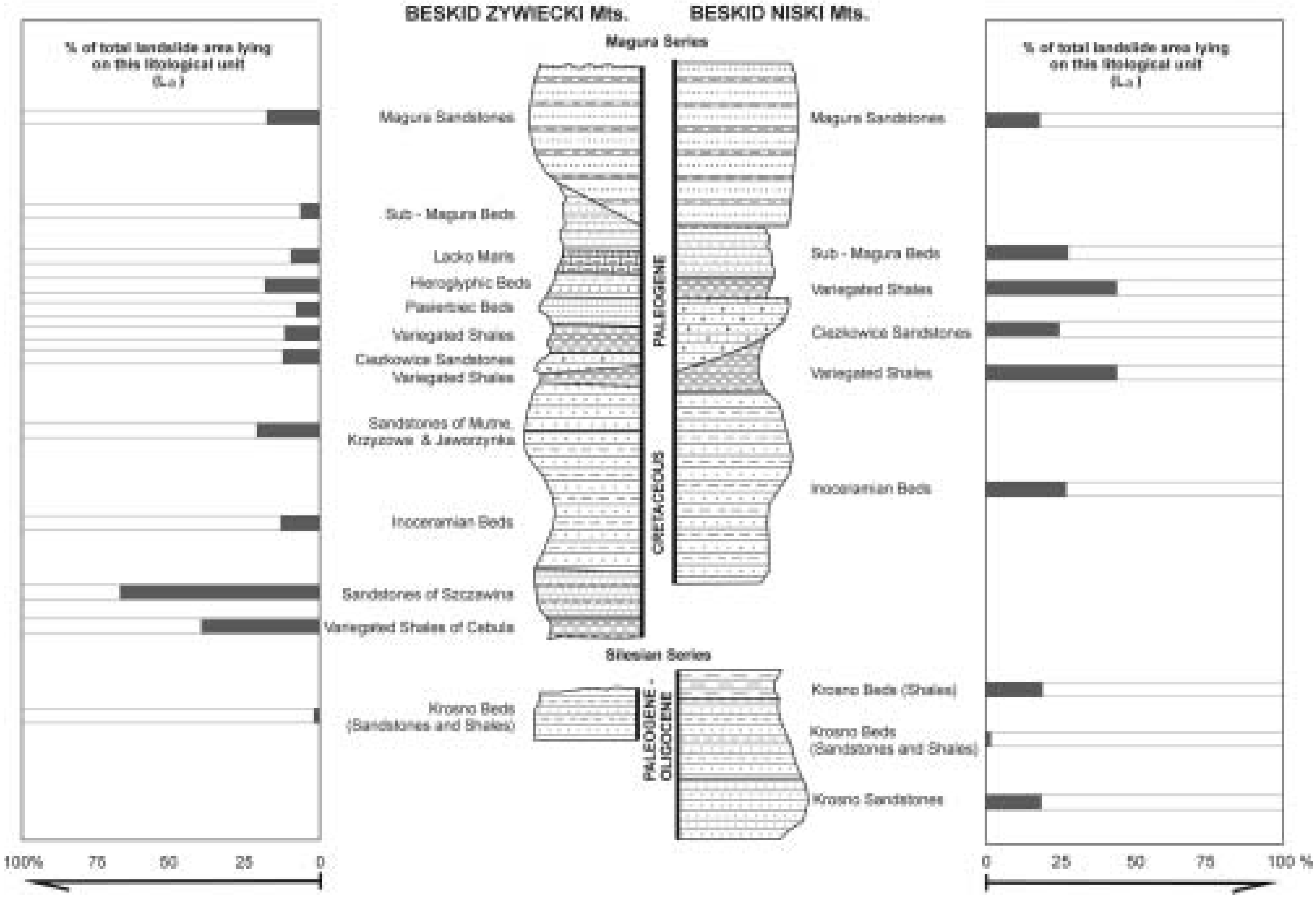


FIG. 2 - Lithostratigraphic profiles of the Beskid Żywiecki Mts. and the Beskid Niski Mts.

either on the Fore-Magura group of nappes or on the Silesian Nappe (Ślączka & Kamiński, 1998).

The sedimentary structures and tectonics are well reflected in the morphology of the two studied regions. In the region of Szymbark, the inverse relief is related to the Magura sandstones. The NW-SE oriented syncline ridge of Maślana Góra - Jelenia Góra (fig. 1A), with the highest summit reaching 753 m a.s.l., forms the upper elevation level. The ridge is dissected by the transverse SW-NE oriented faults. The steep slopes of this ridge are attributed to the massive Magura sandstones which are underlain by the Sub-Magura and variegated shales, and the Inoceramian Beds lying beneath. The second elevation level is formed by lower and relatively flat hills reaching up to 400-550 m a.s.l. In the northern part of this region two scales of the Inoceramian Beds occur and are additionally tectonically controlled due to their proximity to the zone where Magura nappe overthrusts the Silesian nappe. The bottom of river and stream channels are at 290 m to 350 m a.s.l. The floor of the Bystrzanka stream valley is narrow with fragments of young Pleistocene terraces. The tributaries are of erosional nature and dissect alluvial deposits as well as the bedrock. Above the Bystrzanka stream, concave-convex and convex-concave slopes rise. The differences in elevation of the order of 50 m to 300 m, slope gradients of 8° to 35°, and a dense network of small erosional-denudation valleys render the area prone to landsliding.

