# The Cracow-Częstochowa Upland (Southern Poland) — The Land of White Cliffs and Caves

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The Cracow and the Częstochowa uplands, known under the joint name the Cracow-Częstochowa Upland, are located in southern Poland and belong to the larger unit — the Cracow-Wieluń Upland, which forms a strip of land about 160 km long and about 20 km wide (Fig. 1). This is a vast area of gentle hills rising about 100 m above the surrounding valleys. Simultaneously, the Cracow-Wieluń Upland is one of the best-known area in Europe where Upper Jurassic carbonate buildups are exposed and preserved as spectacular and picturesque rock towers, pinnacles, cliffs and monadnocks.

The exposures of Upper Jurassic limestones extend from Cracow to Wieluń. The rocks show distinct regional diversity. The best-known elements of the upland relief are picturesque cliffs built of Upper Jurassic (Oxfordian and Kimmeridgian) limestones in which numerous karst features can be observed. The scenic value of these cliffs is reflected in a common name of the area between Cracow and Częstochowa — "The Cracow-Częstochowa Jurassic Terrain" (Różycki, 1953) or "Polish Jurassic Chain" (Różycki, 1960). For centuries cliffs and high hills' summits have been the sites of castles and fortified churches. These landforms determine the scenic value of the Jurassic Terrain being the top-class aesthetic, geological, geomorphological and educational treasures (Nita, 2004).

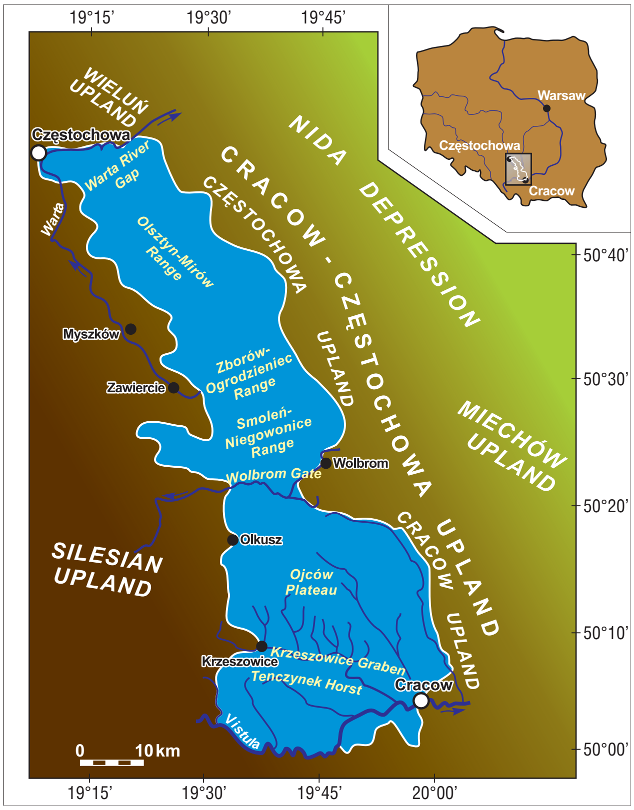


**Fig. 1.** Location and geographic division of the Cracow-Częstochowa Upland with hill ranges

## The relief

Among three uplands constituting the Cracow-Wieluń Upland, the northernmost is the Wieluń Upland, which extends between Wieluń and Częstochowa towns. This is a plateau of low elevation (about 300 m a.s.l.) and insignificant relative heights. It is covered with Quaternary fluvio-glacial and aeolian deposits from which the Upper Jurassic rocks locally protrude.

The "Land of White Cliffs and Caves" includes the remaining two uplands — the Częstochowa Upland and the Cracow Upland. The relief of the Częstochowa Upland is highly diversified. The landscape is dominated by structurally controlled planation surface (Nita, 2004) with limestone massifs, ridges and hills capped by spectacular cliffs (Figs. 2, 3). The elevation of the upland reaches 500 m a.s.l. A special feature of hill ranges built of Upper Jurassic limestones is their strike concordant with the parallel of latitude. The monadnocks rising from the plateau are of erosional origin (Pokorny, 1963). In the Upper Jurassic limestones intensive karstification is observed, which results in a variety of karst features: caves, vast depressions resembling the "polje" (Pulina, 1999) and other morphological depressions with karst springs and ponors (Głazek et al., 1992). It is suggested that some caves developed within the Upper Jurassic limestone massifs overlying the tectonic zones in the Paleozoic basement by combined action of meteoric and hydrothermal solutions (Pulina et al., 2005). Among over 1800 caves discovered in the Cracow-Wieluń Upland both the longest ("Wierna", 1027 m) and the deepest ("Studnisko", 77.5 m below surface) caves are located in the Częstochowa Upland (Gradziński & Szelerewicz, 2004).

