Acta Geologica Polonica, Vol. 54 (2004), No. 4, pp. 587-596

Biostratigraphy of the Santonian in the SW margin of the Holy Cross Mountains near Lipnik, a potential reference section for extra-Carpathian Poland

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ABSTRACT:

REMIN, Z. 2004. Biostratigraphy of the Santonian in the SW margin of the Holy Cross Mountains near Lipnik, a potential reference section for extra-Carpathians Poland. *Acta Geologica Polonica*, **54** (4), 587-596. Warszawa.

The set of outcrops near the village of Kije, on the SW margin of the Holy Cross Mountains provides a nearly complete Santonian succession that has a great potential to become a Santonian reference section in Poland. The Coniacian/Santonian boundary is defined here by the first occurrence (FO) of the inoceramid bivalve species *Cladoceramus undulatoplicatus* (ROEMER 1852). The uppermost Santonian is characterized by common *Sphenoceramus patootensiformis* (SEITZ 1965). The top of the stage (and the base of the Campanian Stage) is documented by the last occurrence (LO) of the crinoid species *Marsupites testudinarius* (SCHLOTHEIM 1820). The substage division of the Santonian is based on inoceramids, with the lower boundary of the Middle Santonian indicated by the LO of *Cladoceramus undulatoplicatus* and the base of the Upper Santonian by the FO of representatives of *Cordiceramus muelleri* (PETRASCHECK 1906) group.

Key words: Cretaceous, Santonian, Stratigraphy, Biostratigraphy, Magnetostratigraphy, Ammonites, Inoceramid bivalves, Crinoids.

INTRODUCTION

The purpose of the present paper is to document the lithostratigraphy and biostratigraphy of the Santonian succession near the villages of Lipnik and Kije, on the SW margin of the Holy Cross Mountains (Text-fig. 1). Good excavations, the permanent railway-cutting, together with a series of temporary exposures that appeared during my field work in the years 2000 and 2001, enabled the collection of rich inoceramid material, as well as ammonites and crinoids. Some of these taxa are recorded from Poland for the first time. This material allowed the application of the new Santonian stage and substage definitions discussed during the Brussels Symposium (LAMOLDA & HANCOCK 1996), as well as the introduction of a new biostratigraphic zonation. Although parts of the succession require further study, the Lipnik section may become a standard reference section for the Santonian in extra-Carpathians Poland.

The first accounts of the general succession and biostratigraphy of the Upper Cretaceous of the region were published by MAZUREK (1923a, 1925, 1926, 1932, and 1948). In the vicinity of Kije and Lipnik he recognized the Santonian, based on the occurrence of *Actinocamax verus* MILLER 1823, *Inoceramus patootensis* DE LORIOL (= *Sphenoceramus patootensiformis* SEITZ, 1965), *I. pachti* (= *S. pachti*) (ARKHANGELSKY 1912), *I. cardissoides* (= *S. cardissoides*) (GOLDFUSS 1835) and *Parapachydiscus carezi* (= *Nowakites carezi*) (DE GROSSOUVRE 1894).

In close proximity to the Kije-Lipnik area, Albian through Santonian deposits were recognized by MITURA (1954), and slightly farther to the west, north of Jędrzejów, the complete Upper Cretaceous succession was studied by SENKOWICZ (1959). He described the Santonian based on the occurrence of *Inoceramus pachti* (= *S. pachti*). In the northwestern part of the SW margin of the Holy Cross Mountains, CIEŚLIŃSKI (1956) described Santonian strata with *Actinocamax verus* and *Inoceramus patootensis* (= *S. patootensiformis*).

The inoceramid biostratigraphy of the Santonian in the study area was recently provided by WALASZCZYK (1992), in the context of his general study of the Turonian through Santonian of the Central Polish Uplands. He distinguished three inoceramid zones in the Santonian. The base of the stage he defined traditionally, with the FO of *Sphenoceramus pachti*, and its top with the LO of *Marsupites testudinarius*.

GEOLOGICAL SETTING

The study area constitutes part of the south-western margin of the Holy Cross Mountains (HCM), a border zone between the Szczecin-Łódź-Miechów Synclinorium, to the south, and the Mid-Polish Anticlinorium, to the north. The Santonian strata, like the whole Upper Cretaceous succession in the region, dip gently at 10 to 20° SW. The exposures form a narrow belt between Przedbórz in the NW and Busko Zdroj in the SE (Text-fig. 1)

The Santonian successions of the western and eastern parts of the Miechów Synclinorium differ markedly. In the north-eastern part, i.e. the south-western margin of the HCM, the Santonian forms an expanded and

