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Synsedimentary slumping in fold-and-thrust system of the Magura Zone: evidence from olistoliths in the Beloveža Formation (Zbludza area, Poland)

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Abstract: An accumulation of blocks of thick-bedded sandstones and marls, interpreted as olistoliths, was found in the Beloveža Formation in the SE part of the Beskid Wyspowy range (Polish part of the Outer Western Carpathians). The host sediments are bluish shales and thin-bedded fine-grained sandstones. Some bodies of marls and sandstones, up to several millions of cubic meters in volume and standing out in relief, are also interpreted as olistoliths. The olistoliths were deposited during synsedimentary shortening of the Magura Basin, by submarine slumps moving down the slope of an accretionary prism, across depositional zones. The olistoliths described here resemble in their characteristics and geological position those known from the Kamienica Nawojowska valley. This similarity may suggest that olistoliths may have wider extent in this part of the Magura Nappe.

Key words: Outer Western Carpathians, Magura Nappe, Bystrica Subunit, olistoliths.

Introduction

Olistoliths have been found in the deposits of the Magura Nappe quite recently. They were earlier found in other units of the Polish part of the Outer Western Carpathians: Silesian Nappe (Szymakowska 1976) and Skole Nappe (Dżułyński et al. 1979; Kotlarczyk 1988). In the Magura Nappe, olistoliths have been found in the Kamienica Nawojowska valley (Bromowicz 1996, 1998), Jaworki (Cieszkowski et al. 2003) and in the vicinity of Żywiec and Sucha Beskidzka (Chodyń et al. 2003). Large submarine slumps described earlier in the Magura Nappe, include those at Szczawa (Cieszkowski et al. 1987) and at Poręba Wielka (Książkiewicz 1958), the latter described as "wildflysch" by Burtan & Łydka (1978) and as chaotic deposits–tectonic-melange (Oszczypko-Clowes & Oszczypko 2004).

The present author found large blocks of thick-bedded sandstones and marls in the deposits of the Bystrica Subunit, near Zbludza and Wola Kosnowa (Fig. 1). Some of these rocks are in marked contrast with the host sediments of bluish shales and thin-bedded fine-grained sandstones.

Geological setting

The area between Zbludza and Wola Kosnowa (the SE part of the Beskid Wyspowy) belongs to the Bystrica (Nowy Sącz) Subunit of the Magura Nappe (Paul 1980). The oldest strata exposed at the surface in this part of the Bystrica Subunit belong to the Łabowa Shale Formation (Lower and Middle Eocene; Fig. 1), which is overlain by the Beloveža Formation (Early–Middle Eocene), up to 350 m thick in the Zbludza section (Oszczypko 1991; Fig. 2). In the southern part of the area the Beloveža Formation is overlain by a series, 100–150 m thick, described by Oszczypko (1991) as the Bystrica Formation (Fig. 1) and composed of thick-bedded blue-grey, firmly cemented marls (Łącko Marls), fine-grained sandstones and shales. Higher in the section lies a series of rocks lithologically similar to the Beloveža Formation but with the Łącko marls — the Żeleźnikowa Formation. It is overlain by the Maszkowice Member of the Magura Formation (Oszczypko et al. 1992), developed as thick-bedded sandstones and submarine slumps with intercalations of very thick-bedded Łącko marls. In the northern part of the area, the Beloveža Formation is overthrusted on thick-bedded sandstones of the Modyń Mountain (Fig. 1). These sandstones belong probably to the Maszkowice Member as is indicated by the presence of the Łącko marls, whose outcrops were found in the southern margin of the Modyń range.

The blocks are embedded in deposits of the Beloveža Formation (Figs. 1, 2), often at their contact with the Łabowa Shale Formation (flysch with variegated shales). Some blocks are included in a submarine slump. The submarine slump consists of thick-bedded sandstone blocks (Fig. 3) chaotically dispersed in uniform bluish shale matrix. The slump clearly stands out within the deposits of the Beloveža Formation. Its contact with the host deposits has been clearly observed in the northern part of the outcrop. The contacts of the other blocks with the deposits of the Beloveža Formation are less clear because the blocks have been excavated by the stream erosion and possible even slightly moved.