The second studied region, the Koszarawa catchment (fig. 1B) is developed of the Magura nappe series comprising rocks from the Upper Cretaceous to Oligocene. In general, the rock members occurring here are developed similarly to those in the surroundings of Szymbark (fig. 2). Differences in elevations are much larger, varying from 1557 m a.s.l. at Pilsko summit to 357 m a.s.l. in the lower course of the Koszarawa river valley. In the southern part of this region, numerous mountain ridges separated by deep river valleys are found. This fragment is characterised by the height differences of the order of 600 m to 800 m. The small intra-mountain, tectonically controlled, Jeleśnia basin is found in the middle part of the discussed region. In the northern part the height differences reach up to 250 m.

LANDSLIDES AND THEIR LITHOLOGICAL CONTROL

The landslides in the studied region of Szymbark occur mainly on variegated shales and Inoceramian beds. They cluster principally in the lower part of the Bystrzanka catchment (fig. 1A). These are complex landslides (Dikau & *alii*, 1996), where rock masses moved downslope on numerous failure surfaces. Almost all the landslides inventoried here, or at least their sections, were subjected to rotational or translational movements and rejuvenated many times. The displaced masses included both the hillslope sediment covers and the Carpathian flysch rocks. The landslides which are considered in this study are relatively large and deep, with a thickness of a few to almost 50 metres. They are confined to particular sections of the slopes or stretch over the entire hillside from the ridge crest to the valley bottom. However, the landslides occupying the mid- and downslope sections of the slope profiles predominate.

The landslides in the Koszarawa catchment are developed on the rock series belonging mainly to the Magura nappe and occupy almost 3483 ha, featuring a scattered distribution (fig. 1B). Landslides having a size of 1 ha to 5 ha are the most numerous here, while in the Beskid Niski Mts. those of a size reaching to 1 ha predominate (tab. 1). The above diversification can be attributed to the relief energy, especially to the differences in elevation and the slope lengths. When considering the surface area of the landslides, those exceeding 20 ha are the most extensive in the Koszarawa catchment, while those ranging from 1 ha to 5 ha occupy the largest area in the region of Szymbark. Based on the data compiled in table 1, it can be concluded that the slopes of the Beskid Niski Mts. are mainly modelled by smaller landslides when compared with Koszarawa region. In the region of Szymbark, the landslides prevail on the slopes with gradients of 9° to 13° and similarly in the Koszarawa catchment they are most numerous on the hillslope inclined at 10° to 17° (Wójcik, 1997).

The landslide type, morphology and slid material depend on the bedrock on which these landslides have developed. Taking into account the number of landslide bodies as well as the area they occupy, the landslides developed on the sandstone flysch predominate in the Koszarawa catchment, and among them those developed on the Magura sandstones are the most numerous. This is related to the fact that almost 61% of the catchment area is composed of these rocks.

TABLE 1 - Landslide characteristics

Size interval [ha]	No. of landslides BN	No. of landslides BZ	% of landslides BN	% of landslides BZ	Area of landslides [ha] BN	Area of landslides [ha] BZ	Area of landslides % BN	Area of landslides % BZ
<1	226	139	64.9	29.2	86.20	69.71	16.9	2.0
1-5	103	170	29.6	35.7	229.73	437.41	25.1	12.6
5-10	14	76	4.0	16.4	99.25	536.50	19.4	15.4
10-20	3	55	0.9	11.5	35.47	810.36	7.0	23.2
>20	2	35	0.6	7.3	59.79	1628.79	11.7	46.8
	348	475	100.0	100.0	510.44	3482.77	100.0	100.0

BN - Beskid Niski Mts. - region of Szymbark
BZ - Beskid Żywiecki Mts. - Koszarawa catchment

TABLE 2 - Lithostratigraphic units versus landslide area in the Beskid Niski Mts.

Lithostratigraphic unit	Area of rock series ha	Area of rock series %	Area of landslides ha	Area of landslides %	% of landslide area in the given rock series L_a
Magura Beds	192.22	11.0	37.03	7.3	19.3
Sub-Magura Beds	12.38	0.7	3.54	0.7	28.6
Variegated Shales	285.73	16.4	127.27	24.9	44.5
Ciężkowice Sandstones	70.81	4.0	18.21	3.6	25.7
Inoceramian Beds	1067.22	61.1	302.82	59.3	28.4
Shales - Krosno Beds	106.58	6.1	21.21	4.2	19.9
Shales & Sandstones - Krosno Beds	12.53	0.7	0.36	0.1	2.9
Total	1747.47	100.0	510.44	100.0	*n.a.*

For particular rock series, the landslide index L_a, defined as the ratio of landslide area to the given rock series area has been calculated. In the case of the region of Koszarawa, the highest values of L_a are obtained for the sandstones of Szczawina (fig. 2). A more extensive discussion on the relation of the landslide areas to lithological units in the Beskid Żywiecki Mts. is given by Wójcik (1997).

