

A fossil feather from the Upper Cretaceous of Kras (Slovenia)

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Abstract – A fossil feather preserved as a carbonised trace is described from the Tomaj Limestone at Križ, in the Kras region of southwestern Slovenia. The Tomaj Limestone is a platy and laminated limestone with cherts, which occurs within a well-bedded rudist limestone of the Santonian–Campanian Lipica Formation. It was deposited in a lagoon environment and has yielded a diverse fossil assemblage. Whether this feather belonged to a bird or to a dinosaur is unclear, but it is an addition to the scanty record of Late Cretaceous feathers, from a palaeobiogeographically interesting area. **To cite this article:** E. Buffetaut et al., *C. R. Palevol 1 (2002) 705–710*. © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

Feather / Aves / Late Cretaceous / Karst / Slovenia

Résumé – Une plume fossile du Crétacé supérieur du Karst (Slovénie). Une plume fossile conservée sous forme de trace carbonisée est décrite, en provenance du calcaire de Tomaj de Križ, dans la région du Karst (Sud-Ouest de la Slovénie). Le calcaire de Tomaj est un calcaire en plaquettes laminé contenant des chailles, que l'on rencontre dans un calcaire à rudistes bien stratifié de la formation Lipica (Santonien–Campanien). Il s'est déposé dans un milieu lagunaire et a livré un assemblage paléontologique diversifié. Il est difficile de déterminer si cette plume appartient à un oiseau ou à un dinosaure. Provenant d'une région intéressante du point de vue paléobiogéographique, elle vient s'ajouter à la courte liste des plumes du Crétacé supérieur. **Pour citer cet article :** E. Buffetaut et al., *C. R. Palevol 1 (2002) 705–710*. © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

Plume / Aves / Crétacé supérieur / Karst / Slovénie

Version abrégée

Bien que connues depuis le Jurassique supérieur jusqu'au Pléistocène, les plumes restent des fossiles relativement exceptionnels, correspondant à des types de fossilisation particuliers [9]. Nous décrivons ici une plume provenant du calcaire de Tomaj (Santonien–Campanien) de Križ, dans la région du Kras (ou Karst), au sud-ouest de la Slovénie (Fig. 1). Le Kras, ou plateau de Trieste–Komen, appartient géologiquement aux Dinarides externes. On y rencontre fréquemment des calcaires à chailles en plaquettes, constituant un faciès spécial à l'intérieur de différentes formations de plate-forme du Crétacé supérieur [5, 6, 16, 17, 26]. La plupart de ces couches bitumineuses font partie du Calcaire de Komen, mais quelques-unes, connues sous le nom de calcaire de Tomaj, se trouvent dans la formation Lipica (Santonien–

Campanien). Ce calcaire s'est déposé dans un milieu lagunaire, mais, contrairement au calcaire de Komen, il ne montre pas de traces d'environnement intertidal. De nombreux fossiles pélagiques indiquent des connections aisées avec la mer ouverte [14, 15, 27–30]. On observe, à certains niveaux, des morts en masse de poissons [7] et de saccoomidés, liées à un mélange des eaux. Pendant les périodes calmes, des organismes nectoniques et planctoniques pouvaient vivre dans la colonne d'eau au-dessus du fond anoxique. Le calcaire de Tomaj contient aussi une riche mégaflore [10], provenant d'une zone émergée située au sud. La plume fossile a été trouvée dans le calcaire de Tomaj à Križ, au sud-ouest de Tomaj (Fig. 1). Les foraminifères trouvés au-dessous et au-dessus indiquent l'intervalle Santonien supérieur–Campanien inférieur.

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Cette plume (Fig. 2) est longue de 28,5 mm et sa largeur maximale est de 7 mm. Elle est conservée sous la forme d'une pellicule sombre, sans beaucoup de relief, sur une plaque de calcaire. Il s'agit apparemment d'un cas de conservation sous forme de trace carbonisée, le type le plus fréquent de conservation des plumes [9]. Le calamus n'est pas conservé, et il n'y a pas de trace d'une région plumacée à la base du vexille. Le rachis est bien visible, ainsi que des barbes, mais on ne peut pas distinguer de barbules. Cependant, le fait que les barbes aient conservé leur position d'origine suggère qu'elles étaient connectées par des barbules et des barbicelles. Les barbes font un angle de 20 à 30° avec le rachis. Le vexille, qui semble avoir conservé son contour d'origine, est asymétrique ; son extrémité distale est arrondie.