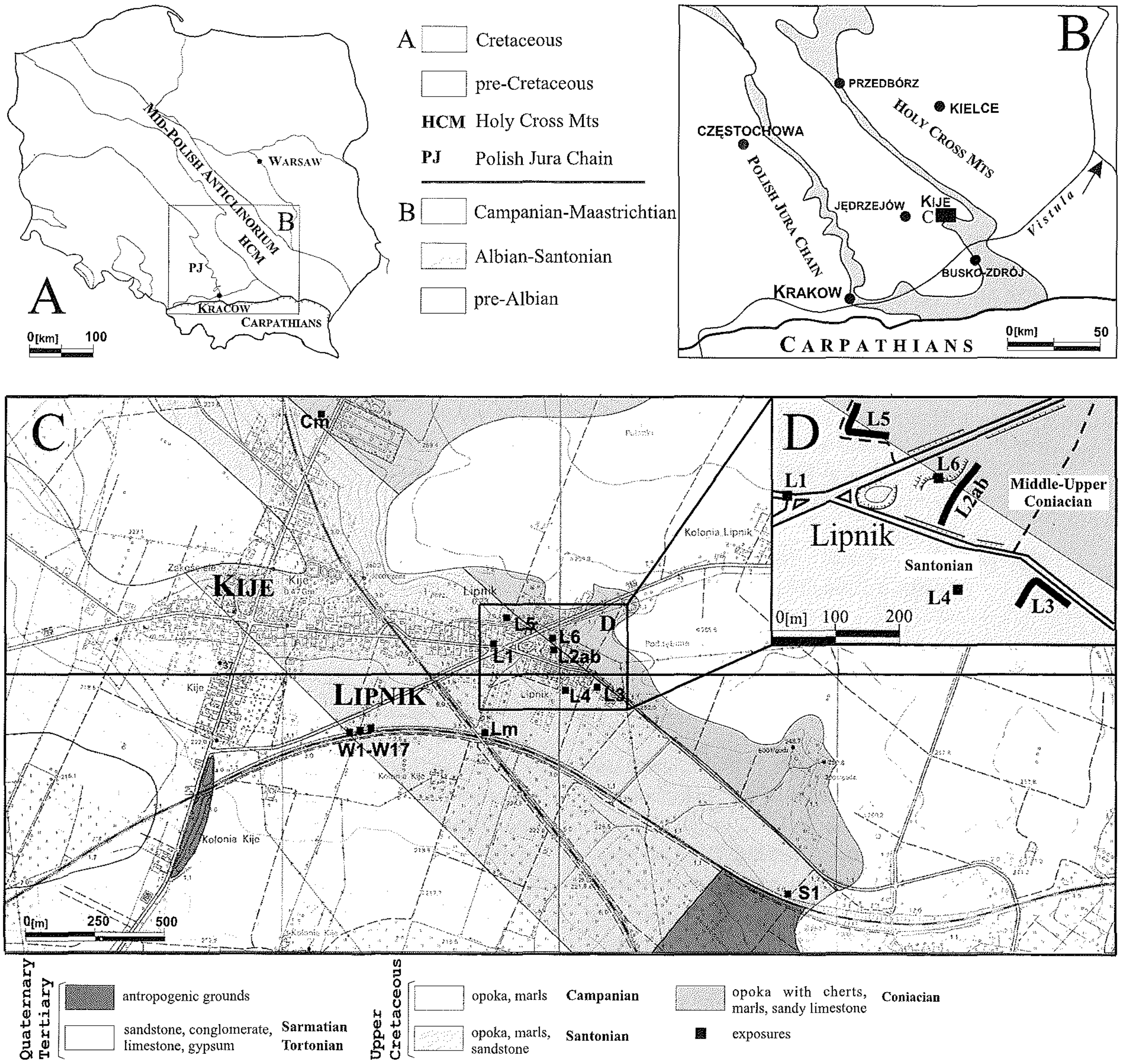

Fig. 1. A) Upper Cretaceous deposits in extra-Carpathians Poland; B) Geological sketch-map of the Miechów Through and location of the study area; C) Geological map of the study area. In comparison with previous map (SENKOWICZ, 1955), the Coniacian/Santonian boundary is moved toward the NW and the fault, as well as the Maastrichtian deposits shown in the SE part of the area do not exist; D) Exposures near Lipnik

stratigraphically complete, 150 m thick sequence, while in the south-western part, i.e. in the Polish Jura Chain, the succession is very incomplete and often only a few meters thick (MARCINOWSKI 1974, HELLER & MORYC 1984, WALASZCZYK 1992).

The Upper Coniacian, Santonian and Lower Campanian succession in the vicinity of Kije is definitely the best exposed interval of this part of the Upper Cretaceous in Poland.

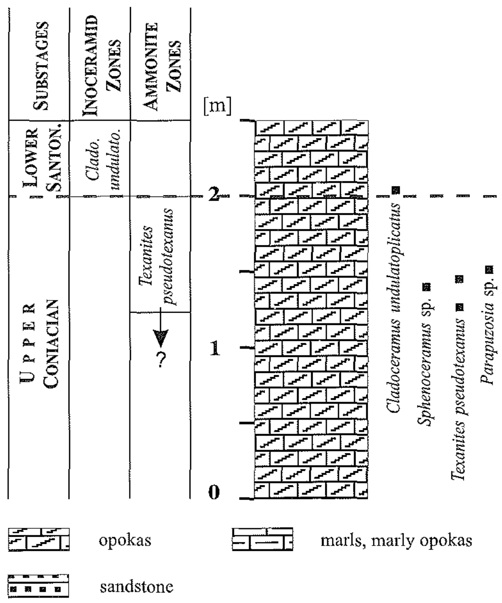

Fig. 2. Lithologic log and macrofaunal records in the L6 section (for location see fig. 2); *Clado. undulato.* = *Cladoceramus undulatoplicatus*