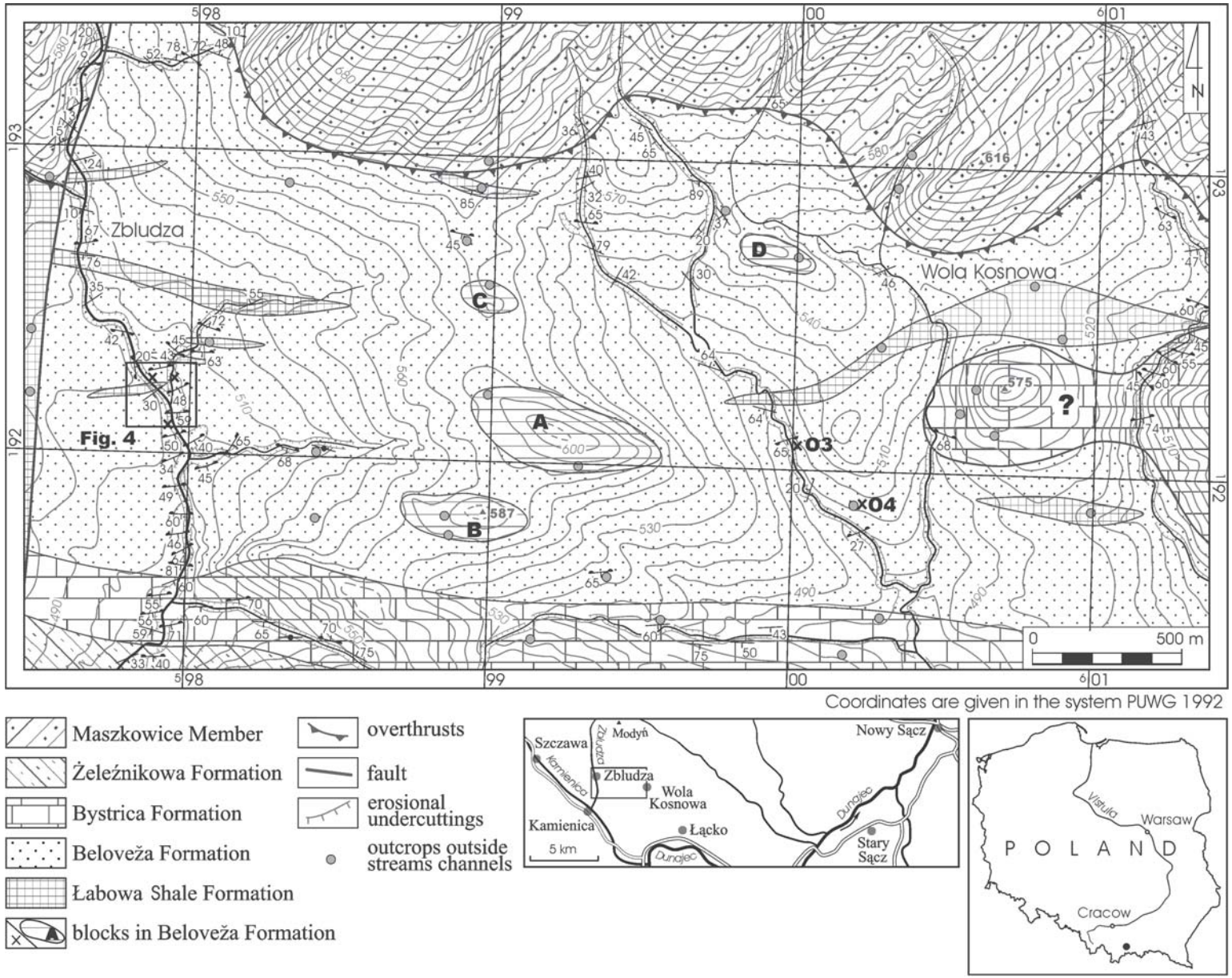

Fig. 1. Geological map of the Wola Kosnowa and Zbludza region.

