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FRACTURED CLASTS IN NEOTECTONIC RECONSTRUCTIONS: AN EXAMPLE FROM THE NOWY SĄCZ BASIN, WESTERN OUTER CARPATHIANS, POLAND

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Abstract

This paper presents the results of a detailed analysis of fractured clasts hosted within Miocene and Pleistocene paraconglomerates that are exposed close to a map-scale overthrust. Both these paraconglomerates bear numerous fractured clasts (22–50%). The architecture of fractures (joints and minor faults) is well organized and independent of both clast orientation and the degree of clast roundness. The fractures were formed *in situ*, most probably due to neotectonic activity of the map-scale overthrust. The number of fractured clasts is positively correlated with the clast size, and negatively correlated with the grain-size of clasts of detrital rocks. The number of fractured clasts increases in clasts of detrital rocks, compared to those of quartzites and magmatic rocks.

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Key words: fractured clasts, neotectonics, Outer Carpathians, Poland

INTRODUCTION

Analysis of fractured clasts in gravels and conglomerates has commonly been applied to palaeostress studies and dating of faulting during the past few tens of years (Tokarski, Świerczewska 2005, and papers cited therein). In the Polish segment of the Outer Carpathians, fractured clasts are fairly numerous in young Cenozoic (Miocene through Holocene) gravels and paraconglomerates, which crop out close to regional thrust faults (Fig. 1), pointing to recent activity of the latter. One can expect, therefore, that kinematic analysis of fractured clasts can provide a wealth of new data pertaining to reconstructions of structural development of the Carpathians in the Neogene and Quaternary.

It is likely that only well-organized fracture architecture is suitable for kinematic analysis. Therefore, the aim of our study is to describe the influence of textural properties and lithology of gravels and paraconglomerates on fracture architecture, and to make an attempt at kinematic analysis of fractures. This paper is a continuation of recently initiated research, the first results of which were already published (Tokarski, Świerczewska 2005). Up to now, we managed to document that: (a) the number of fractured clasts in a given clast population is positively correlated with the clast diameter and negatively correlated with the size of grains within clasts of detrital rocks; (b) the fractures include both those inherited after joints cutting host strata in the source areas, and those formed *in situ* in the studied rock series; (c) the inherited fractures, showing chaotic architecture, are mainly oriented at right angle or nearly perpendicular (80–90°) to clast a-b surfaces; (d) neofractures formed *in situ*, showing well-organized architecture, are oriented both perpendicular (80–90°) and at smaller angles (<80°) versus a-b clast surfaces.

The choice of study object (site "Na Kocie"; Fig. 2) results from its interesting tectonic setting. This site is situated close to a regional thrust fault and close to the margin of the Nowy Sącz Basin, which is also tectonically controlled. In addition, the analysed strata bear a wealth of lithologically differentiated fractured clasts, and are disturbed by both small-scale (individual clasts) and larger-scale tectonic deformations. Finally, site "Na Kocie" is placed not far (1,750 m south-east) from an exposure of Pleistocene gravels at Kwasowiec, recently described by two of us (Tokarski, Świerczewska 2005). The latter gravels, showing poor roundness measures and monotonous lithology (exclusively mudstones and sandstones) and bearing numerous fractured pebbles, provide good comparative material for that dealt with in the present paper.

GEOLOGICAL SETTING

The Outer Carpathians are composed of several, N-verging thrust sheets, the largest and innermost of which is the Magura Nappe (Fig. 1). This nappe comprises four slices that are separated by reverse faults, locally passing into