LOCALITY DETAILS

The Santonian in the study area is dominated by opokas, with subordinate marly limestone and thin bands of marls. The opokas are pale grey, hard and thick-bedded with sporadic quartz and glauconite and common inoceramid debris. The opokas pass gradually upwards into marls (Text-figs 1D, 4, 7; section L1). The marls are soft, grey and thin-bedded, with rare glauconite and quartz.

The opoka-dominated part approximates to the Lower Santonian. The marly part comprises the Middle and the Upper Santonian (Text-fig. 7)

The Middle-Upper Coniacian succession in the area is developed similarly to the Lower Santonian: opokas with subordinate marly limestone and marly intercalations. Biostratigraphic data are provided by two sections in Lipnik, L2ab and L6 (Text-fig. 1D). Section L2ab yielded numerous specimens of the Middle Coniacian zonal index, *Volviceramus* ex gr. *involutus* (J. DE C. SOWERBY 1828) and extends up to the base of the Santonian, which is documented here by occurrences of the inoceramid *Cladoceramus undulatoplicatus* (Text-fig. 4). The Coniacian – Santonian transition is apparently continuous, but the precise entry level of *C. undulatoplicatus* is unknown. The apparently continuous succession across the boundary in this section is confirmed by the observation in the L6 section of *Texanites pseudotexanus* (DE GROSSOUVRE 1894) in the lower part and *Cladoceramus undulatoplicatus* in its topmost part (Text-figs 2, 3) – simultaneously the lowest in situ occurrence of *C. undulatoplicatus*. The thickness of the Middle-Upper Coniacian exposed in the both sections is about 15-20 m, but the total thickness of the substages in the studied once is estimated at about 30 m.

Fig. 3. Photographic view of the L6 section with precise points of macrofaunal finds

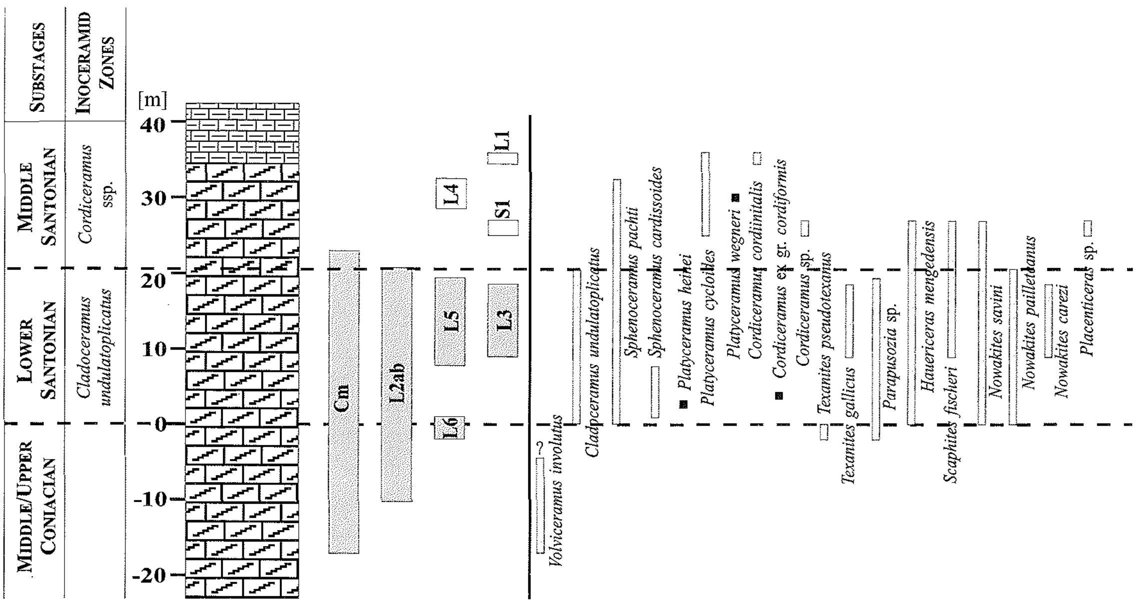

Fig. 4. Composite lithologic log and macrofaunal record for the Middle-Upper Coniacian and Lower Santonian of the study area. Black dots mark the position of specimens found in situ; ranges of specimens found loose are extended for the entire thickness of their source location