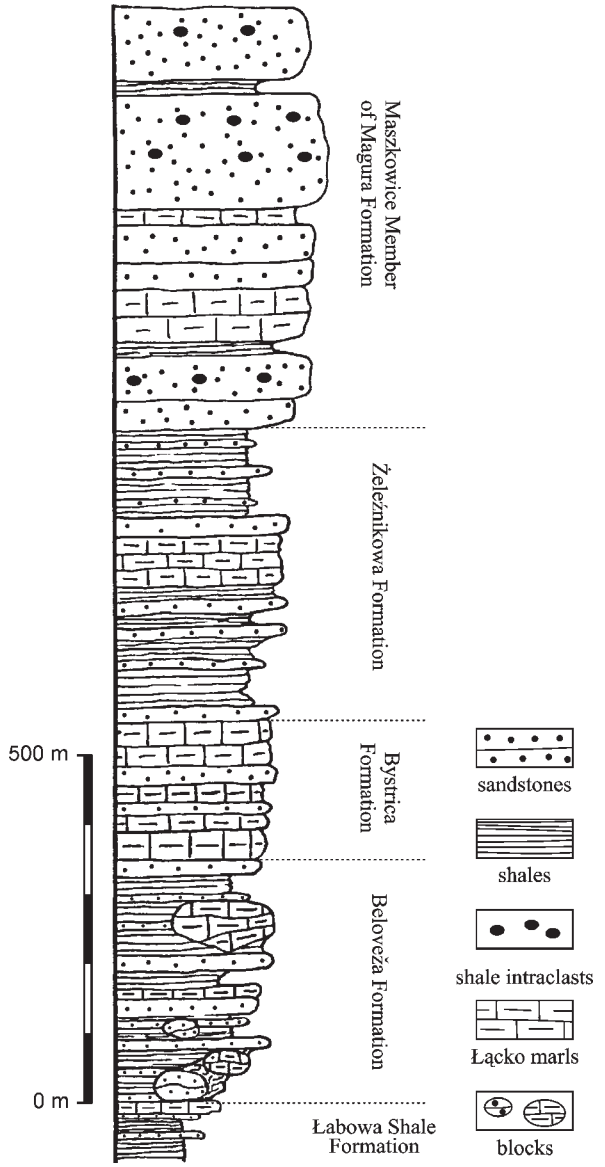

Fig. 2. Lithostratigraphy of Bystrica Subunit in section of the Zbludza Stream (partly based on Oszczypko 1991).

Fig. 3. Zbludza Stream. Block of thick-bedded sandstone embedded in bluish matrix. Hammer (30 cm long) as a scale.

Description of the blocks

An exotic blocks or other rock mass transported by submarine gravity sliding or slumping and included within the binder of an olistostrome are called olistoliths (Bates & Jackson 1980). The term "olistolith" is variously defined in literature. Abbate et al. (1970) considered as olistoliths only the blocks larger than 4 m in length, reserving the term "clast" for the smaller ones. A giant-sized block has been called "olisthotrymma" (Richter 1973). The author uses the term "olistolith" in a less restrictive sense with respect to their size. The blocks described here are about 1 m to several meters in length, though some blocks up to million cubic meters are also discussed here. Following Bromowicz (1998) the blocks are described as monolithic — built exclusively of one rock type, usually sandstone or marl, and polylithic — composed of various rock types, commonly sandstones, marls and shales.

The greatest accumulation of blocks was found in the channel of the Zbludza Stream and in its left tributary (Fig. 4). Exposures are relatively good and long but narrow with respect to block size. Some of the blocks lie loose on the outcrop, but some are still embedded in their host sediment — grey-bluish soft plastic clay with sparce, chaotically scattered sandstone blocks. The most representative examples of blocks are described below.

An ellipsoidal, monolithic block O1 (Figs. 4B, 5) lies in the channel of the left tributary of the Zbludza Stream [GPS: 597 932; 192 260]. It is a fragment of a thick (1.5–2 m) bed of brown-grey, fine-grained, slightly graded sandstone with scattered grains up to five milimeters. The outer surfaces of the block are smooth, locally covered with slickensides and patches of fibrous calcite. The sole of the bed (Fig. 5) is covered with depositional structures (hieroglyphs) and numerous straight and arcuate fractures, locally with small steps due to displacements up to 10–12 cm high, usually smaller (Fig. 6).

Nearby lies another, larger (at least 7.5 m^3 in volume), block O2 (Fig. 4B) partly excavated by the stream. This is a block of a thick (ca. 2 m) bed of brown-grey fine-grained sandstone with dispersed granule-size grains. Its top is flat and the other surfaces are even.