Les plumes ont longtemps été considérées comme caractéristiques des oiseaux, mais des découvertes récentes dans la formation Yixian (Crétacé inférieur du Nord-Est de la Chine) ont révélé l'existence de plumes ou de téguments ressemblant à des plumes chez divers théropodes non aviens (voir la synthèse récente de Wellnhofer [31]). Bien que la position exacte de certaines de ces formes soit encore discutée (*Caudipteryx*, qui possède des plumes évoluées, est généralement considéré comme appartenant aux oviraptorosaures, qui seraient des oiseaux secondairement non volants [20]), il ne fait pas de doute que certains dinosaures « non aviens » possédaient des plumes de type moderne [25]. De ce fait, les ressemblances entre la plume de Križ et celles des oiseaux modernes n'impliquent pas qu'il s'agisse d'une plume d'oiseau. Sa présence en milieu marin, où elle a pu être laissée par un oiseau volant ou nageur, pourrait suggérer une origine avienne plutôt que dinosaurienne, mais une identification précise est difficile. On ne peut déterminer la position précise sur le corps de l'animal de cette plume, qui ne semble pas être une rémige primaire ou secondaire.

La présence de cette plume dans un dépôt marin est intéressante, car la plupart des plumes fossiles viennent de

sédiments lacustres [9]. Cependant, le Calcaire de Tomaj s'est formé en milieu lagunaire, et l'on connaît des plumes fossiles dans des environnements de ce type, par exemple les plumes d'*Archaeopteryx* des calcaires lithographiques du Jurassique supérieur de Franconie [12], et les plumes isolées de la formation Crato (Crétacé inférieur du Brésil) [19]. Les conditions anoxiques régnant au fond de la lagune de Tomaj ont dû faciliter la conservation de la plume sous forme de trace carbonisée.

La plume du Santonien/Campanien de Križ s'ajoute à la courte liste des plumes connues dans le Crétacé supérieur [19], qui comprenait jusqu'ici des spécimens de la formation Niobrara (Santonien du Kansas) [32], de l'ambre santonien de la formation Foremost (Alberta) et de la formation Taneishi (Japon), ainsi que de l'ambre turonien de la formation Raritan (New Jersey) [13, 19]. S'il s'agit d'une plume avienne, elle augmente aussi les maigres données, jusqu'ici exclusivement ostéologiques, concernant les oiseaux du Crétacé supérieur d'Europe. Divers spécimens fragmentaires du Maastrichtien de Transylvanie ont été rapportés à des oiseaux, mais pourraient en fait appartenir à de petits théropodes [9]. *Volgavis marina* est connu par des éléments de mâchoires du Maastrichtien terminal du bassin du Don en Russie d'Europe [21, 23]. Quelques spécimens du Campanien du Sud de la Suède, y compris *Parascaniornis* [18] ont été attribués à des oiseaux marins archaïques de l'ordre des Hesperornithiformes [22, 24]. On connaît des restes d'énantiornithes [1, 4] et de l'oiseau géant non volant *Gargantuavis philoinos* [2, 3] dans plusieurs sites du Campanien supérieur ou du Maastrichtien inférieur du Sud de la France. La plume de Slovénie peut faire espérer à l'avenir plus d'informations sur les oiseaux qui habitaient au Crétacé supérieur la plate-forme carbonatée dinaro-adriatique, située dans la Téthys et partiellement émergée, et dont les relations biogéographiques sont encore mal comprises.

1. Introduction

Although they have been reported from various geological formations ranging in age from Late Jurassic to Pleistocene, fossil feathers are still relatively exceptional fossils corresponding to special types of fossilisation [9]. This paper describes a fossil feather that was collected in the Santonian–Campanian Tomaj Limestone at Križ, near Tomaj, in the Kras region (also known as Karst) of southwestern Slovenia (Fig. 1). This feather, which belongs either to a bird or to a dinosaur, represents a novelty for the Upper Cretaceous fossil assemblage of Kras, and an addition to the scanty record of Late Cretaceous feathers.