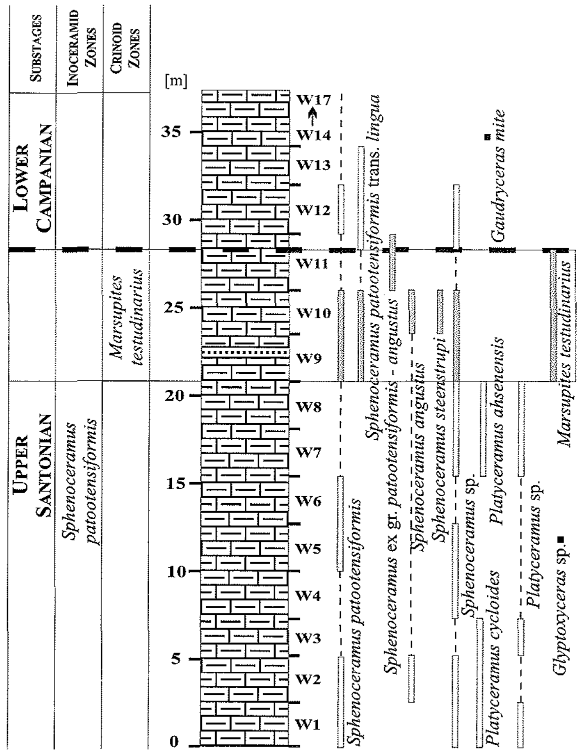

Fig. 5. Composite log of the Upper Santonian and basal Campanian of the railway-cutting compiled from the W1-W17 excavations (for their location see Fig. 1; their photographic view – see Figs 6a, 6b)

The Coniacian/Santonian boundary interval and the Lower Santonian strata were best exposed in the villages of Lipnik and Kije. Temporary exposures in these villages yielded most of the Early Santonian palaeontological material (Text-fig. 1D; sections L1, L2ab, L3, L4, L5, L6). Two other localities of Coniacian/Santonian age (Text-fig. 1C; Cm and S1), to the NW and SE of Lipnik respectively, can be easily correlated with localities in Lipnik (Text-figs 1, 4).

A fairly complete Santonian succession is accessible in the railway-cutting to the SW and SE of Lipnik (Text-fig. 1C; sections S1, Lm, W1-W17). The thickness of the Santonian is estimated here at about 170 m. The Lower Santonian is well exposed; the rest of the succession, particularly the Middle Santonian, needs some excavation to make the sections available for detailed study.

The Lower Santonian strata are readily accessible on the northern side of the railway-cutting about 1.5 km SE of Lipnik, opposite the 250.7 m hill (Text-fig. 1; section S1). The strata are fairly fossiliferous, with *Sphenoceramus* ex. gr. *pachti-cardissoides* relatively common throughout the succession.

To the NW, the hard Lower Santonian opoka passes into soft marls of the Middle Santonian. Exposures are very poor and only a few inoceramid specimens have been found.

Still higher in the Santonian succession, close to the railway bridge over the railway-cutting (Text-fig. 1C; section Lm), I found a single specimen of *Cordiceramus recklingensis* (SEITZ, 1961), a member of the *C. muelleri* (PETRASCHECK) group. This species is taken here as a