A submarine slump series — is exposed in the channel of the Zbludza Stream [GPS: 597 850; 192 244] over a length of 25 m. It consists of sandstone blocks (Figs. 4, 7) chaotically embedded in bluish shales (Fig. 3). Below are described those blocks which have at least about 1 m in length. Two blocks of them (at least 12 m^3 and 2.5 m^3) are medium-grained, feebly cemented grey sandstone rich in shale clasts. The sandstone is rich in coalified plant detritus and chaotically dispersed flakes of muscovite up to 1 mm in size. The outer surfaces of block display flattened fragments and numerous joints of various density and orientation. Another five blocks (3.3 m^3; 1.2 m^3; 1.1 m^3; 0.4 m^3; 0.3 m^3) included in the slump series consist of fine-grained blue-grey, compact sandstone in some blocks with lamination (horizontal or convolute), devoid of abundant muscovite and detritus. The sandstones include clay clasts with pyrite (2–4 cm in diameter), which acquire

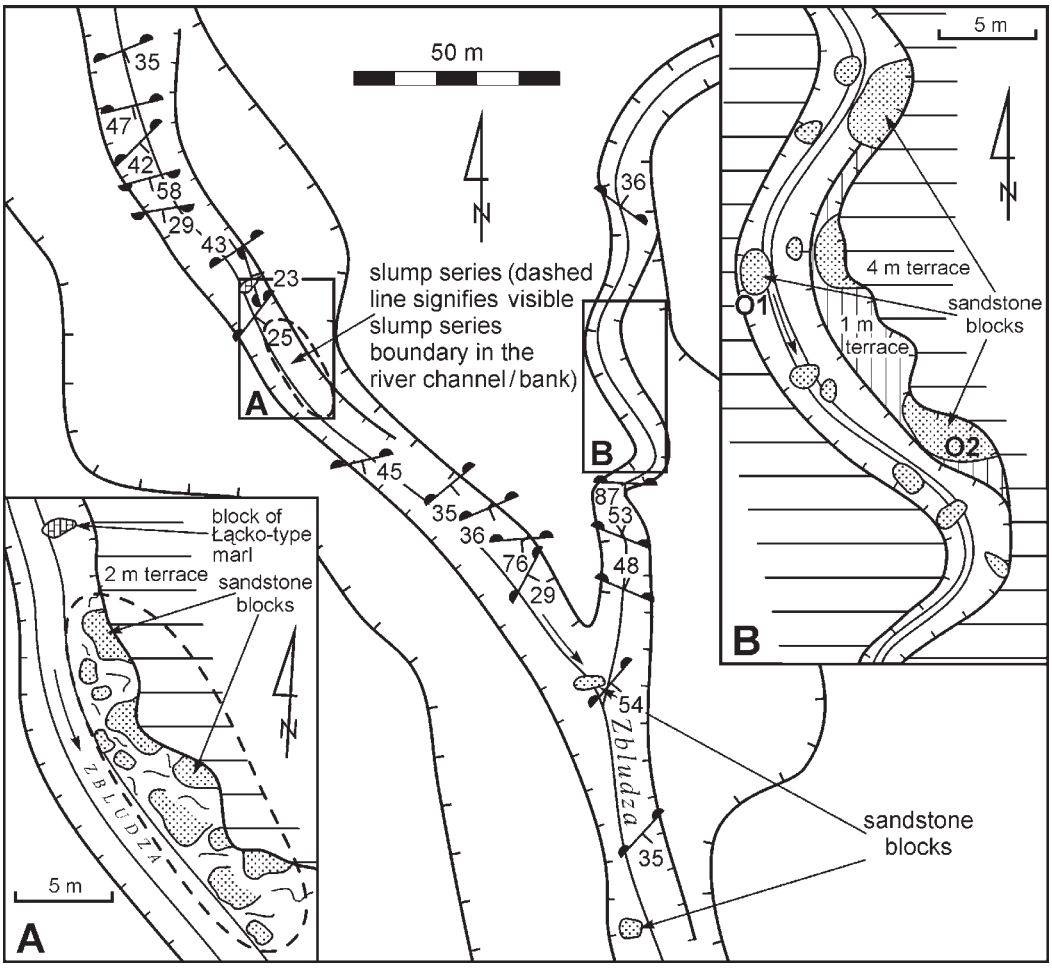

Fig. 4. Sketch of detailed location of the blocks in the Zbludza Stream and its tributary.