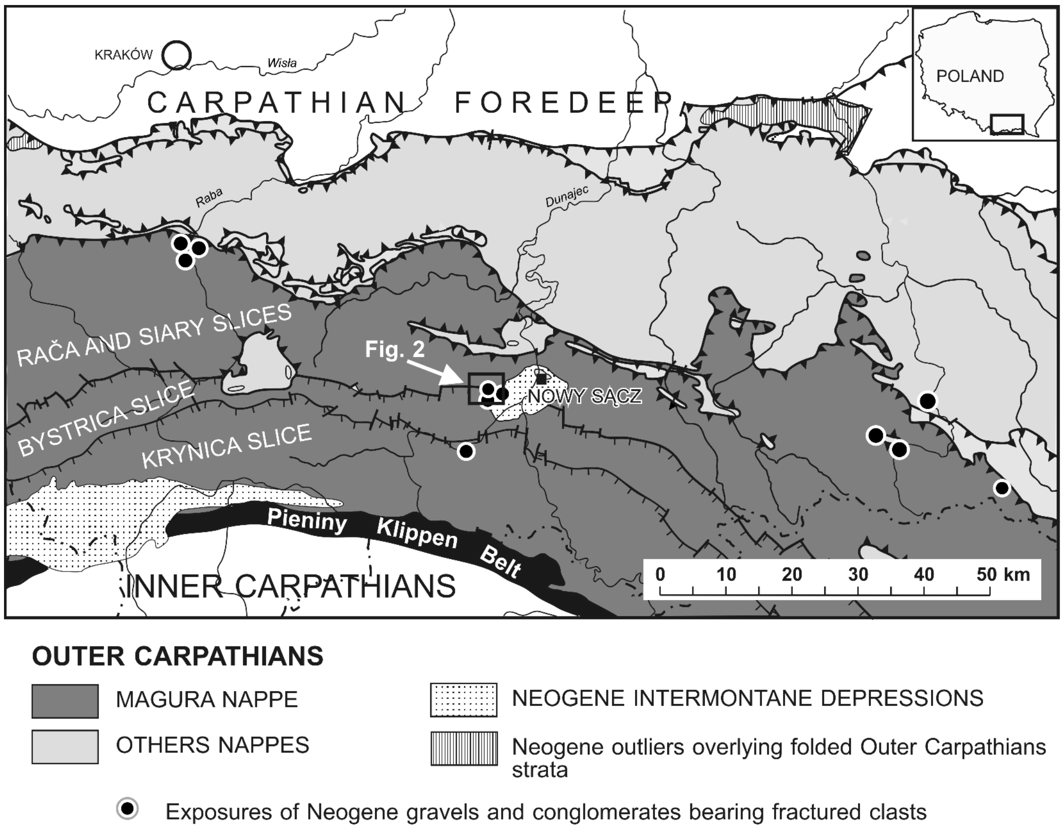

Fig. 1. Geological sketch-map of the Polish segment of the Outer Carpathians showing the location of study area and exposures of gravels and conglomerates bearing fractured clasts (geology based on Żytko *et al.* 1989).

thrusts. This tectonic edifice originated in the Palaeogene and Miocene due to south-directed subduction of oceanic or suboceanic lithosphere of the southern portion of the European plate (*e.g.* Tokarski 1978 and references therein). The structures produced during subduction-related shortening are overprinted by normal faults (Zuchiewicz *et al.* 2002, and papers cited therein), which were formed during gravitational collapse. These faults bound intramontane basins filled with Neogene and Quaternary strata. The Nowy Sącz Basin represents one of these structures. The lower portion of