The southernmost component of the Cracow-Wieluń Upland — the Cracow Upland — is a rolling plateau with low hills and ridges built of Upper Jurassic rocks. The ridges are monadnocks formed by selective erosion of facially diversified Upper Jurassic rocks (Alexandrowicz & Alexandrowicz, 2003). Highest hills rise to over 500 m a.s.l. The plateau is dissected by deep valleys where karst springs and ravines can be found (Głazek et al., 1992). In their slopes numerous cliffs are observed, full of a number of karst features including spectacular caves (Figs. 4, 5; Gradziński, 1962, Dżułyński et al., 1966; Gradziński & Szelerewicz, 2004). One of such forms is the "Ciemna (Dark) Cave" where the largest chamber among all caves in the Cracow-Wieluń Upland has been discovered (over 80 m long and 30 m wide; Gradziński & Szelerewicz, 2004). In the landscape of the Cracow Upland three morphological forms are distinct: planation surfaces, deeply incised valleys and ravines, and limestone cliffs towering over the plateau and framing the valley slopes (Dżułyński, 1953; Alexandrowicz & Alexandrowicz, 2003). The strikes of the valleys correspond to orthogonal joint system in the Upper Jurassic rocks (Małecki, 1958).

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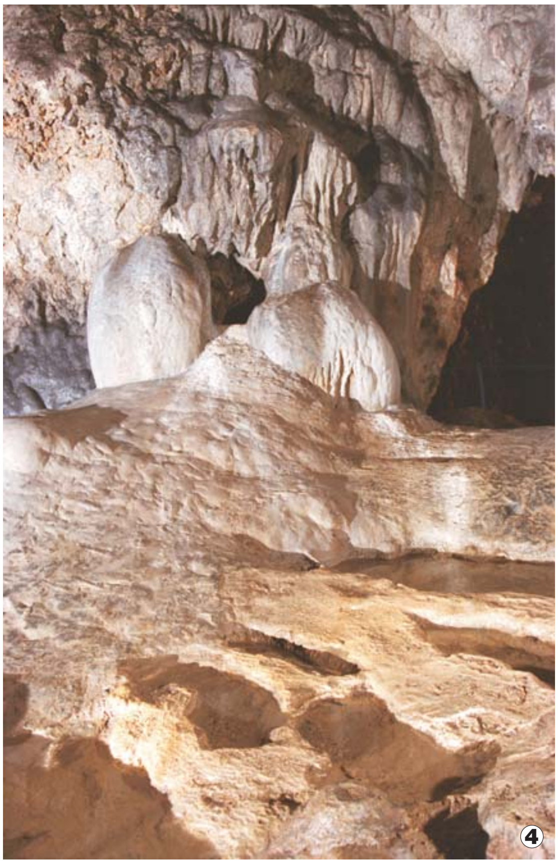




**Fig. 2.** The Ogrodzieniec Castle integrated into the Upper Jurassic carbonate buildups complex. Courtains connect the carbonate buildups. The Częstochowa Upland; Zborów-Ogrodzieniec Range. Photo by A. Walanus

**Fig. 3.** In the "Rzędkowice Cliffs" both the Upper Jurassic carbonate buildups of impressive shapes (right side) and the debris flow deposits (cliff on the left) are observed. The Częstochowa Upland; Zborów-Ogrodzieniec Range. Photo by J. Matyszkiewicz

**Fig. 4.** The "Nietoperzowa (Bat) Cave" developed in Upper Jurassic massive limestones with vadose and phreatic karst features. The Cracow Upland; Ojców Plateau. Photo by A. Dajek

**Fig. 5.** Landscape of the Vistula River valley in the western part of Cracow. The Tyniec Abbey was founded onto the Upper Jurassic rocks forming a fragment of carbonate buildups complex. In the foreground — the "Okrąglik Cliff" with the "Nad Galoską Cave" are seen where the oldest human settlement in the vicinity of Cracow was discovered. The Cracow Upland. Photo by J. Matyszkiewicz