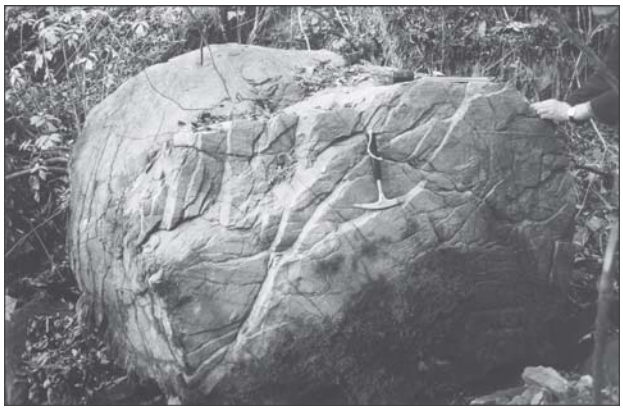

Fig. 5. Block O1 in the left tributary of the Zbludza Stream. Hammer (30 cm long) as a scale.

Fig. 6. Small displacements (steps) on the O1 block surface. GPS receiver (11 cm long) as a scale.

a rusty crust when weathered. The flat outer surfaces of the blocks display numerous fractures, often filled with thick calcite veins, of various orientation and density, often with small displacements. There is also a block (0.7 m^3) of blue-grey compact graded sandstone, with clasts up to 5–7 mm in size. A block of the Łącko-type marl is present near the sandstone olistoliths (Figs. 4A, 8). It is a very well rounded ovate, strongly fractured block with a complex array of small steps on its surface.

Two blocks have also been found SW of the center of Wola Kosnowa. A fragment of the first O3 (Fig. 1) [GPS: 599 999; 192 090] is exposed in the bed of a nameless

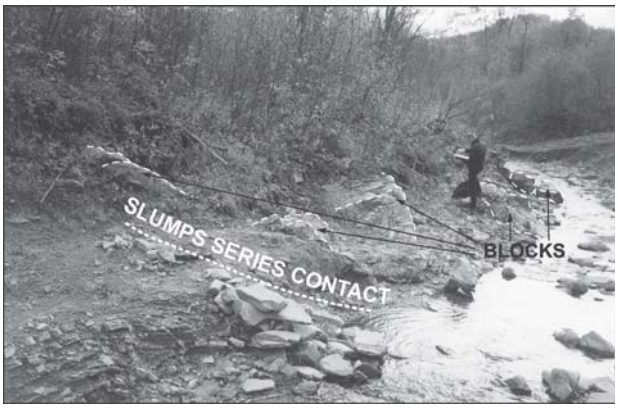

Fig. 7. Zbludza Stream. Slump series contact with the host deposits.

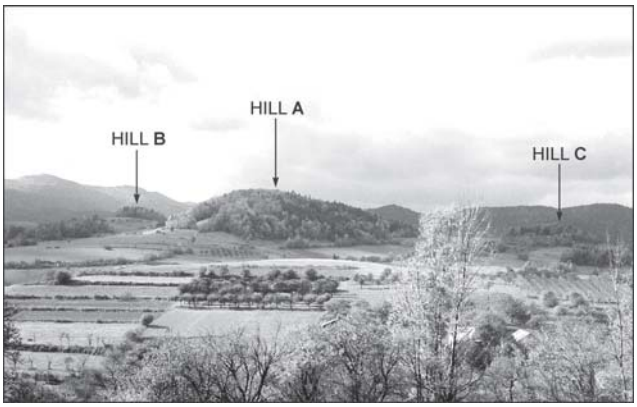

Fig. 9. View from Wola Kosnowa (from east).

Fig. 8. Zbludza Stream. Block of the Łącko-type marl. Hammer (30 cm long) as a scale.

stream, the other O4 (Fig. 1) [GPS: 600 055; 191 970] in a field-road scarp. However, the exposures are so poor that neither their size nor their shapes could be determined. Both are at least 3–4 m thick and are polylithic (sandstone, marl, shale); the first is distinctly stratified.