Tab. 2 illustrates the lithological conditioning of landslides in the region of Szymbark. The L_a index is the highest in the case of the landslides developed on the shale flysch (variegated shales and Sub-Magura shales), although the shale series do not occupy the largest area in this region (tab. 2). The shale flysch represents weak rocks prone to slipping and this factor confirms that lithology is a very important factor which controls mass movements. However, in the region of Szymbark the largest landslide areas are associated with the Inoceramian beds (sandstone flysch) and these landslides usually do not run-out to other lithological units. Moreover, all the landslides developed on Sub-Magura beds and Ciężkowice sandstones extend from these lithological units. Such landslide pattern outlines the significant role of other causative factors, such as mutual arrangement of sandstones and shales, strike and dip of rock layers.

Flow-like landslide at Maślana Góra Mt.

As resulted from the comparison of the typical landslides in the two discussed Carpathian regions, these mass movements lead to terrain modifications, by leaving behind cliff-like scarps at the head of the slumps as well as by bulging the slipped material giving rise to undulated topography. Debris/earth flows, which significantly contribute to the landscape remodelling by cutting into the underlying bedrock, depositing debris at the footslope, stripping soils and vegetation cover, are rather sporadic events. Nevertheless, such forms have been identified at

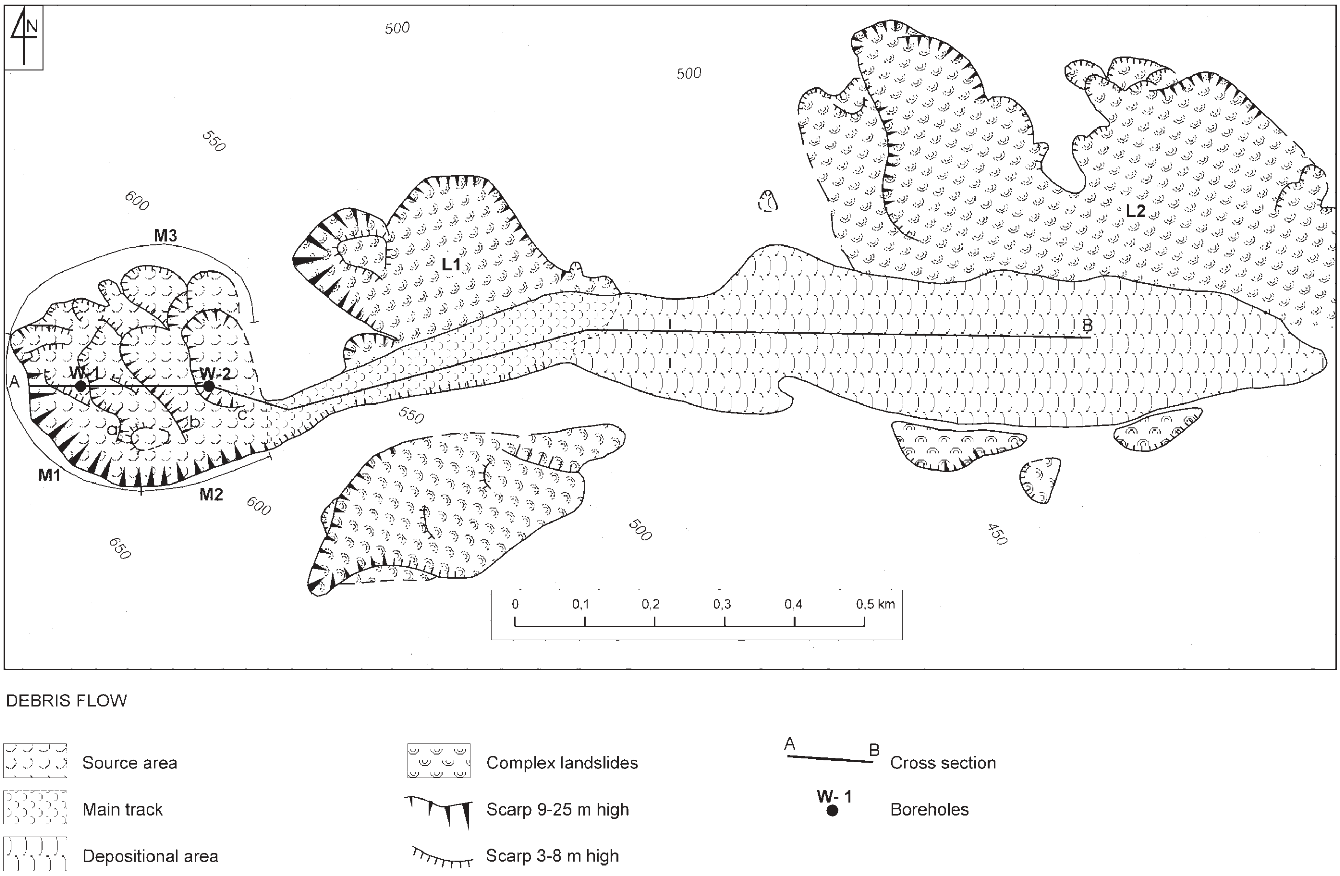


FIG. 3 - Flow-like landslide at Maślana Góra Mt., the Beskid Niski Mts.

the northern slopes of Mędralowa Mt. in the Beskid Ż ywiecki Mts. (fig. 1B) and at the north-eastern slopes of Maślana Góra Mt. in the Beskid Niski Mts. (fig. 1A). The latter is a good illustrative example of both the landscape transformation and climatic influence.