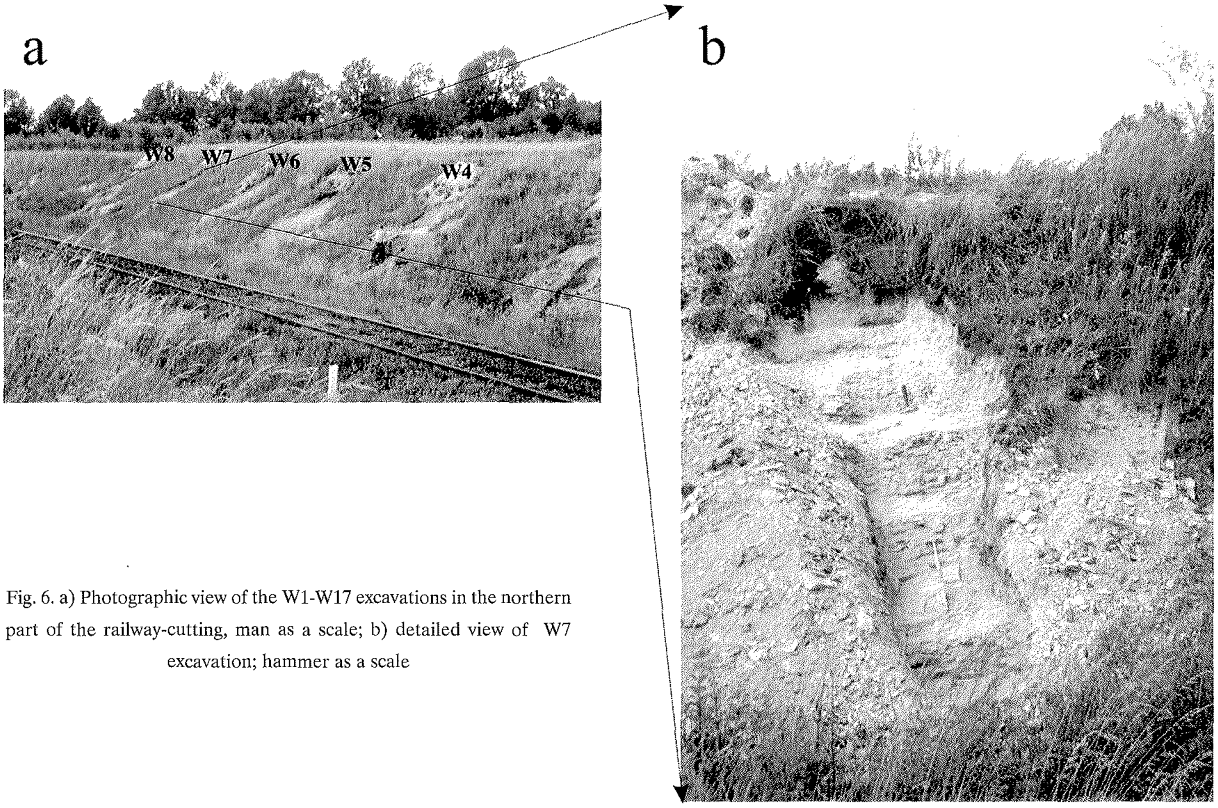

Fig. 6. a) Photographic view of the W1-W17 excavations in the northern part of the railway-cutting, man as a scale; b) detailed view of W7 excavation; hammer as a scale

boundary marker for the base of the Upper Santonian, but its precise entry level is unknown.

In the Upper Santonian, up to the base of the Campanian, there is a distinct increase in the abundance of inoceramids compared with the Middle Santonian. *Sphenoceramus patootensiformis* (SEITZ) is common, as are *Sphenoceramus angustus* (BEYENBURG, 1936) and *S. lingua* (GOLDFUSS, 1935). Relatively frequent are also large *Platyceramus cycloides* (WEGNER, 1905) and *P. ahsenensis* (SEITZ, 1961). These two species, which can measure up to 0.5-0.8 m, are often covered with *Ostrea boucheroni* WOODS *non* COQUAND. Ammonites are rare but some specimens of *Glyptoxoceras* sp. and *Gaudryceras mite* (HAUER, 1866) were noted. In the upper part of the Upper Santonian *Marsupites testudinarius* (SCHLOTHEIM) occurs commonly.

The Santonian/Campanian boundary transition was collected bed-by-bed in a series of artificial exposures (W1-W17) made on the northern side of the railway-cutting (Text-figs 1C, 5, 6a, 6b). The interval studied in this way embraces the uppermost Santonian and lowermost Campanian, and is approximately 35 m thick.

The whole Upper Santonian Substage and the lower Lower Campanian is composed of a monotonous succession of marls. In the uppermost part of the Santonian, close to the entry level of *Marsupites testudinarius*, occurs a bed of sandstone (thickness about 10 – 15 cm; Text-fig. 5). Above the LO of *M. testudinarius* no change in the macrofauna is observed, although it becomes less abundant. The ammonite *Gaudryceras mite* was noted exclusively from this interval.

BIOSTRATIGRAPHY

The stage and substage definitions as used herein follow the criteria accepted provisionally during the Brussels Symposium (KAUFMANN & *al.* 1996; LAMOLDA & HANCOCK 1996; HANCOCK & GALE 1996) and, partly at least, emended subsequently. Due to the occurrence of the key taxa in the study area most of the stage and substage boundaries could be drawn directly. In the case of the Upper Santonian, another basal boundary criterion is proposed herein, albeit one that appears to be equivalent to the Brussels proposal.

Following the Brussels criteria:

The base of the Santonian Stage was proposed at the entry level of *Cladoceramus undulatoplicatus*.

The base of the Middle Santonian Substage was proposed at the extinction level of *Cladoceramus undulatoplicatus*.

The base of the Upper Santonian Substage was proposed at the FO of *Uintacrinus socialis* GRINNELL

1876. In the study area this crinoid was not found and consequently the Brussels criterion cannot directly be applied. The base of the Upper Santonian is defined herein instead by the FO of *Cordiceramus muelleri*, which is supposed to approximate the Brussels criterion (e.g. NIEBUHR & *al.* 1999).

The base of the Campanian stage is marked by the extinction level of *Marsupites testudinarius*.

BIOZONATION

Inoceramids are the only macrofossil group which allows zonation of the entire succession investigated. Other macrofossils, known for their stratigraphical potential are either rare, such as ammonites, or almost totally absent, as in the case of belemnites. A single belemnite, *Actinocamax verus,* was reported by MAZUREK (1948).

The ammonite fauna is relatively common only in the Lower Santonian and it does not provide a basis for establishing a detailed zonation. Moreover, some of the collected specimens belong to long-ranging species.

The traditional basal Santonian inoceramid markers – *Sphenoceramus pachti* and *S. cardissoides* (e.g. Seitz 1965, TRÖGER 1989) – are not suitable boundary markers because they are restricted to North Temperate areas (LAMOLDA & HANCOCK 1996). Moreover, the FOs of the above-mentioned taxa are located below the lowest occurrence of *Cladoceramus undulatoplicatus* (see KAPLAN & KENNEDY 2000).