## Geology

The Cracow-Wieluń Upland is a part of large tectonic units — the Silesian-Cracow Monocline — built of Triassic, Jurassic and Cretaceous sediments (Fig. 6). These rocks unconformably overlay various, folded Paleozoic (locally, even the Precambrian) units of the Paleozoic European Platform. The Silesian-Cracow Monocline extends NNW-SSE. Together with preserved fragments of Permian formation it constitutes the Permian-Mesozoic structural complex, which unconformably covers the diversified paleorelief of denudated Paleozoic basement. Formation of the Silesian-Cracow Monocline has initiated in the Young Cimmerian orogenic phase but its final structural pattern is mostly an effect of Laramide movements and, to less extent, also the Miocene deformations.

### Pre-Jurassic basement

The Paleozoic rocks, which form the basement of the Silesian-Cracow Monocline crop out in a few localities from which the most important occur in the southern part of the Cracow Upland. The Paleozoic formations are cut by the Cracow-Lubliniec Fault Zone (Buła et al., 1997; Buła, 2000, 2002; Żaba, 1999) which is presumably a segment of transcontinental Hamburg-Cracow Tectonic Line (Franke & Hoffman, 1999). The Cracow-Lubliniec Fault Zone has probably early Proterozoic roots. It separates two tectonic blocks: the Upper Silesian and the Małopolska ones located in the southwestern foreland of the Eastern European Craton, within the Central European part of the Paleozoic Platform (Dadlez et al., 1994). Both the Małopolska and the Silesian blocks are members of a mosaic of crustal terranes, all showing diversified internal structures, ages and origin. From all sides the blocks are bordered by distinct, deep structural discontinuities represented by multistage, frame fault zones commonly of transcontinental scale. In the border zone of the Silesian and Małopolska blocks various Lower Paleozoic and older structural complexes are in direct contact. These units differ in lithology, age, character and intensity of transformations, and tectonic style (Buła, 2002; Żaba, 1999). Common complexes in both blocks have started to form as late as in the Early Devonian.

The activity of the Cracow-Lubliniec Fault Zone is closely connected with the magmatism, particularly with granitoid plutons located exclusively in the marginal part of the Małopolska Block. The Cracow-Lubliniec Fault Zone shows numerous bends and arches, and its width usually does not exceed 500 m (Żaba, 1999; Buła et al., 1997; Buła, 2000, 2002). The zone has been active since the Oldest Paleozoic to the Recent (Żaba, 1999; Morawska, 1997) and influenced both the facial development of overlying Triassic and Jurassic rocks (Jędrys et al., 2004; Krajewski & Matyszkiewicz, 2004; Matyszkiewicz et al., 2006a, 2006b) and the tectonic pattern of the overburden (Żaba, 1999). It also probably determined, to some extent, the development of karst processes in the Upper Jurassic complex (Pulina et al., 2005).