The landslide form occurring on the north-eastern slopes of Maślana Góra Mt. is an outstanding feature in the region of Szymbark due to its shape and size (fig. 1 and fig. 3). This landslide, which is over 2 km long, sets off at the height of 652.5 m a.s.l. and descends to the valley bottom to 387.5 m a.s.l. (fig. 3). It fills the valley up to 10 m to 15 m, and its tongue overrides the river alluvia resting about 2 m above the present-day floor of the stream channels. Morphometry of this landform is given in tab. 3. The landslide in its upper part resembles a slump, while its middle and lower sections form an elongated tongue, whose length significantly exceeds the width. The spreading of the tongue is confined due to control of the palaeorelief.

The thickness of the landslide deposits has been estimated based on the analysis of erosional incisions along the tongue, especially in the part where the streams cut

TABLE 3 - Morphometry of the flow-like landslide at Maślana Góra Mt.

	Length (m)	Width (m)	Area (ha)	Average gradient (degrees)	Elevation (m a.s.l.)	Average thickness of colluvium	Volume (m^3)
Maślana Góra flow-like landslide	2050	60-350	36.46		652.5 - 587.5		
Source area	450	350	10.90	15	652.5 - 550.0	35	4358000
Track zone	350	60-100	4.59	9	550.0 - 505.0	7	321000
Accumulation lobe	1250	200-250	23.00	6	505.0 - 587.5	12	2760000

through the deposits overlying the undisturbed bedrock of Inoceramian beds. The tongue comprises coarse material: debris, cobbles, blocks and boulders of sandstone, whose diameters range from a few centimetres to 1.2 m to 1.5 m, embedded in a matrix of the sandy-clay-loamy material. Only at the landslide front, where the landslide deposits overlie the alluvial deposits, the amount of sandy-loam material exceeds that of debris and boulders. The tongue material is neither sorted nor oriented, indicating that the flow downslope is a chaotic mixture.

In the middle of the tongue, below the gully outlet, between the lateral landslides marked L1 and L2 (fig. 3), the levees associated with landslide deposits are found. They advance onto the slope structures undisturbed by earlier landslide movement and they are preserved only in some parts. The observed parts of the northern levee are up to 0.5 m high. The lower parts of the tongue are confined due to narrow erosional valleys and the colluvium fills up the earlier palaeovalley.

When examined, three sections indicating the mechanism and mode of displacement of the rock masses can be distinguished. These are: the upper section, being the source area, middle section - the track, and the lowermost section where colluvium is accumulated as an elongated tongue. The upper section is about 400 m long and up to 350 m wide with the height difference of 100 m (652 m to 560 m a.s.l.). This part is the rock-debris slump comprising a spring pot and a slope above it. The rotational displacement left behind the main high scarp 20 m to 25 m, developed in the massive Magura sandstones dipping opposite to the slope inclination. Thus, the slide in this section can be classified as obsequent.

From the west, the main scarp has an amphitheatre shape (M_1 in fig. 3), while in the south, the scarp is almost a straight line and corresponds to the fault zone (M_2 in fig. 3). Below the main scarp, there are steps formed by slumped blocks, flattening and depressions. The orientation of the secondary scarps follows that of the main scarp. Some of the depressions are filled up with organic material. The 8 m to 15 m high secondary scarps are oblique to the slope inclination (a, b, c in fig. 3). In the northern part several minor and probably younger scarps