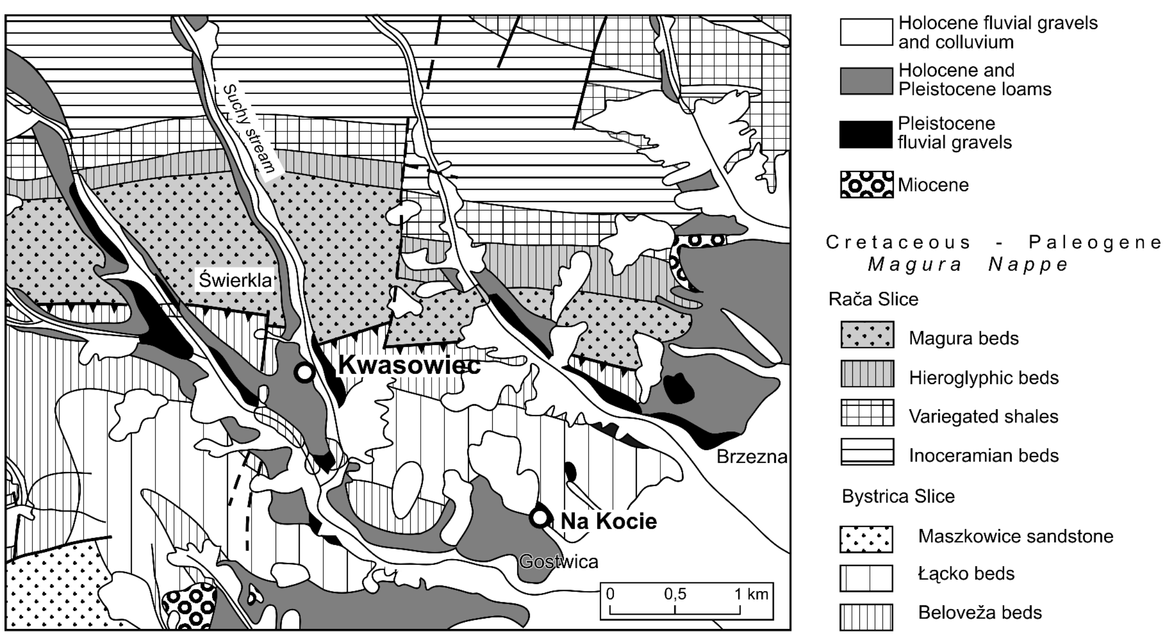

Fig. 2. Study area showing the location of "Na Kocie" and Krasowiec exposures (geology based on Oszczypko, Wójcik 1989); for location see Fig. 1.

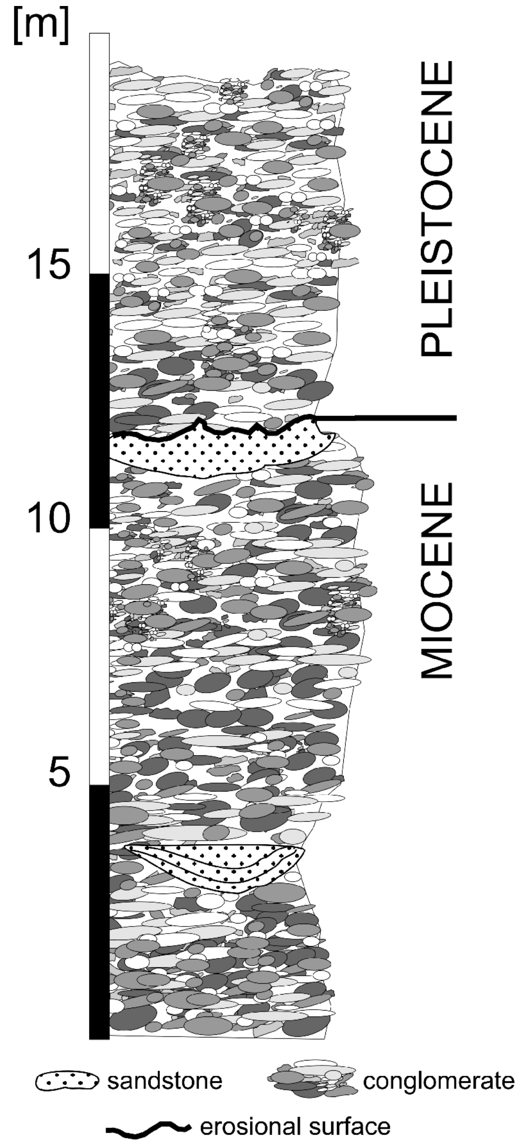

Fig. 3. Section of the "Na Kocie" exposure.

its sedimentary fill includes Miocene clays and sands, together with locally occurring paraconglomerates with sandstone intercalations. The upper portion, in turn, comprises Pleistocene and Holocene fluvial gravels (Oszczypko 1973, Zuchiewicz 1984).

MATERIAL AND METHODS

We analysed clasts comprised in Miocene and Pleistocene, poorly indurated paraconglomerates exposed at a single site. Quantitative analysis concerned: (a) percentage of clasts versus matrix; (b) clast lithology, size, shape, degree of roundness and orientation; (c) percentage of fractured clasts; and (d) fracture architecture. Detailed description of the applied methods was presented by Tokarski and Świerczewska (2005).

Exposure "Na Kocie"

The studied exposure (Fig. 2) is situated in the hanging wall of the Bystrica slice thrust over the Rača slice, ca. 1,200 m away from the thrust surface. The present-day erosional margin of the Nowy Sącz Basin, coinciding with the extent of the Neogene infill, is placed 300 m due south of "Na Kocie" exposure.

The analysed rock series is exposed in a 19-m-high, undermined slope of a small stream valley. The lower part, 11 m high (Fig. 3), is composed of paraconglomerates bearing sandstone intercalations. This complex is of Late Badenian and/or Early Sarmatian age (Oszczypko *et al.* 1991, and papers cited therein), and its base is not exposed. The Miocene complex is unconformably overlain by 8-m-thick Pleistocene fluvial gravels dated to the Elsterian-2 (Butrym *et al.* 1989, Oszczypko *et al.* 1992). Both complexes are separated by an erosional surface.