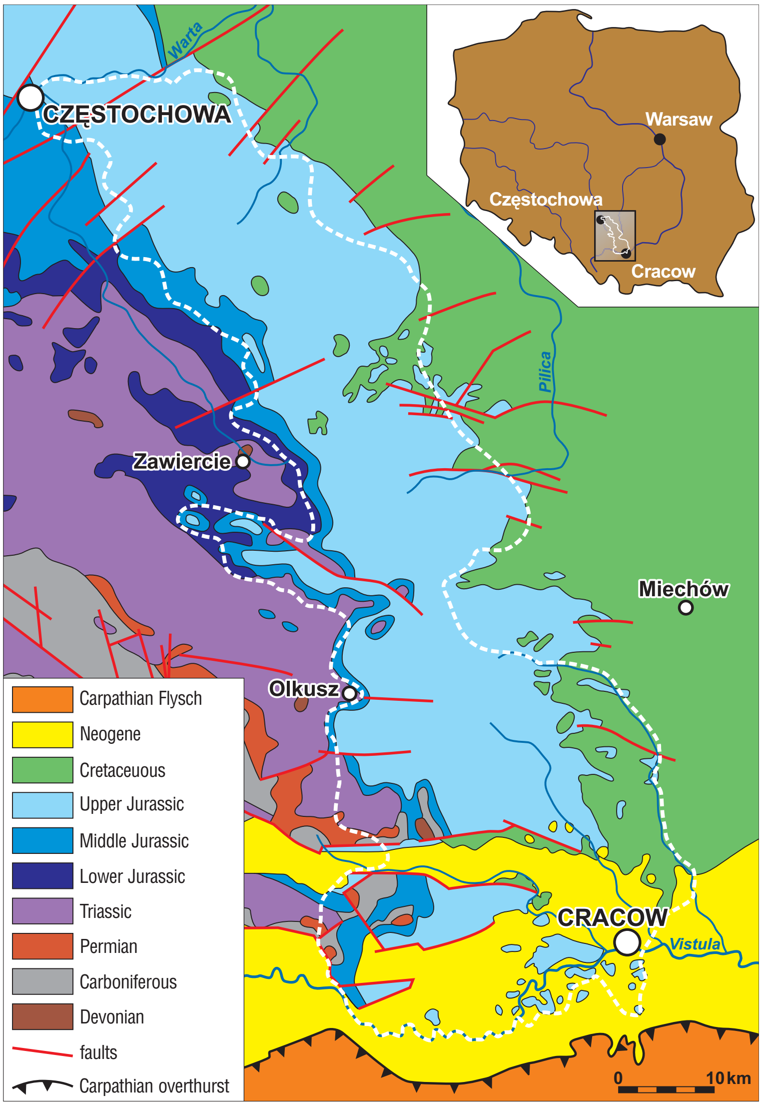


**Fig. 6.** Simplified geological map of the Cracow-Częstochowa Upland without Quaternary strata (after Rühle et al., 1977)

### Development of Upper Jurassic rocks in the Polish Jurassic Terrain

In both the Częstochowa and the Cracow uplands the Upper Jurassic rocks cover the Middle Jurassic strata or lie directly upon the older, Paleozoic basement. In the last years, in the Zalas quarry located in southern part of the Cracow Upland an exposure was discovered in which Upper Jurassic rocks directly lie upon the Permian rhyodacitic intrusion (Matyszkiewicz et al., 2007). In both the Częstochowa and the Cracow uplands Upper Jurassic strata represent the Oxfordian and the lower part of the Kimmeridgian. Generally, the rocks can be divided into the bedded and the massive facies, both characterized by significant facial diversity (Dżułyński, 1952; Różycki, 1953).

### The bedded facies

In both uplands the Upper Jurassic succession includes a dozen-meter-thick series of marls and marl-limestone alternations belonging to the Lower Oxfordian and to the lower part of the Middle Oxfordian. Sometimes, these strata are named the Jasna Góra Beds (from the name of the hill atop of which the famous Holy Mary Sanctuary is located; Różycki, 1953). The late Middle Oxfordian, the Upper Oxfordian and the Middle Kimmeridgian rocks show high diversification of bedded facies. In the Częstochowa Upland poorly lithified bedded limestones with rare cherts dominate. These strata bear local names (Różycki, 1953; Kutek et al., 1977; Trammer, 1985; Heliasz, 1990; Głazek et al., 1992; Kutek, 1994). In the Cracow Upland the bedded facies is represented by thin-bedded, platy, chert-free limestones locally intercalated by thin marl layers. However, these rocks, although determined as "platy limestones" (Dżułyński, 1952), differ significantly from classic, lithographic limestones of the Solnhofen type. Both the Middle and Upper Oxfordian rocks are developed mostly as thick-bedded limestones with cherts (Dżułyński, 1952; Matyszkiewicz, 1989, 1997; Krajewski, 2000) and minor clotted, pelitic and chalky limestones (Krajewski, 2001).

In both uplands, in the whole Upper Jurassic complex the gravity-flow deposits occur locally (Bukowy, 1960; Marcinowski, 1972; Bednarek et al., 1978; Kutek & Zapaśnik, 1992; Koszarski, 1995; Matyszkiewicz, 1996; Krajewski, 2000; Matyszkiewicz & Olszewska, 2007; Matyszkiewicz et al., 2007). Frequency of their occurrence increases up the Upper Jurassic sequence, which is an effect of diversified paleorelief of topographic prominence about 100 m (Fig. 9; Matyszkiewicz, 1999), produced by both the aggradational growth of carbonate buildups and the active, Late Jurassic synsedimentary tectonics (Kutek, 1994; Matyszkiewicz, 1997; Krajewski, 2000).