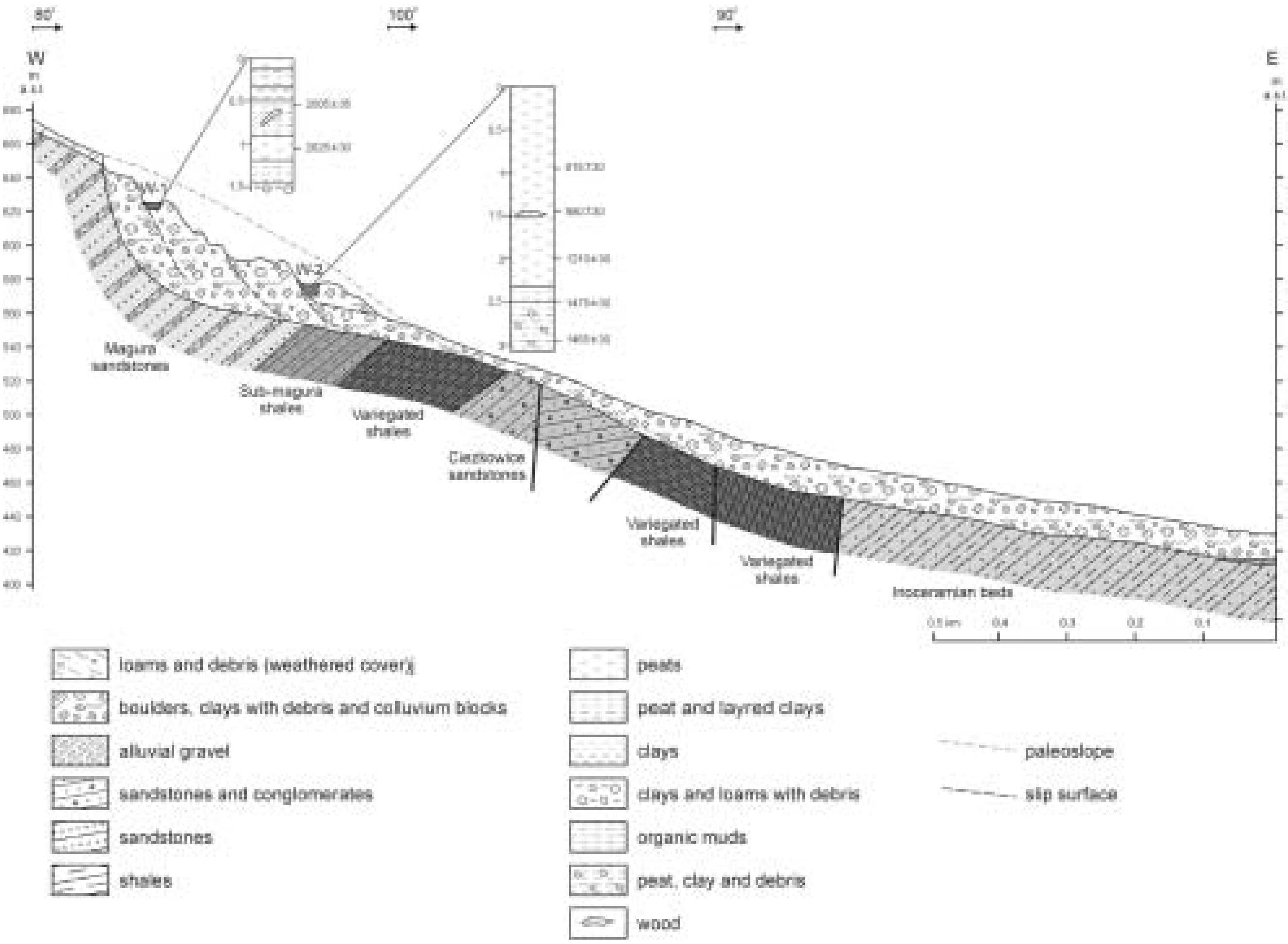


FIG. 4 - Cross-section of the flow-like landslide at Maślana Góra Mt.

occur and are linked with the outline of the main scarp (M_3 in fig. 3).

The second section of the discussed form is a track zone which stretches from 560 m to 505 m a.s.l. and very likely coincides with the incision of the palaeovalley. It is a relatively narrow zone (60 m to 100 m), reaching a length of over 400 m, cut in the variegated shales and Ciężkowice sandstones. The thickness of landslide deposits is small here and does not exceed 5 m to 9 m (fig. 3, fig. 4, tab. 3). The colluvium slumped and discharged from the source area overlies the variegated shales. In the lower part of the discussed track, on its left-hand side, there is a lateral structural landslide extending ca. 300 m alongside (L1 in fig. 3). This landslide has 15 m to 20 m high rock scarp and clearly clearly visible inner steps, developed on rocky-debris grouping, and debris-boulder humps. A part of this landslide is presently active. This slide can presumably merge with the track zone and add material to the landslide below.

The depositional zone begins below the height of 500 m a.s.l. (fig. 3). It is almost 1250 m long where the colluvium brought from above forms the elongated tongue (tab. 3). The accumulation tongue overlies the terrain undisturbed by earlier mass movements. Both sides of the tongue are confined by the incision valleys. The accumulation zone is distinct based on lithological differences. The variegated shales and Inoceramian beds present in the substratum are covered by the colluvium containing the Magura and Ciężkowice sandstones, which allows for differentiating between the underlying rocks and the overthrust material.

Taking into account the significant length of the form (a couple of kilometres), the involved landslide material (the chaotic mixture of rock clasts and blocks exceeding even 1 m in diameter) as well as the material's angle of response, it is believed that water saturation aided downslope high-speed movement. The initial landslip set off preparatory conditions, and then underwent liquefaction to continue downslope as a flow which terminated as a tongue on a low grade slope. Unfortunately, there is not sufficient evidence to estimate the velocity of movement. However, considering the triggering factors, only an exceptional rainfall was capable of causing such displacement of rock masses. Bearing in mind all the difficulties when differentiating mudslides or debris slides from flow slides (Dikau & *alii*, 1996), the term slide-debris flow or flow-like landslide seem to be the most appealing to describe the discussed phenomena at Maślana Góra Mt.