Miocene complex

The Miocene paraconglomerates are both clast- and matrix-supported. The sandy-calcareous cement makes up to 22% of the rock volume. Clasts are up to 30 cm in diameter and are composed exclusively of rocks occurring in the Outer Carpathians (Magura Nappe). The studied population of 100 clasts includes: marls (37%), siltstones (2%), and fine- (29%), medium- (27%) and coarse-grained (5%) sandstones. The clasts are: well rounded (13%), rounded (23%), sub rounded (35%), sub angular (28%) and angular (1%), and are orderly arranged (Fig. 4A). The "a" axes of the clasts plunge gently (<30°) to the NNW and SSE, less frequently to the NNE and SSW. Most of the clasts are discoidal or ellipsoidal in shape.

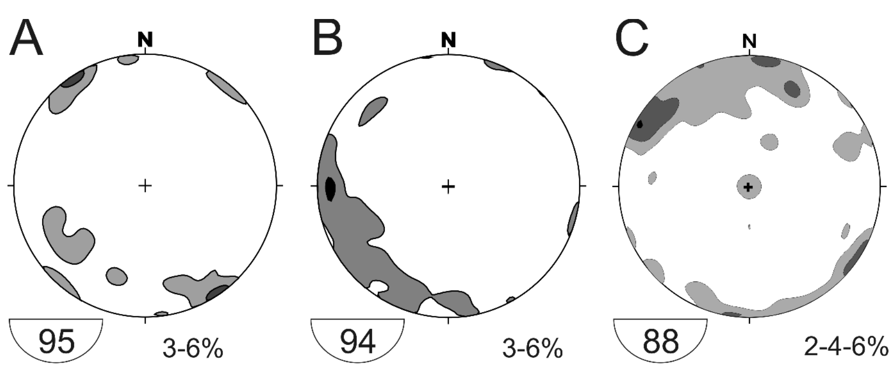

Fig. 4. Orientation of "a" axes of clasts: **A** – Miocene conglomerate (Na Kocie); **B** – Pleistocene conglomerate (Na Kocie); **C** – Pleistocene gravels (Kwasowiec; based on Tokarski, Świerczewska 2005); lower hemisphere plots; number in semicircle (lower left corner) is the number of measurements.

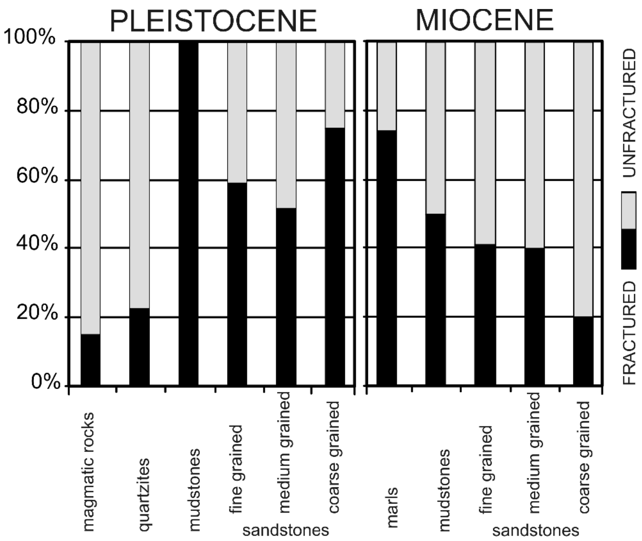

Fig. 5. Histogram showing percentage of fractured clasts for individual lithologies.

The lower portion of the Miocene complex bears a lens-like intercalation of sandstones alternating with siltstones and claystones, 250 cm long and up to 80 cm thick. The upper boundary is sharp, the lower one transitional. The uppermost portion of the Miocene complex bears another sandstone intercalation, up to 1 m thick. The last sandstone intercalation is presently poorly exposed and therefore we have not studied it in detail.

Pleistocene complex

The Pleistocene paraconglomerates are both clast- and matrix-supported. The share of sand-silty matrix does not exceed 27% of the rock volume, and clasts are up to 27 cm in diameter. Apart from rocks building the Magura Nappe, there also occur clasts of quartzites and magmatic rocks derived from the Inner Carpathians (cf. Butrym *et al.* 1989, Oszczypko *et al.* 1992). The studied population of 100 clasts comprises: mudstones (1%), fine- (23%), medium- (32%) and coarse-grained (4%) sandstones, quartzites (19%), and magmatic rocks (21%). The clasts are well rounded (37%), rounded (41%), sub-rounded (18%) and sub-angular (4%), and are arranged orderly (Fig. 4B). The majority of clast “a” axes plunges gently (<30°) towards the west and south. Most clasts are discoidal or ellipsoidal in shape.