## The massive facies

In the Częstochowa Upland carbonate buildups form isolated complexes, which have started to grow in the Early Oxfordian, as revealed by the presence of small spongeous bioherms in the Jasna Góra Beds (Trammer, 1985, 1989). In this area microbial-spongeous buildups are gradually replaced to the north by spongeous-microbial ones of poorly developed rigid framework, which makes them less resistant to weathering. In Kimmeridgian strata from the Częstochowa area the coral patch reefs appear (Roniewicz & Roniewicz, 1971; Heliasz & Racki, 1980). Facial diversity and resulting differences in resistance against weathering gave rise to the formation of carbonate monadnocks in the Częstochowa Upland that contributed to prominent morphological diversity of this area (Figs. 2, 3).

Similarly to the Częstochowa Upland, the development of massive facies in the Cracow Upland has commenced in the Early Oxfordian. At the Early/Middle Oxfordian break small spongeous and spongeous-microbial bioherms were formed. In the Middle and Late Oxfordian intensive aggradational growth led to the formation of larger, microbial-spongeous buildups (Fig. 5) followed by microbial ones (Trammer, 1985, 1989; Matyszkiewicz, 1989, 1997; Matyszkiewicz & Felisiak, 1992; Matyszkiewicz & Krajewski, 1996; Krajewski, 2000, 2001; Matyszkiewicz et al., 2006a, 2006b). The peak of buildup growth in the Cracow Upland came in the Late Oxfordian when progradation produced a single, vast carbonate complex (Krajewski, 2001).

## Structural frames of Upper Jurassic buildups distribution in the Polish Jurassic Terrain

Comparison of the structure of Paleozoic basement with the local facial diversity of Upper Jurassic deposits revealed a distinct coincidence between the magmatic activity along the Cracow-Lubliniec Fault Zone, and the localization of large carbonate buildups in the Polish Jurassic Terrain. Positions of two main granitoid complexes of the Paleozoic basement correspond to the positions of main hill ranges built of Upper Jurassic massive limestones (Fig. 7). Such coincidence suggests that both the formation and the growth of carbonate buildups were strongly influenced by the presence of granitoid intrusions in the basement (Matyszkiewicz et al., 2006a, 2006b, 2007).

Due to higher resistance to weathering in comparison with enclosing Paleozoic deposits, some intrusions were not completely denudated before the Late Jurassic and were left as morphological heights of the shelf bottom (Dżułyński, 1950; Matyszkiewicz et al., 2007). The areas where denudation of Paleozoic basement did not reach the top surfaces of granitoid batholiths were subjected to lower subsidence in comparison with adjacent areas (Fig. 8) and, thus, become favorable sites of structural uplifts known from the Upper Jurassic basin (Fig. 9). In the uplifts high water circulation rates and related supply of nutrients gave rise to intensive production of carbonate rocks and flourishing growth of benthic fauna, leading to the formation of vast complexes of carbonate buildups. The buildups formed also over numerous, small intrusions and then expanded and coalesced into large complexes (Matyszkiewicz et al., 2006a). Detailed microfacial studies of carbonate buildups complex from the "Zegarowe (Clock) Rocks" located in the southern part of the Częstochowa Upland suggest that locally the physical and chemical properties of sea water and its salinity might have been modified by hydrothermal solu-