The assemblage of landslides (L2 in fig. 3), located north of the left-hand side incision valley, where the accumulation tongue terminates, is not related to the development of the Maślana Góra slide-debris flow. This is inferred from the specific relief here as well as the different structure of the tongue compared to the surrounding area.

Two development stages can be distinguished based on the performed studies. The slope profile, prior to the slump, was different from its present-day shape - the slope was convex. This likely singular episode affected the bedrock together with the weathered mantle, and resulted in a travelled distance of 1000 m to 1500 m. In the source zone the estimated thickness of colluvium is ca. 30 m to 45 m at present. Due to the failure, the original slope surface has been lowered by ca. 20 m at average, what referred to the area of 10 ha, amounts to 2,180,000 m^3 of rock material discharged from the source area. The estimated volume of colluvium in the accumulation tongue is more than 2,760,000 m^3 (tab. 3). The amount missing to balance the volume perhaps originates from the lateral landslide (L1 in fig. 3) located east of the source area. The secondary movements in the source area were observed later on, after the flow-like landslide has been formed.

AGE AND CLIMATIC IMPLICATIONS FOR LANDSLIDING

In spite of the relatively long distance between the studied areas both sites have undergone similar palaeoclimatic changes. More humid climate during the Subboreal and later on (Ralska-Jasiewiczowa & Starkel, 1988) in the Carpathians would have caused intensification of mass movements.

Until now, the formation time of the landslides in the region of Szymbark has not been determined directly. However, in the context of the examination of Sawicki landslide (fig. 1A) at the southern side of the Maślana Góra ridge (Gil & *alii*, 1974) and inferring from the colluvium tongue overlying the low terraces, it could have been concluded that the formation of the discussed landslide is younger than the last glaciation. Our data from the north-eastern slope of Maślana Góra Mt. were dated to the Subboreal/Subatlantic transition phase and Subatlantic period.

Almost the same applies to the Koszarawa catchment. In this region a landslide assemblage is also of upper Holocene origin, and was dated to the middle Subboreal (3730±50 yrs BP) period. Pollen analysis of organic sediments revealed the presence of cereals pollen.

Vegetation and climatic conditions at Maślana Góra Mt.

The landslide depressions on the north-eastern slope of Maślana Góra Mt. are filled with organic material which has been studied to provide evidence on the landslide history and climatic conditions. The samples originate from the boreholes: W-1 located between the main scarp and the uppermost inner step at an elevation of 625 m a.s.l. (fig. 3, fig. 4), and W-2 located below the lowest step (c in fig. 3) at 587.5 m a.s.l. The thickness of organic deposits in borehole W-2 is two times thicker than in W-1. The lithologic profiles of both the boreholes are shown in fig. 4.

Due to the location of both the landslide depressions within a forest belt and their rather small surfaces, the pollen diagrams represent very local changes of vegetation. The total pollen and spores concentration in some levels (peat) was low and very low. Poorly preserved sporomorphs may suggest unstable conditions of accumulation, and aeration of the peat layers.

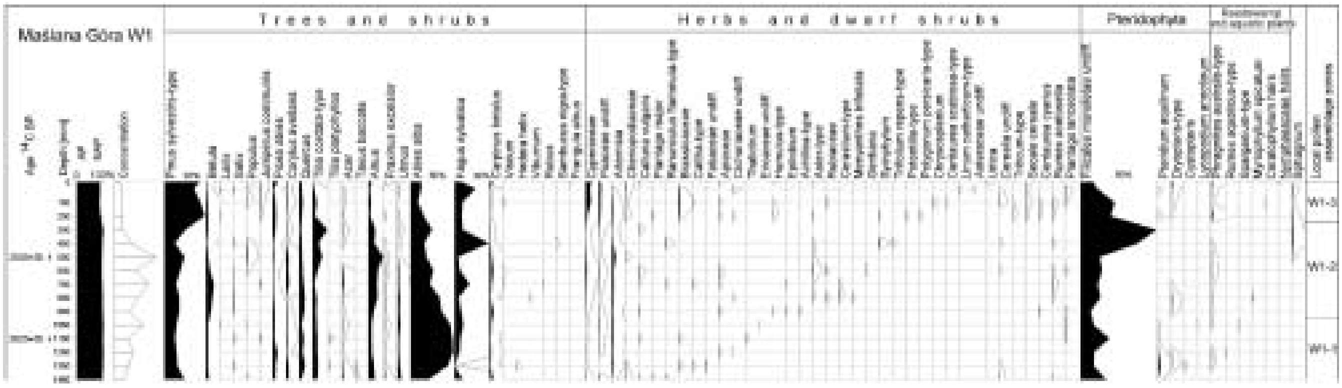


FIG. 5 - Percentage pollen diagram from the Maślana Góra Mt., borehole W-1.

The pollen diagram of the borehole W-1 (fig. 5) has been divided into 3 local pollen assemblage zones (L PAZs), which are numbered from the bottom upwards. It records expansion of fir (*Abies alba*), and later on beech (*Fagus sylvatica*). Currently, these two species form the lower forest belt in the Carpathians.