Fractured clasts

Paraconglomerates of both complexes bear numerous clasts cut by one fracture and some clasts cut by several fractures. These fractures are restricted to single clasts; the matrix is not fractured.

In the Miocene conglomerate, a population of 100 large clasts (>2 cm) comprises 50% fractured clasts, while in the Pleistocene conglomerate; the respective share of this group is 45%. Population of 50 small clasts (<2 cm) contains 22% of fractured clasts in the Miocene conglomerate, and amounts to 26% in the Pleistocene conglomerate. Different lithologies represent different numbers of fractured clasts; clasts of detrital rocks tend to have more fractures compared to quartzites and magmatic rocks (Fig. 5).

Clast architecture is well organized and similar in both conglomerates (Fig. 6). Most of the fractures are arranged sub-vertically, and tend to form two sets oriented NW and NE. The latter set is less common in the Miocene conglomerate. The proportion of fractures situated at right angle and nearly perpendicular (80–90°) to clast a-b surfaces amounts to 37% and 50% in the Miocene and Pleistocene conglomerates, respectively (Fig. 7).

In both conglomerates, infrequent clasts are cut by normal faults (Fig. 8) of throws up to 13 mm. These faults do not pass into the matrix.

Structures within sandstones

A sandstone intercalation exposed in the lower part of the Miocene complex is cut by numerous reverse faults of displacements up to 1 cm (Fig. 9A). Poles to both fault planes and bedding surfaces plot on a single great circle, whose axis is horizontal and oriented NE–SW (Fig. 9B). Joints cutting this sandstone body are oriented both perpendicular (NW) and parallel (NE) to the reconstructed axis of the great circle. Identically oriented fractures (NW and NE) cut a pebble situated in the lower portion of this body.

INTERPRETATION

The architecture of clast-cutting fractures is well organized and comparable in both conglomerates (Fig. 6), imply-

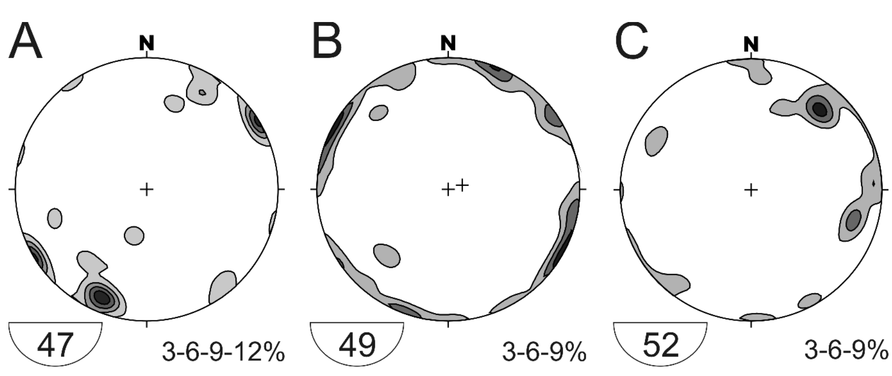

Fig. 6. Orientation of clast-cutting fractures: **A** – Miocene conglomerate at exposure “Na Kocie”; **B** – Pleistocene conglomerate at exposure “Na Kocie”; **C** – Pleistocene gravels (population II) at Kwasowiec (C – based on Tokarski, Świerczewska 2005).