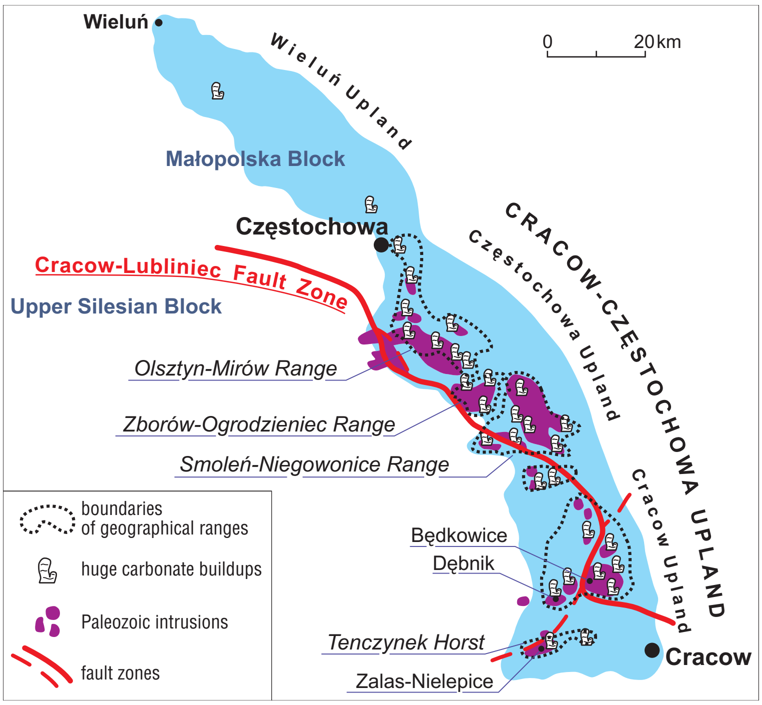


**Fig. 7.** Location of main complexes of the Upper Jurassic carbonate buildups versus Paleozoic intrusions in the Cracow-Częstochowa Upland (after Jędrys et al., 2004; modified)

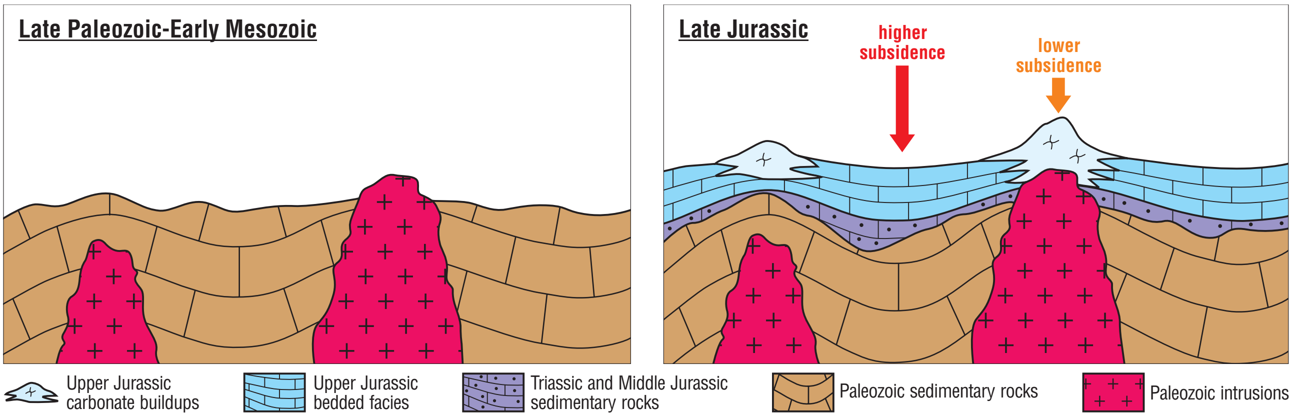


**Fig. 8.** Factors controlling the growth of Upper Jurassic carbonate buildups in the Cracow-Wieluń Upland. Not to scale. The Late Paleozoic — Early Mesozoic denudation of Paleozoic deposits locally reached the top of intrusions which, due to increased resistance to weathering, built highs upon the Late Jurassic carbonate ramp. In most cases, however, the Early Mesozoic denudation did not reach the top of intrusions. The Late Jurassic growth of carbonate buildups proceeded upon highs of the sea bottom underlain by intrusions (right-hand side of the sketch). At those places where denudation did not reach the top of intrusions, differential subsidence led to the formation of sea bottom highs that became colonized by benthic organisms, whose intense development favored the origin of carbonate buildups (after Matyszkiewicz et al., 2006b)

tions ascending along large deep fractures of the Cracow-Lubliniec Fault Zone (Matyszkiewicz et al., 2006a).

The carbonate buildups complexes of the Cracow-Wieluń Upland do not continue north of Częstochowa. In that area the Cracow-Lubliniec Fault Zone and the related intrusions extend outside the Upland, which confirms the evident relationships of Late Jurassic deposition with the Paleozoic basement structures. It seems that an important controlling factor of buildups distribution in the Polish Jurassic Terrain was also the Jurassic synsedimentary tectonics reflected in numerous gravity flow deposits and neptunic dykes (Fig. 9; Kutek, 1994; Matyszkiewicz, 1996, 1997; Krajewski, 2000). Therefore, the coincidence of several factors: diversified subsidence, synsedimentary tectonics and local discharge of hydrothermal solutions (Matyszkiewicz et al., 2006a) ascending along the Cracow-Lubliniec Fault Zone influenced the growth of at least some large complexes of carbonate buildups. The prese-