In the W1-1 L PAZ *Abies* pollen attained its maximum values nearly up to 40%. It corresponds well with the regional expansion of fir in the Polish Carpathians. At 2500 BP a new centre of fir expansion appears in the Beskid Niski range (Obidowicz & *alii*, 2004). Fir is a species of high moisture demands. Presently, the most favourable moisture conditions *Abies* meets in the Carpathians when the level of annual precipitation reaches at least 700 mm (Jaworski & Zarzycki, 1983). According to radiocarbon dating and revealed pollen stratigraphy, accumulation of organic sediments in this depression (fig. 4) started at the transition from the Subboreal to Subatlantic periods.

In the W1-2 L PAZ increase in pollen values of certain taxa, which are associated with newly opened areas, (*Artemisia*), and trees with higher light demands, such as *Betula*, *Populus*, and *Corylus* may suggest opening of the forest and, a renewal of the mass movements at around 2000 ^{14}C years BP. Accumulation of clays with debris forming inserts in peat (0.36 m to 0.5 m), as shown in the profile of the borehole W-1, support the above proposition (fig. 4).

The second depression at 587 m a.s.l., is an indication of a next rejuvenation of landsliding. Peat deposition in this depression started ca. 1500 years BP (1465 ± 30BP), that is during the middle Subatlantic and has been lasting until present. That was probably the last very distinct period of formation of the highest part of the discussed slide debris flow, since in the profile of organic deposits there are no significant minerogenic intercalations.

The pollen diagram, obtained from the organic material from the discussed depression, records vegetational changes which spanned approximately 800 years (fig. 4, tab. 4). The first Local Pollen Assemblages Zone (W2-1) is characterised by a significant proportion of *Abies* pollen, ca. 50%, implying rather high annual precipitation in the area.

In the W2-4 and W2-5 L PAZs an increase in NAP (namely, Cyperaceae, *Artemisia*, Poaceae undiff., *Phragmites australis* type, and trees such as *Betula*, *Quercus*, and *Corylus*), suggests the presence of open areas and opening of dense forest cover. At the same time significant decrease in *Abies* and *Fagus* pollen is observed. These changes, which take place at ca. 1000 ^{14}C years BP and later, may indicate a mass movement around the peat-bog.

TABLE 4 - AMS radiocarbon dating of Maślana Góra Mt. depressions

core W-1

Depth, mm	Lab. no.	Macrofossil dated	^{14}C age BP	Age cal. yr BP (2 σ range)
55	Poz-6469	*Cenococcum graniformae*, Coleoptera	2005 ± 35	2050 - 1870
115	Poz-6470	*Abies* seeds, needles	2625 ± 30	2785 - 2710

core W-2

Depth, mm	Lab. no.	Macrofossil dated	^{14}C age BP	Age cal. yr BP (2 σ range)
80	Poz-6471	*Abies* seeds, needles	615 ± 30	660 - 540
140	Poz-6472	*Abies* seeds, needles	980 ± 30	960 - 790
200	Poz-6273	*Abies* seeds	1210 ± 30	1190 - 1050
250	Poz-6475	*Fagus* seed	1475 ± 30	1420 - 1300
278	Poz-6476	*Abies* needles, mosses	1465 ± 30	1410 - 1300

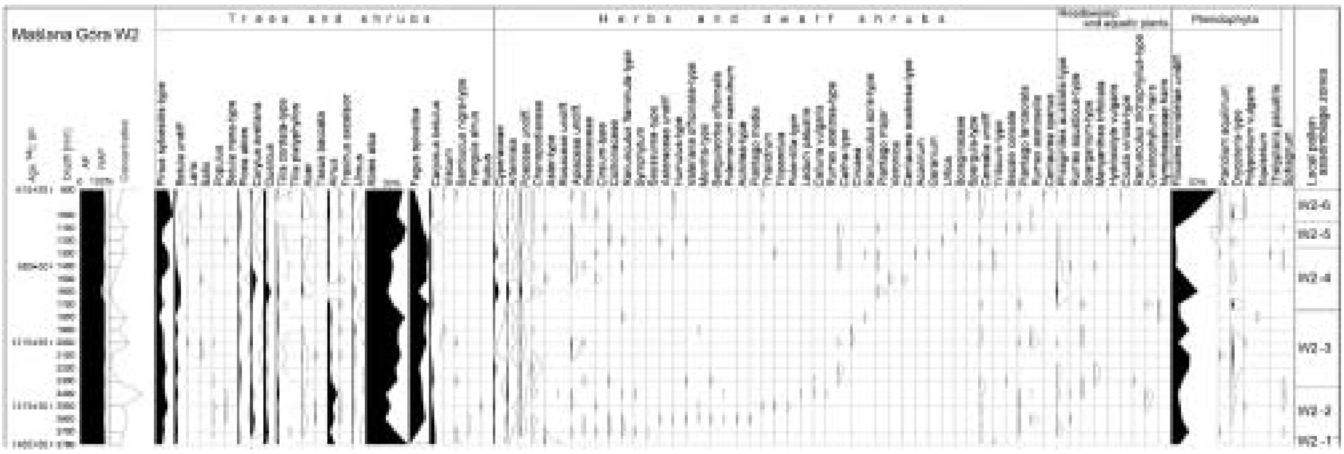


FIG. 6 - Percentage pollen diagram from the Maślana Góra Mt., borehole W-2.