Similarly, the ammonite formerly used to define Coniacian/Santonian boundary – *Texanites pseudotexanus* – has its FO well below the FO of the inoceramid *Cladoceramus undulatoplicatus* (KAPLAN & KENNEDY 2000; see also Text-figs 2, 3). Moreover, as shown by KAPLAN & KENNEDY (2000), *T. pseudotexanus* seems to be limited to the uppermost part of the Coniacian, with its FO in the upper part of the *Magadiceramus subquadratus* inoceramid Zone, and its LO approximately at the entry level of *Cladoceramus undulatoplicatus*.

MIDDLE-UPPER CONIACIAN

Inoceramid zonation of the Upper Coniacian in the study area is problematic because the stratigraphically important taxa are rare or absent. The only relatively common species is the Middle Coniacian zonal index *Volviceramus involutus* (SOWERBY 1828).

The Upper Coniacian zonal index, *Magadiceramus subquadratus* (SCHLÜTER 1887), has not been found in the study area, although WALASZCZYK (1992) reported it from nearby areas.

The presence of the *M. subquadratus* Chron may be inferred from some finds of the ammonite *Texanites pseudotexanus*. However, although this species appears in the *M. subquadratus* Zone, its main occurrence is in the uppermost Coniacian *Sphenoceramus pachticardissoides* Zone (KAPLAN & KENNEDY 2000).

Although the terminal Upper Coniacian *S. pachticardissoides* inoceramid interval Zone (KAPLAN & KENNEDY 2000) cannot be proved, a single specimen of a juvenile *Sphenoceramus* aff. *pachti* was noted below the FO of *Cladoceramus undulatoplicatus* in the L6 section in Lipnik (Text-figs 2, 3).

SANTONIAN

The *Cladoceramus undulatoplicatus* inoceramid taxon range Zone

DEFINITION: This zone characterizes the Lower Santonian Substage. The index species is widely distributed (see discussion in WALASZCZYK & COBBAN 2003; LAMOLDA & HANCOCK 1996) and easily recognizable.

REMARKS: This is the first report of *Cladoceramus undulatoplicatus* from Poland apart from a single report from the North Sudetic area (MITURA & *al.* 1969). In the study area the zone is dominated by representatives of the *Sphenoceramus pachti-cardissoides* group. The genus *Platyceramus* is represented by *P. cycloides* (WEGNER), *P. wegneri* (BOEM 1915) and *P. heinei* (SEITZ 1961). Rare *Cordiceramus cordiformis* (J. DE C. SOWERBY 1823) were also found.

Relatively common are ammonites, represented here by *Texanites pseudotexanus* (DE GROSSOUVRE 1894), *Texanites gallicus* COLLIGNON 1948, *Scaphites fischeri* RIEDEL 1931, *Hauericeras mengedensis* (SCHLUTER 1876), *Nowakites carezi* (DE GROSSOUVRE 1894), *N. savini* DE GROSSOUVRE 1894, *N. pailletteanus* (D'ORBIGNY 1841), *Placenticeras* sp. and *Parapuzosia* sp.

The *Cordiceramus* ssp. inoceramid interval Zone

DEFINITION: This zone characterizes the Middle Santonian Substage. The base of the zone is defined by the LO of *Cladoceramus undulatoplicatus* and its top by the FO of representatives of the *Cordiceramus muelleri* (PETRASCHECK) group; in the study area by the FO of *Cordiceramus recklingensis* (SEITZ).

REMARKS: *Cordiceramus cordiformis* and *C. cordiinitalis* (SEITZ 1961) are accompanied by *Platyceramus cycloides* and *Sphenoceramus pachti*, *S. cardissoides.*

The base of the *Cordiceramus* ssp. interval Zone, and simultaneously the top of the underlying *Cladoceramus undulatoplicatus* Zone, cannot be precisely located in the study area. However, because all the cladoceramids were found in the opoka-dominated part of the succession, this boundary is placed here in the upper third part of this unit, just below the main facies change (Text-fig. 7).

The biostratigraphy of this zone is still poorly known and further work is needed. Most of the inoceramid records, apart from the long-ranging *P. cycloides*, are from the lowest part of the zone (see Text-fig. 7) and was found as a loose specimen.

The *Cordiceramus muelleri* inoceramid interval Zone

DEFINITION: This zone characterizes the lower part of the Upper Santonian Substage. It ranges from the FO of representatives of the *Cordiceramus muelleri* (PETRASCHECK 1906) group to the FO of *Sphenoceramus patootensiformis*.

REMARKS: The Brussels proposal of the FO of *Uintacrinus socialis* as the basal marker taxon for the substage could not be applied in the study area due to the absence of the index crinoid. The entrance of *Cordiceramus recklingensis* (SEITZ 1961), a member of the *C. muelleri* group, is used here as an alternative basal marker taxon (SEITZ 1961, 1967; TRÖGER 1989; WALASZCZYK & COBBAN 2004 *in press*), but the precise level of entry is not documented. This interval is based here on the occurrence of *C. recklingensis* at a single horizon.

The *Sphenoceramus patootensiformis* inoceramid taxon range Zone

DEFINITION: This zone characterizes the upper part of the Upper Santonian and the lower part of the Lower Campanian. Its base is defined by the FO of the index species.