2. Geological setting

Kras, in a strict tectonic sense, can be defined as the Trieste–Komen plateau (synclorium) or the Komen

thrust sheet, but, in a wider geotectonic sense, this area of southwestern Slovenia belongs to the Outer Dinarides.

Platy and laminated limestones with cherts that occur as a special facies unit within different Late Cretaceous platform formations are characteristic for Kras [5, 6, 16, 17, 26]. The major part of these bituminous (carbon-rich) beds belongs to the Komen limestone, whereas a minor part of the platy and laminated limestones, termed the Tomaj limestone, occurs within the thick-bedded Santonian–Campanian Lipica formation.

The strata of the Tomaj limestone were deposited in a lagoon environment and, contrary to the Komen limestone, they show no trace of intertidal conditions. A good connection of the sedimentary environment with the open sea is indicated by abundant pelagic micro-

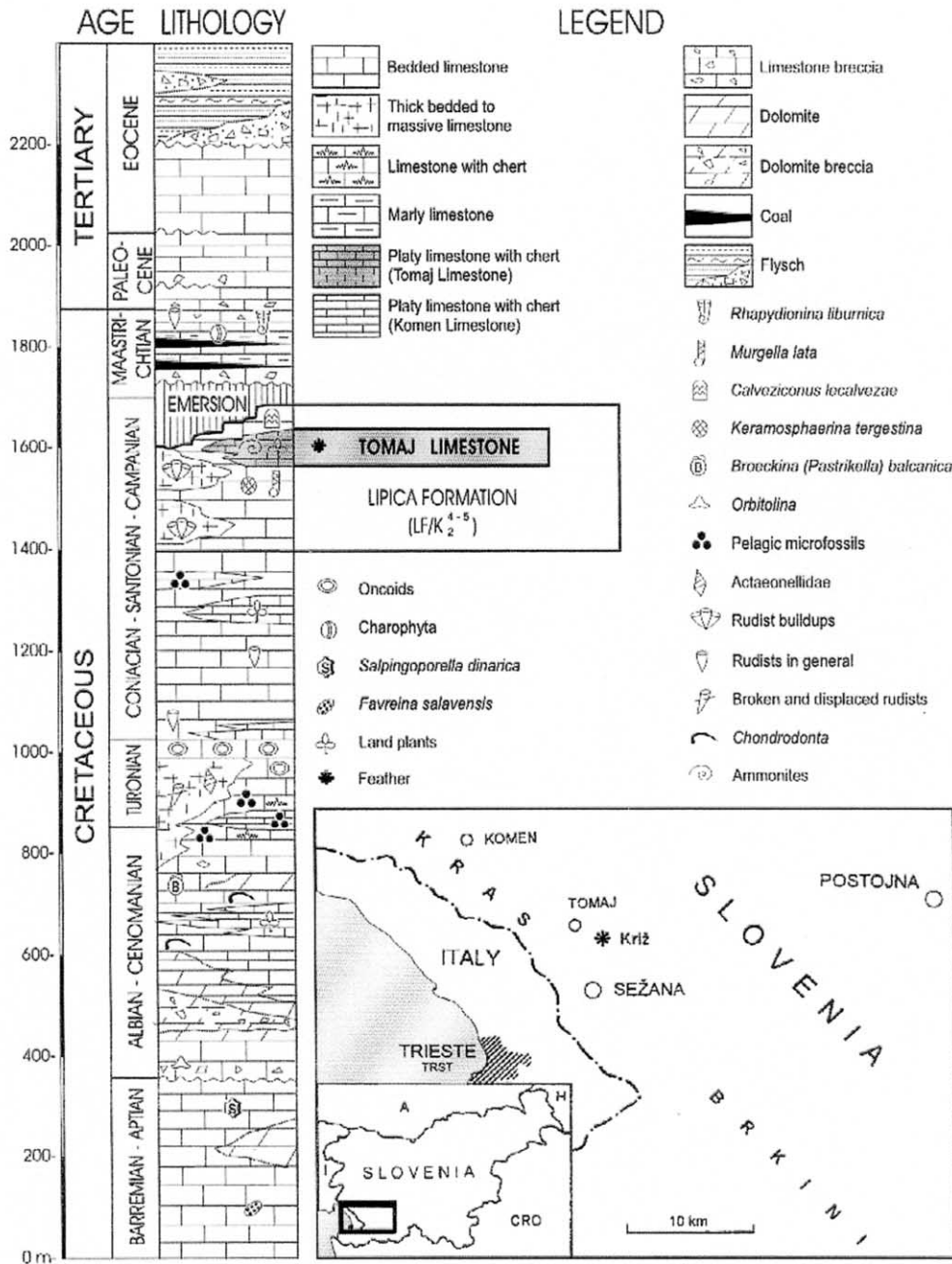


Fig. 1. Stratigraphic column of the Cretaceous strata of Kras, in southwestern Slovenia, with map showing Križ, the locality where the fossil feather described in this paper was found in the Tomaj limestone.

Fig. 1. Colonne stratigraphique du Crétacé du Kras (Sud-Ouest de la Slovénie), avec une carte montrant la localisation de Križ, où la plume décrite dans cet article a été trouvée, dans le calcaire de Tomaj.

and megafossils [14, 15, 27–30]. Mass mortality of fishes [7] and saccocomids is observed at certain levels and is connected with the mixing of the otherwise well-stratified waters of the lagoon. During quiet periods, above the seafloor where anoxic conditions prevailed, the water column allowed the existence of nektonic and planktonic organisms [7]. The Tomaj

limestone also contains a rich megafloora [10] derived from a landmass that began to rise south of the ‘Tomaj Lagoon’ during the Late Santonian.

The fossil feather was collected in the Tomaj limestone at Križ, southwest of Tomaj (Fig. 1). Based on the abundant foraminifers *Murgella lata* (Luperto Sinni) in

the underlying strata, and *Calveziconus lecalvezae* Caus & Cornella in overlying beds, it is placed in the Upper Santonian–Lower Campanian.

3. Description