Also interesting are the blocks labelled: A, B, C and D on Fig. 1. They are marked in relief as domed hills (Fig. 9, see also Bogacz & Węcławik 1969), with locally steep slopes (NE slopes of olistolith A). The minimum volumes of these blocks are estimated as: A — $2.5\times10^6\,m^3$, B — $0.9\times10^6\,m^3$, C — $0.12\times10^6\,m^3$, D — $0.3\times10^6\,m^3$. These seem to be polylithic blocks, composed mainly of marls and sandstones. Their shapes are ellipsoidal and their longer axes are oriented W–E, that is parallel to the structural strike and perpendicular to the direction of thrusting. Their internal structure was recognized in a few outcrops located in road-cuts or by inspection of loose rock fragments in ploughed fields, where the Łącko marls predominated.

Discussion

The blocks described above are interpreted as olistoliths on the grounds of their litology, shape and relation to encompassing rocks. The rock types in the olistoliths, namely the marls of the Łącko type and coarse-grained sandstone with shale clasts, may come from the higher members of the Bystrica Formation where these types of rocks are common. So, the very coarse-grained sandstone olistoliths with shale clasts may come from the Maszkowice Member, as this type of sandstone is characteristic in this member (Oszczypko et al. 1990; Oszczypko 1991). The olistolith of marl may come from the Bystrica or Żeleźnikowa Formation or even the Maszkowice Member. The acceptance of such a source for the olistoliths seems paradoxical at first glance, as they would come from the stratigraphically higher members. However, as may be seen in the stratigraphical scheme by Oszczypko (1991), in Middle Eocene all the lithostratigraphic members concerned are diachronous (Fig. 10), reflecting the outward migration of the sedimentation zones. During the sedimentation of the Beloveža Formation, the sediments of the Maszkowice Member were already present at surface more internally and possibly involved in thrusting.

Data from Poręba Górna (Oszczypko et al. 1999) and from Żeleźnikowa (Oszczypko 1986) indicate that thick-bedded sandstones and marls occur sporadically in the upper part of the Łabowa Shale Formation and in the Beloveža Formation. Therefore, the olistoliths could be