REMARKS: The index species is accompanied by *Sphenoceramus lingua* (GOLDFUSS), *Sph. patootensiformis* (SEITZ) trans. to *lingua* (GOLDFUSS), *Sph. angustus* (BEYENBURG), *Sph.* ex gr. *patootensiformis - angustus*, *Sph. steenstrupi* (DE LORIOL), *Platyceramus cycloides* (WEGNER), *P. ahsenensis* (SEITZ). A few specifically indeterminate specimens of the ammonite genus *Glyptoxoceras* were also found.

The middle part of the zone is characterized by the common occurrence of the crinoid *Marsupites testudinarius*, the LO of which marks the base of the Campanian Stage.

The *Marsupites testudinarius* crinoid taxon range Zone

DEFINITION: The zone characterizes the uppermost part of the Upper Santonian. It ranges from the FO of the index species and its upper limit – the LO of *Marsupites testudinarius* – marks the Santonian/Campanian boundary.

REMARKS: The *M. testudinarius* Zone overlaps with the middle part of the *Sphenoceramus patootensiformis* inoceramid Zone. The size of the *M. testudinarius* calyx plates increases up-section, the stratigraphically youngest specimens being 30% larger then the oldest ones. The morphological succession from almost smooth to strongly ornamented plates recognized elsewhere (SIEVERTS 1927; MILSOM & *al.* 1994; MITCHELL 1995; HANCOCK & GALE 1996), is not confirmed here, but this may be because of their poor preservation, most of the plates having etched surfaces. Probably, the earlier of the two morphotypes is not present in material seen from the study area; all the calyx plates seem belong to the later morphotype, *M. testudinarius* s.s. (C. J. WOOD observation, personal communication).

MAGNETOSTRATIGRAPHY

The results of preliminary palaeomagnetic research (NAWROCKI unpublished data, 2003), indicate that the *Marsupites testudinarius* Zone and the lowermost part of the Campanian lie in the long Cretaceous Quiet Zone (magnetochron 34N), which started in the Aptian. This result seems to be at variance with data from Italy, Gubbio Section (PREMOLI-SILVA 1977), where the base of magnetochron 33R is 1 m below the FO of the planktonic foraminifer *Globotruncana elevata* BROTZEN, 1935, a level correlated with the LO of *M. testudinarius*. This also does not agree with the English data, where the base of magnetochron 33R is placed in the middle *Uintacrinus socialis* Zone (see MONTGOMERY in GALE & *al.* 1996), thus well below the top of *M. testudinarius* Zone.

Otherwise the results from the section investigated correlate well with the data from Germany (HAMBACH & KRUMSIEK 1991), where the base of magnetochron 33R is located within the Lower Campanian, well above the FO of *Placenticeras bidorsatum* (ROEMER 1841), which is usually taken to be equivalent to the LO of *M. testudinarius*.

Newest data form Russia provided by FOMIN & MOLOSTOWSKII (2004) give new light of this controversial topic. Although the long Cretaceous Quiet Zone (magnetochron 34N) is dominated by normal polarity they recognized a number of short-lived reversed magne-