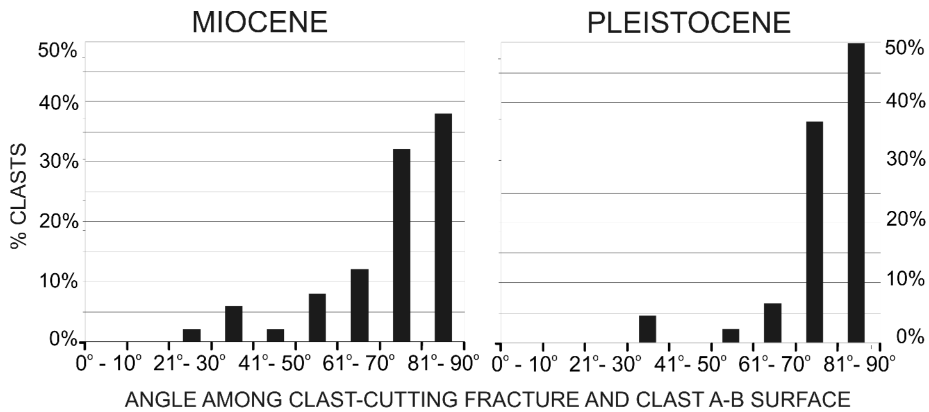

Fig. 7. Histogram showing angles among clast-cutting fractures and clast a-b surfaces: **A** – Miocene conglomerate; **B** – Pleistocene conglomerate.

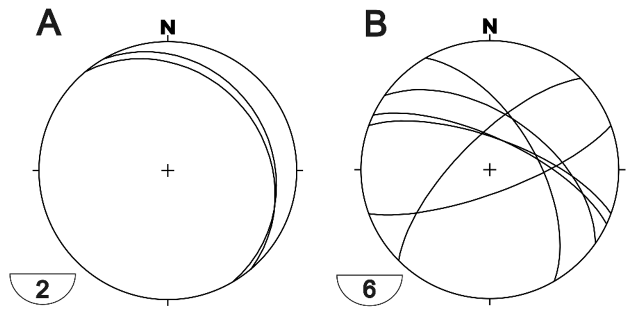

Fig. 8. Normal faults cutting clasts within conglomerates of Miocene (**A**) and Pleistocene (**B**) age; lower hemisphere plots; number in semicircle (lower left corner) is the number of measurements; each fault is represented by a great circle.

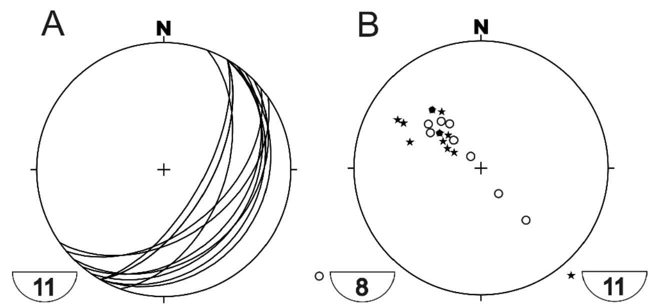

Fig. 9. Structures comprised within sandstone intercalation in the lower part of the Miocene complex: **A** – reverse faults; **B** – poles to reverse faults (asterisks) and bedding surfaces (small circles); numbers in semicircles (lower corners) denote number of measurements.

ing that fractures in the two complexes were formed *in situ* and are of the same origin.

We infer that the sandstone intercalation in the lower part of the Miocene complex originated during deposition of the latter as a channel fill that was later folded. This is testified to by the position of poles to bedding on a single great circle (Fig. 9), the axis of which is horizontal and oriented NE–SW. The same great circle bears poles to reverse faults, which cut the rock body in question. It means that both folding and reverse faulting took place in a compression stress field of $\acute{o}_1$ oriented NW–SE.

Most of clast-cutting fractures in the two conglomerates are sub-vertical and clustered into two sets oriented NW and NE. We conclude that these fractures represent joints formed in a compression stress field of σ_1 oriented NW. The NW-striking fractures are extensional features parallel to σ_1 σ_2 plane, whereas NE-striking fractures represent joint surfaces formed during stress relaxation (cf. Caputo 1995). In addition, fractures cutting clasts in the two conglomerates are parallel to joints within sandstone intercalation in the lower part of the Miocene complex. This implies that all these structures, except for normal faults, originated in the same stress field.

DISCUSSION AND CONCLUSIONS

1. In both complexes, the number of fractured clasts is positively correlated with the clast size, and negatively correlated with the diameter of grains in clasts of detrital rocks (Fig. 5). The number of fractured clasts increases in clasts of detrital rocks, compared to those of quartzites and magmatic rocks. These data point to the role of clast size and lithology in controlling the number of fractured clasts, as already shown by Tokarski and Świerczewska (2005).

2. Clast-cutting fractures are well organized (Fig. 6), irrespectively of the orientation of clast "a" axes which are different for each complex (Fig. 4). This means that such fractures were formed *in situ* and that clast orientation does not influence the bearing of fractures.