The feather from Križ (Fig. 2) is 28.5 mm long and its maximum width is 7 mm. It is preserved as a dark film showing little relief on a slab of Tomaj limestone, and is apparently an instance of preservation as a carbonised trace, the most common type of feather fossilisation [9]. Carbonisation is a common type of fossilisation in the Tomaj limestone. The specimen shows relatively few details, but there is no doubt that it is a feather (interpretation as a plant fossil was ruled out by Inna Dobruskina during her study of the fossil flora from the Tomaj limestone). The calamus is not preserved, and there is no indication of a plumaceous region at the base of the vane. The rachis is well visible, and barbs, most of them undisturbed, can easily be seen, but no barbules can be distinguished; however, the fact that the barbs have mostly kept their original position suggests that they were connected by barbules and hooklets. The barbs are attached to the rachis at an angle of about 20° to 30°. The vane, which seems to have largely kept its original outline, is asymmetrical, the rachis being somewhat offset. There is no noticeable clip at the distal tip, which is rounded rather than angled.

4. Discussion

Feathers were long considered as characteristic of birds, but recent discoveries in the Early Cretaceous Yixian Formation of northeastern China have revealed the existence of feathers or feather-like integuments in various non-avian theropod dinosaurs, as discussed in detail in Wellnhofer's recent review [31]. Although the exact status of some of the Chinese specimens is still disputed (*Caudipteryx*, which has advanced feathers, is now generally regarded as an oviraptorosaur, but according to a recent analysis this whole group should be regarded as secondarily flightless birds [20]), there is no doubt that some non-avian dinosaurs possessed 'modern' feathers [25]. Therefore, the fact that the Slovenian feather on the whole closely resembles a modern bird feather is not sufficient to definitely refer it to a bird. Its occurrence in a marine environment, where it may have been dropped by a flying or swimming bird, may suggest that an avian origin is more likely than a non-avian one, but a clear-cut identification is obviously difficult.