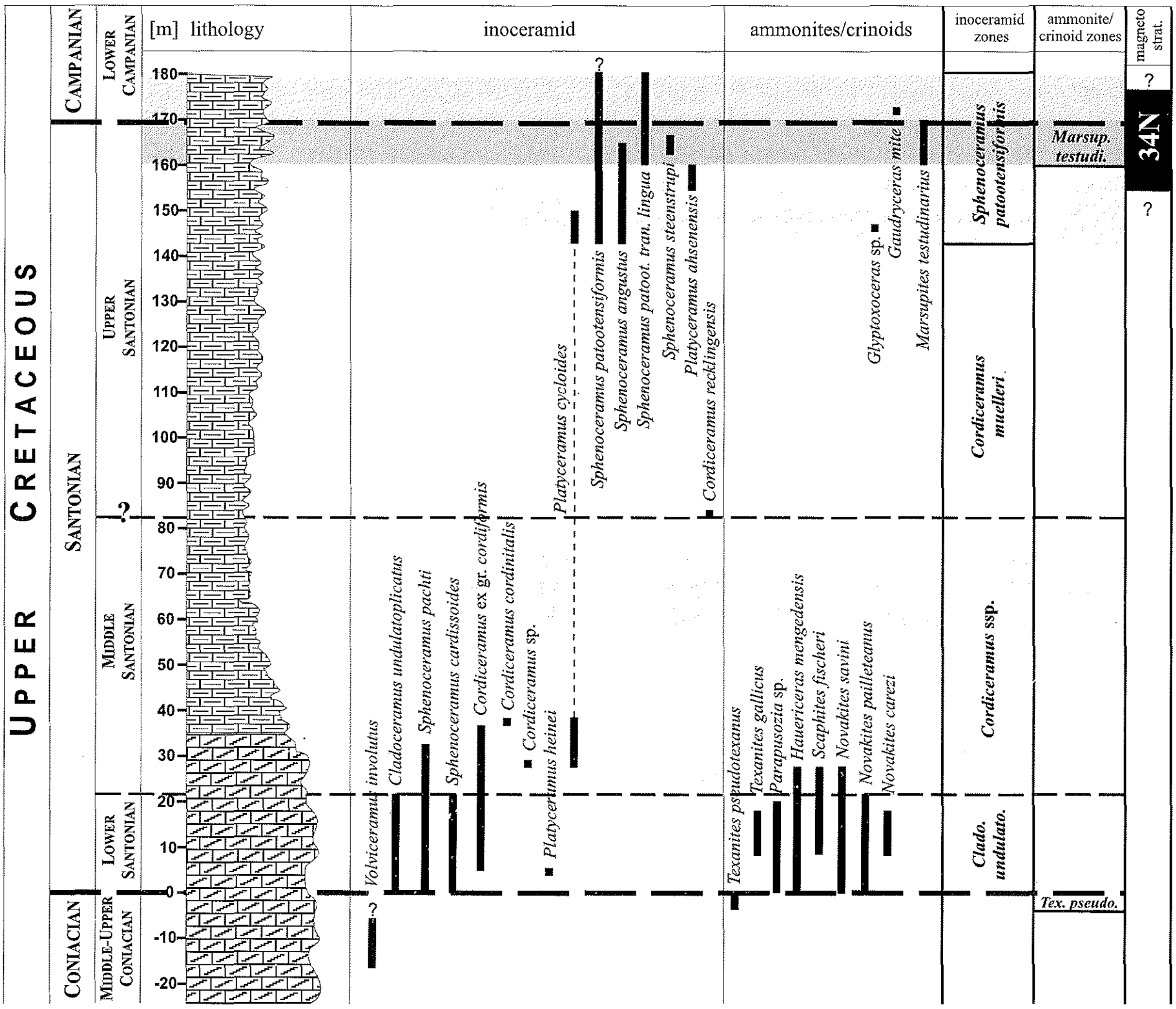

Fig. 7. Composite log, vertical ranges of macrofauna, biostratigraphy and chronostratigraphy of the Upper Coniacian through basal Campanian in the Lipnik-Kije area; magnetostrat = magnetostratigraphy; *Marsup. testudi* = *Marsupites testudinarius*; *Cordi. muelleri* = *Cordiceramus muelleri*; *Tex. pseudo.* = *Texanites pseudotexanus*

tochrons dispersed throughout the zone. The presence of an additional magnetochron with reversed polarity in the uppermost Santonian would solve a problem of contradictory datings of the reversal close to the Santonian/ Campanian boundary. Consequently, the base of the Campanian, when defined with the LO of *Marsupites* would fall within a short-lived normal polarity chron.

CONCLUSIONS

The latest Coniacian – Santonian succession near the villages of Kije and Lipnik may by subdivided into six biostratigraphic zones: *Texanites pseudotexanus*, *Cladoceramus undulatoplicatus* range Zone, *Cordiceramus* ssp. interval Zone, *Cordiceramus muelleri* interval Zone, *Sphenoceramus patootensiformis* range Zone, and *Marsupites testudinarius* range Zone. This zonation is much more detailed than that formerly used and is based on well known taxa. In most cases, the stage and substage definitions used in this paper, follow the criteria accepted provisionally during Brussels Symposium (RAWSON & *al.* 1996).

In most cases, the inoceramid, ammonite and crinoid zones are recognized for the first time from the territory of Poland. These new zonal records are of particular biostratigraphic and palaeogeographic significance.

The fauna collected, including ammonites, inoceramids and crinoids, was generally poorly known in Poland previously. The ammonites: *Texanites pseudotex-*

anus, *Texanites gallicus*, *Hauericeras mengedensis*, *Nowakites carezi*, *N. savini*, *N. pailleteanus*, *Scaphites* sp.) and inoceramids e.g. *Cladoceramus undulatoplicatus* improve our knowledge of the palaeogeographic distribution of the mentioned taxa.

Two stage boundary sections, Coniacian/Santonian and Santonian/Campanian respectively, provide a good palaeontological record enabling correlation of the succession in the study area with other European sections.

The very detailed paleomagnetic research should be made around the Santonian/Campanian boundary to solve the problems with discrepancies of dating the base of the Chron 33R(?). The Santonian/Campanian boundary is placed inside the short-lived chron of normal polarity what seem to be in agreement with data from other sections. Because the accuracy of paleomagnetic data are still increasing these research should be made using the same methodology whenever possible.

The Kije-Lipnik sections could be treated as a standard composite reference section for the Santonian in extra-Carpathians Poland.

Acknowledgments

I would like to express my warmest thanks to Ireneusz WALASZCZYK for valuable comments, continuous discussions on the Coniacian through Campanian stratigraphy and for constructive criticism. Great thanks are to Christopher WOOD for a careful review and linguistic improvement of the final version of this paper. Warm thanks are to Ryszard MARCINOWSKI for his review and help in ammonite determinations, and an anonymous referee, for critical comments.

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Manuscript submitted: 10th October 2003
Revised version accepted: 20th June 2004