3. The degree of clast roundness at Kwasowiec (cf. Tokarski, Świerczewska 2005) is much worse compared to that of both "Na Kocie" complexes. This implies that the degree of roundness does not influence the orientation of neofractures (cf. Fig. 6C).

4. The two conglomerates studied at "Na Kocie" exposure bear clasts cut by fractures oriented both at right angle or nearly perpendicular (80–90°) and at smaller angles (<80°) to the clast a-b surfaces (Fig. 7). This observation supports our previous conclusion (Tokarski, Świerczewska 2005) that

such an orientation of fractures can be diagnostic for fractures formed *in situ* in the studied gravels and conglomerates.

5. Fractures cutting clasts within the conglomerates represent extensional joint fractures that were formed in a compression stress field, of σ_1 oriented NW–SE. The sandstone intercalation in the lower part of the Miocene complex was folded and reverse-faulted in the same stress field. It is probable that the origin of these deformations was related to neotectonic activity of the Bystrica thrust. Similar architecture of joints cutting clasts in the Pleistocene fluvial gravels at Kwasowiec (Fig. 6C) appears to suggest that this activity must have been of a wider extent. In contrast, the origin of normal faults cutting clasts of both complexes was probably different and associated with neotectonic activity of the margin of the Nowy Sącz Basin.

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REFERENCES

Butrym J., Krysowska-Iwaszkiewicz M., Oszczypko N., Zuchiewicz W. 1989. Late Cenozoic Conglomerates on NW Margin of the Nowy Sącz Basin, West Carpathians, Poland. *Bulletin of the Polish Academy of Sciences, Earth Sciences* 37, 179–191.

Caputo R. 1995. Evolution of orthogonal sets of coeval joints. *Terra Review* 7, 479–490.

Oszczypko N. 1973. The geology of the Nowy Sącz Basin. *Biuletyn Instytutu Geologicznego* 271, 101–197 (in Polish with English summary).

Oszczypko N., Rutkowski J., Zuchiewicz W. 1992. Brzezna. Coarse-clastic Neogene and Quaternary sediments on the NW margin of the Nowy Sącz Basin (original: Brzezna. Gruboklastyczne utwory neogenu i czwartorzędu północno-zachodniego obramowania Kotliny Sądeckiej). In Zuchiewicz W., Oszczypko N. (eds) *Przewodnik LXIII Zjazdu Polskiego Towarzystwa Geologicznego, Koninki, 17-19 września 1992*, 160–165. Instytut Nauk Geologicznych UJ, Państwowy Instytut Geologiczny, Polskie Towarzystwo Geologiczne, Kraków (in Polish).

Oszczypko N., Stuchlik L., Wójcik A. 1991. Stratigraphy of Fresh-Water Miocene Deposits of the Nowy Sącz Basin, Polish Western Carpathians. *Bulletin of the Polish Academy of Sciences, Earth Sciences* 39, 433–445.

Oszczypko N., Wójcik A. 1989. Detailed Geological Map of Poland, 1:50,000, sheet Nowy Sącz (original: Szczegółowa Mapa Geologiczna Polski 1:50 000, arkusz Nowy Sącz). Państwowy Instytut Geologiczny, Warszawa (in Polish).

Tokarski A.K. 1978. Orogenesis and morphogenesis of Outer Carpathians and plate tectonics. *Studia Geologica Carpatho-Balcanica* 12, 29–43.

Tokarski A.K., Świerczewska A. 2005. Neofractures versus inherited fractures in structural analysis: A case study from Quaternary fluvial gravels (Outer Carpathians, Poland). *Annales Societatis Geologorum Poloniae* 75, 95–104.

Zuchiewicz W. 1984. The Late Neogene–Quaternary tectonic mobility of the Polish West Carpathians. A case study of the Dunajec drainage basin. *Annales Societatis Geologorum Poloniae* 54, 133–189.

Zuchiewicz W., Tokarski A.K., Jarosiński M., Márton E. 2002. Late Miocene to present day structural development of the Polish segment of the Outer Carpathians. *Stephan Mueller Special Publication Series* 3, 185–202.

Żytko K., Zając R., Gucik S, Ryłko W., Oszczypko N., Garlicka I., Nemčok J., Eliaš M., Menčik E., Stranik Z. 1989. Map of the tectonic elements of the Western Outer Carpathians and their foreland. In Poprawa D., Nemčok J. (eds.) *Geological Atlas of the Western Carpathians and their Foreland, 1: 500,000*. Państwowy Instytut Geologiczny, Warszawa.