If so, this event would correspond with the Little Ice Age climatic changes (Alexandrowicz, 1997), but the human activities in the area cannot be ignored.

DISCUSSION AND FINAL REMARKS

The landslides in the Carpathians are believed to be mainly related to the presence of the shale series (Thiel, 1989). Although this can be confirmed by the examination of landslides in the Beskid Niski Mts., the same conclusion is not so straightforward in the Beskid Żywiecki Mts. Lithological and tectonic controls are very important in the first region, where distribution of landslides corresponds with a pattern of shales series and the fault zones.

In the second region, the sequence of particular rock series, especially the underlying of massive sandstone even by thin shale series, is more critical for mass movements. The large landslides can be seen along the zones following the lineaments (Wójcik, 1997).

Landscape sensitivity, understood as the response of landscape systems to perturbations on time and spatial scales (Thomas, 2001), manifests itself in a twofold manner in both examined regions. On the one hand, changes in landforms and vegetation evidence radical transformations in an environmental mosaic. This is particularly well exemplified by the flow-like landslide at Ma?lana Góra Mt. This landslide point to a temporal system instability associated with a rapid process due to extreme rainfall episodes. The present-day landform reveals the inherited Pleistocene form features, and its morphometric parameters make it an outstanding landscape element. The landslide itself is also a geoindicator of changing climatic conditions as evidenced by rapid spread out of some taxa, e.g. fir (*Abies alba)* – a tree associated with high precipitation.

On the other hand, the numerously occurring smaller landslides (including complex forms) substantiate the present-day landscape sensitivity. Current slope instability, being the reactivation of dormant landslides and triggering of shallow failures, is mainly a response to varying rainfall conditions. Thus, numerous landsliding is recorded every year or every few years. This leads to progressive landscape modifications but with a far-reaching cumulative effects (e.g. topography undulation, push-up forms, expansion of herb plant communities on newly disturbed areas, etc.).

Biogenic sediments of slide debris flow at Maślana Góra Mt. trace the palaeoenvironmental changes at the transition of Subboreal to Subatlantic. AMS radiocarbon datings of plant macrofossils from the older landslide depressions (W-1) allow for correlating the onset of the mass movements at Maślana Góra Mt. with the Loeben phase of Alpine glacier advances (Bortenschlager, 1982; Hormes & *alii*, 2002). There are a number of landslides in the Polish Carpathians ^{14}C dated at this age (Alexandrowicz, 1997; Margielewski, 1997, 2000). Their development most probably is related to an increase in precipitation at the Subboreal/Subatlantic transition (Ralska-Jasiewiczowa & Starkel, 1988). The date 2625 ± 30 yrs BP is close to that obtained from the material sampled in the Ropa river valley (fig. 1) at the depth of 4 m below the terrace surface, where it is 2675 ± 60 yrs BP (Dauksza & Gil, 1972). The latter is interpreted as a distinct rise in floods and flow oscillations with a simultaneous propensity to formation of braided river channels (Starkel, 1972). These dates point to a coherent activation of processes in the river valleys and slopes.

Time of formation of the younger depression (W2) at Maślana Góra Mt. ^{14}C dated at 1465 ± 30 yrs BP is perhaps related to the increase in fluvial activity in the Upper Vistula River basin at 2350-1800 yrs BP (Starkel & *alii*, 1996). A particular signal of climatic change, that is minerogenic layer in peat sediment linked to a mass movement, was registered in the landslide depression at Kaletowa (western part of the Beskid Wyspowy Mts. - fig. 1) by Krąpiec & Margielewski (2003). Other signals of slope mobilisation during the early Subatlantic wetting are also recorded in the lake sediments of the Tatras (Kotarba & Baumgart-Kotarba, 1997) while the intensified mass movements at that time were recorded in the Alps as well (Corsini & *alii*, 2001).

Transformation of vegetation in the pollen zones W2-4 and W2-5 L PAZs dated at ca. 1000 yrs BP and later, might indicate the continual renewal of the mass movements in the Beskid Niski Mts. This youngest, exclusively palaeobotanical signal is quite difficult for interpretation. It might be attributed to mass movements and/or to the human activities, yet it is difficult to separate these two factors at this stage. However, it should be stressed, that the rise in humidity at around 1000 yrs BP is suggested by increased fluvial activity in the Upper Vistula River basin (Starkel, 2003) as well as by slope mobilisation in the Carpathians (Alexandrowicz, 1997).

The organic sediments from both the studied depressions in the slide-debris flow at Maślana Góra Mt. reasonably document the conditions favouring mass movements, while the vegetation succession recorded, and the radiocarbon dates well support vegetation and climate changes observed in the context of the Polish Carpathians. These changes correspond well with the climatic-vegetational transformations evidenced in the other mountain regions, for example the Alps (Soldati & *alii*, 2004).

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