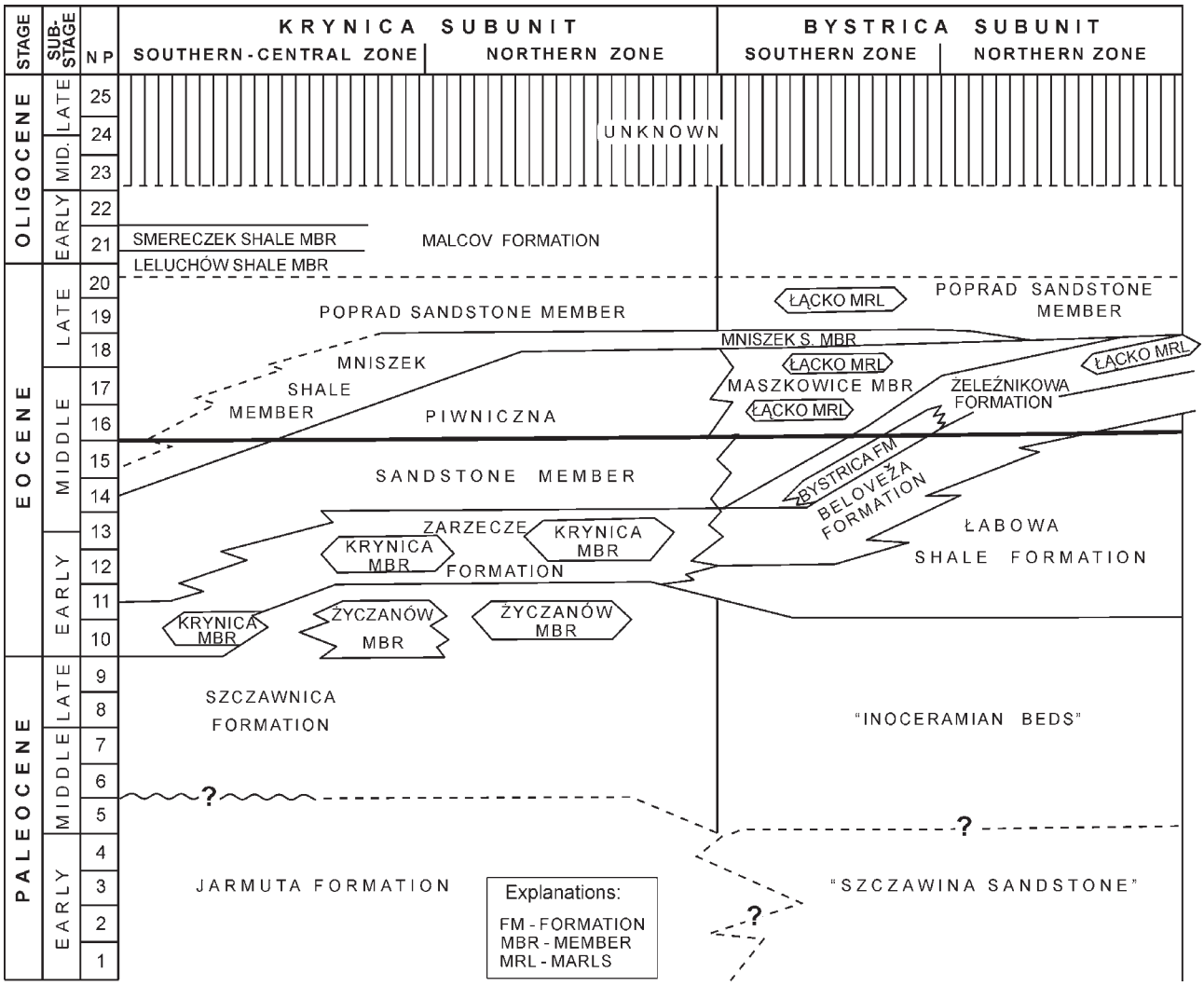

Fig. 10. Stratigraphical scheme of all the lithostratigraphic members of the Magura Nappe (Oszczypko 1991, 2004).

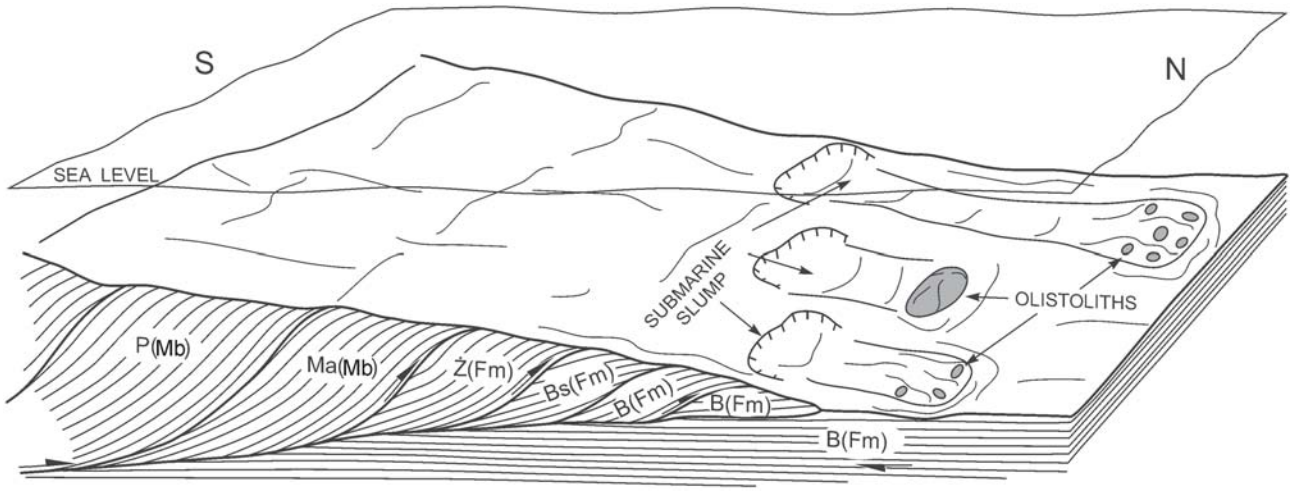

Fig. 11. A scheme showing the mode of formation of olistoliths in the Middle Eocene Magura Basin (the structure of the accretionary prism based partly on Moore & Shipley 1988). The number of thrust slices, locations of thrusts and distribution of lithostratigraphic units are purely schematic. Krynica Zone: **P(Mb)** — Piwniczna Sandstone Member. Bystrica Zone: **Ma(Mb)** — Maszkowice Member, **Ż(Fm)** — Żeleźnikowa Formation, **Bs(Fm)** — Bystrica Formation, **B(Fm)** — Beloveža Formation.

supplied from the fronts of the overriding tectonic slices (Fig. 11) and their sliding transport could be much shorter than in the case of their provenance from the higher lithostratigraphic units.