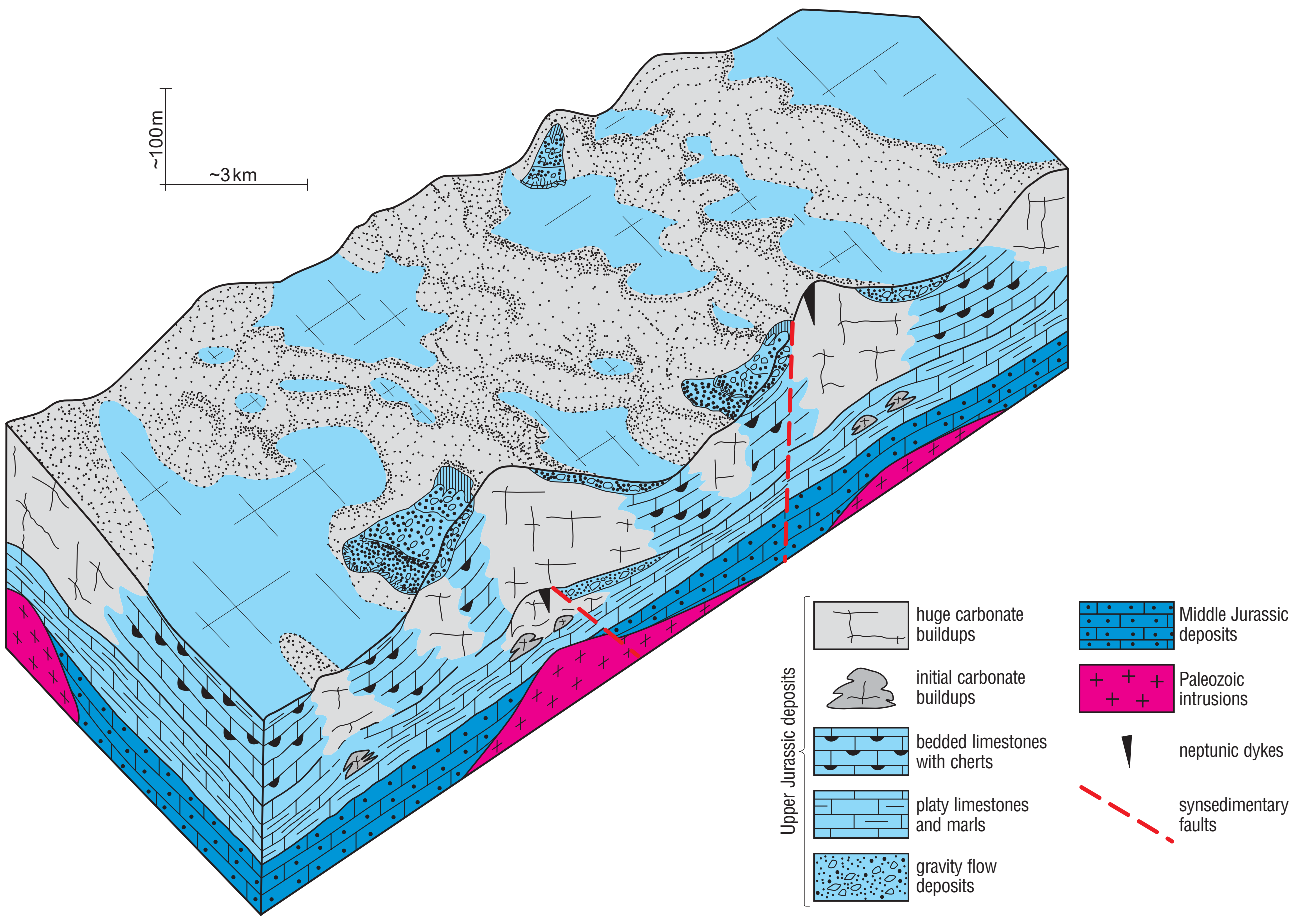


**Fig. 9.** Architecture of Late Jurassic sedimentary basin in the Cracow-Częstochowa Upland (after Matyszkiewicz, 1997; modified)

rved fragments of these buildups are currently the most valuable landforms of the Polish Jurassic Terrain.

This research was financed by the UST-AGH statutory grant no. 11. 11. 140. 560.

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