It is difficult to determine the exact position of an isolated feather on the body of an unknown bird-like

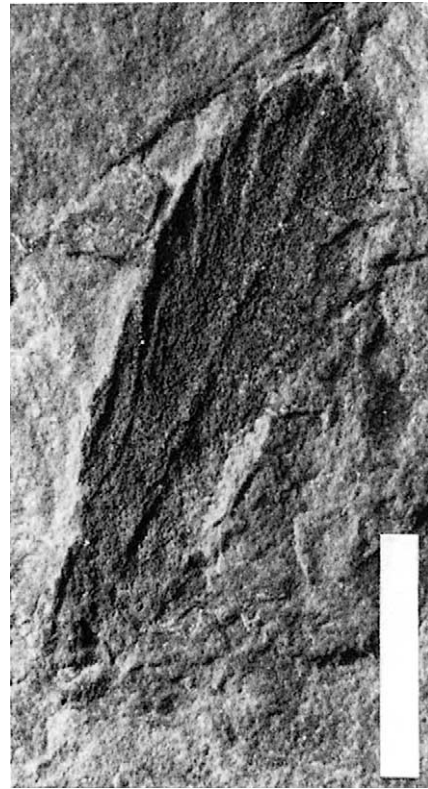


Fig. 2. Feather from the Tomaj limestone at Križ (Kras region, southwestern Slovenia). Scale bar: 10 mm. N° BJ 1742, Jurkovšek Paleontological Collection (registered according to Slovenian legislation with the Ministry of Culture of the Republic of Slovenia and the Natural History Museum of Slovenia).

Fig. 2. Plume provenant du calcaire de Tomaj à Križ (région du Karst, Sud-Ouest de la Slovénie). Barre d'échelle : 10 mm. N° BJ 1742, Collection paléontologique Jurkovšek (enregistrée, conformément à la loi slovène, au ministère de la Culture de la république de Slovénie et au musée d'histoire naturelle de Slovénie).

animal. Despite its asymmetry, the feather from the Tomaj limestone, which is not clipped distally, does not seem to a primary or secondary flight feather; it is somewhat reminiscent of coverlets from the wing of *Columba* figured by Griffiths [12], but its exact position must remain uncertain.

The occurrence of this feather in a marine deposit is noteworthy, as the majority of fossil feathers are from lacustrine settings [11]. However, as noted above, the Tomaj limestone was deposited in a lagoon setting, and fossil feathers are known to occur in such restricted marine environments, the *Archaeopteryx* feathers (whether isolated or associated with skeletons) from the Late Jurassic Plattenkalk of Franconia [12] and the isolated feathers from the Early Cretaceous Crato Formation of Brazil (references in Martill and Davis [19]) being well-known examples. The anoxic condi-

tions at the bottom of the Tomaj lagoon must have facilitated the preservation of the feather as a carbonised trace.

5. Conclusions

The feather from Križ is an addition to the short list of known Late Cretaceous feathers. While a relatively large number of feather localities of Early Cretaceous age have been recorded, very few are known from the Late Cretaceous (see the recent list of Cretaceous feathers in Martill and Davis [19]). The Santonian/Campanian feather from the Tomaj limestone can now be added to the meagre record from the Santonian Niobrara Chalk of Kansas [32], from Santonian amber in southern Alberta (Foremost Formation) and Japan (Taneishi Formation), and from Turonian amber (Raritan Formation) in New Jersey [13, 19].

If it does belong to a bird, the feather from Slovenia also complements the scanty record of Late Cretaceous birds from Europe, which so far consisted only of skeletal remains. Various enigmatic fragmentary specimens from the Maastrichtian of Transylvania have been

ascribed to birds, but they may in fact belong to small theropods (see the review by Csiki and Grigorescu [8]), although the status of some of them is still problematical. *Volgavis marina*, a possible limnofregatid, is known from jaw elements from the Uppermost Maastrichtian of the Don River Basin in European Russia [21, 23]. A few specimens from the Campanian of southern Sweden, including *Parascaniornis* [18] have been referred to archaic diving birds of the order Hesperornithiformes [22, 24]. Remains of enantiornithine birds [1,4] and of the giant flightless bird *Gargantuavis philoinos* [2, 3] are known from several Late Campanian or Early Maastrichtian localities in southern France. To this rather short list may now be added the feather from Slovenia, if it is indeed from a bird. A single feather is of course not a sufficient basis for a discussion of palaeobiogeographical affinities, but it is hoped that in the future more information will be forthcoming about the birds that lived on the Dinaro-Adriatic carbonate platform in the Late Cretaceous. This platform, located in the Tethys Sea, was at least temporarily and locally emergent, but its biogeographical links with other European landmasses are still poorly understood.

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