The hills A, B, C and D (Fig. 1) may be considered as partly excavated olistoliths of rocks more resistant to weathering and erosion than their surrounding. They would thus be olistoliths of the Łącko-type marls (except for olistolith D), supplied from the neighbouring Bystrica Formation.

The presence of olistoliths in the Beloveža Formation indicates synsedimentary translation of sediments within the Magura sedimentary basin by submarine gravity movements. Such processes are corroborated by the presence of the submarine slump series, within the Beloveža Formation. The poor cementation of the blocks, the numerous fractures with slickensides visible on their surfaces, dense jointing and the prevalent smoothing on their outer surfaces, all suggest that the blocks were subject to transport and rounding. The outer surface of the olistolith in the left tributary of the Zbludza Stream (Fig. 5), characterized by a dense array of fine steps and the ovate marl olistolith with the complex array of small steps on its surface (Fig. 8), may be shaped by dilation during the transport of poorly lithified sediment (Hoedemaeker 1973). Slickensides on the outer surfaces and calcite veins in some olistoliths may come from a sedimentary series that was already subject to tectonic deformation soon after deposition.

Mobilization of large-scale mass-movements, capable of translating sediments across depositional zones, required northward inclination of the basin bottom in the southern part of the depositional realm of the Magura Nappe (cf. Bromowicz 1998), that is in the direction opposite to the ongoing southward subduction (Oszczypko 1992; Nemčok et al. 2000). The pile of flysch nappes apparently formed as an accretionary prism (Fig. 11) involving a major part of the Magura Basin fill scraped off its basement. The growth of the accretionary prism favoured the division of the basin into longitudinal depositional zones, now reflected in the diachronous lithostratigraphic units, and at the same time led to downslope mass movements across the depositional zones. A similar explanation, with a subduction zone and an accretionary prism has been accepted by Kemkin (1996) for the origin of the turbidite-olistostrome formations in the southern part of the Sikhote-Alin range in Russia.

The olistoliths from Zbludza and Wola Kosnowa are similar in geological position and size to those described by Bromowicz (1998) from the Kamienica Nawojowska valley, ca. 40 km east of the studied area. Blocks of several cubic meters and of the order of a million cubic meters in size occur at both localities. Both have the same position within the Beloveža Formation of the Bystrica Subunit. The tectonic position of both sites is subject to the same controversy. On the geological maps by Burtan et al. (1981) and Żytko et al. (1989) both sites lie at the northern margin of the Bystrica Subunit, and on the maps by Paul (1980) and Malata et al. (1996) they are somewhat removed from this margin.

Conclusions

The olistoliths found in the Beloveža Formation may be interpreted as the result of synsedimentary shortening of the Magura Basin, due to the southward subduction of its basement. The occurrence of mass movements was favoured by the northward gradient of the basin bottom, related to the growth of an accretionary prism, and to seismic activity characteristic of subduction zones and active thrust faults. The characteristics of the olistoliths indicate that their emplacement occurred before complete lithification.

The similarity in lithology, size and setting of the olistoliths described here and those in the Kamienica Nawojowska suggests that they may be present in an extensive zone of the Bystrica Subunit, between both localities or even beyond them. Thus the phenomenon considered hitherto as a local one, may have a regional extent. The poor exposure, typical of the Outer Carpathians makes such olistoliths difficult to recognize, especially if their lithology is not in such striking lithological contrast with the embedding flysch strata, as in the case of so called "exotics" of crystalline rocks, Paleozoic or Mesozoic limestones. A search for olistoliths in the Eocene of the Magura Nappe, similar to those from Zbludza, Wola Kosnowa and Kamienica Nawojowska may reveal their importance for the reconstruction of the synorogenic sedimentation in the Magura realm.

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