The Ries and Steinheim Meteorite Impacts and their Effect on Environmental Conditions in Time and Space

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Abstract. The Ries and Steinheim Impact about 15 Ma ago had no palaeontologically verifiable effect on the composition of the fauna and the flora in Southern Germany. The destruction was only of local importance. The ecosystem was quickly, about 100 years later, reconstituted by the same rich subtropical vegetation and vertebrates. The fluviatile ecosystem of the „Upper Freshwater Molasse" accelerated the re-colonization. This fast reorganization of the ecotopes was particularly influenced by fluviatile drift.

1 Introduction

About 15 million years ago (14.87 ± 0.36 Ma; Storzer et al. 1995) the Ries and the Steinheim meteorites happened to hit Southern Germany with an explosion power of 250 000 atomic bombs. A disaster of incredible extension destroyed the area where nowadays two romantic villages, Nördlingen (Ries) and Steinheim, are situated in Southern Germany. At a distance of at least 10 km from the center the rocks of the basement were shocked and melted to a depth of 5000 m. Large blocks were ejected 180 km around (Fig. 1), earthquakes occurred and widespread fires burnt the forests down. This was a significant geological event which is directly recorded by the Ries- and Steinheim craters (see Gregor 1992). In contrast to the idea of a devastation over millions of years (Schleich 1984, Spitzlberger 1984), the present authors show that the event was only of regional importance with a short-term effect on the landscape.

The literature contains abundant data regarding the geological, mineralogical, geophysical and paleontological effects, problems and hypotheses associated with the Ries impact event (see Bayerisches Geologisches Landesamt 1964, 1969, 1970, 1977).

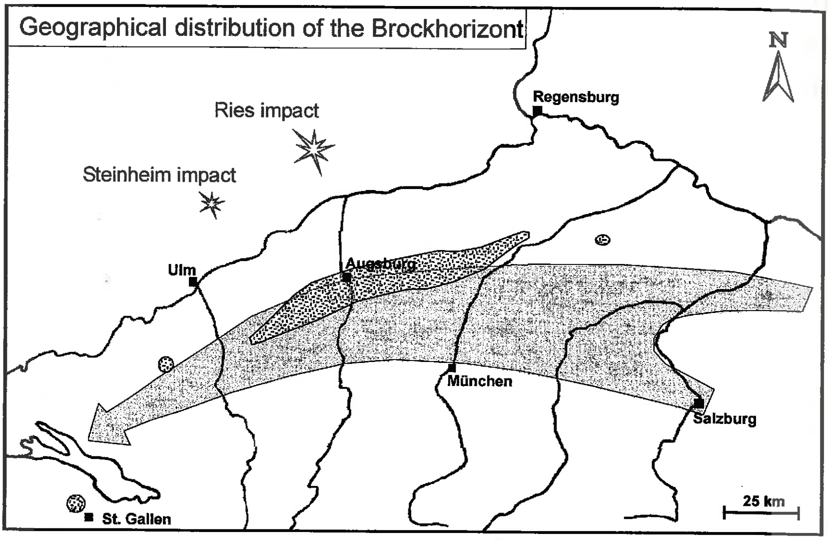

Fig. 1. Geographical location of the Ries and Steinheim impact craters and the distribution of the „Brockhorizont" (dotted areas; greyish arrow indicate the axial outlet of the Molasse basin during the Middle Miocene).

2
The Event – the Impact – the Catastrophe

From the Ries event, abundant evidence remain that help us to understand what happened at that time. Many outcrops contain suevite, a polymict impact breccia with melt rock inclusions, shocked granites, shatter cones in limestones, and brecciated upper Jurassic limestones with fossils like belemnites broken and re-cemented.

Within 200 km radius a compression wave destroyed the forests. Rock fragments, from huge blocks to microscopic fragments, were riding on the front of this wave, coming down at distances known up to 160 km west and 120 km east of the crater centre. They hit the earth with supersonic speed and killed all animals on the surface and in the air. The air was heated by the compression and set fire to the woods within at least the same distance. Burrowing animals may have been killed by the earthquake or the compression wave entering their dens.

The small quarry of Unterneul, about 60 km SSE from the Ries crater, shows some traces of the catastrophe preserved within a channel that was later covered by a small lake and its sediments. This channel was incised through 5 m of sand into a greyish marl bed. In this situation the impact event occurred. The upper 0.2 m of the marl are heavily disturbed by the falling blocks and the compression wave. The sediment, even if already consolidated, was partly reworked and formed a matrix filling the space between undissolved debris of marl. There are horizontal shearing planes with a faint glimmer of oriented mica grains on the surfaces, cutting through fossil snails. Medium-sized to small blocks intruded with sharp edges into the surface of the marl.

The whole channel was later covered by fine clay or, marginally, by the gravels of a small delta. These contain lots of flattened trunks, remains of the broken logs that escaped burning by falling into the water. On the other hand, well rounded wooden blocks were found that have a higher degree of carbonization, gagate near the surface, lignite in the centre, with folded wood structure. These pieces of wood have been compressed before being imbedded in the sediments and were, therefore, no more compressible. Probably they were thrown out from the crater or its immediate neighbourhood, compressed by the immense pressure of the explosion. During their flight into the foreland all edges and splitters burned away until they fell into the water of the channel. Where the immediate cover of the Ries debris is clay, a few centimetres above we find the first shells of the mussel *Margaritifera*, sometimes broken over the edge of a bigger block by the compression of the clay. Half a meter above that layer follows a well-preserved and rich leaf flora.

3
The Stratigraphic Context of the Destruction Horizon in the Upper Freshwater Molasse (Heissig)

During the time of the Ries impact the Alpine foreland was a sedimentary basin, where a system of large longitudinal streams accumulated the gravels, sands and silts of the Upper Freshwater Molasse. Thus, we find the traces of Ries debris and various destructions within this stratigraphic sequence, the so called „Brockhorizont“ (Figs. 1 and 2) of the local geologists.

Following Dehm (1951), the Upper Freshwater Molasse was divided into an Older, Middle and Younger Series (Ältere, Mittlere, and Jüngere Serie), defined by their faunal composition, mainly by the occurrence and size of different proboscideans. The lithological content of these series was partly studied in Lower Bavaria by Blissenbach (1957), Grimm (1965), Stiefel (1957), and other sedimentologists. A more detailed stratigraphy was elaborated by Heissig (1986, 1989, 1997) and Fiest (1986), using fluvial cyclic sedimentation in combination with the faunal composition and the size evolution of certain phylogenetic lineages. This work is still in progress. The new concept has not yet been applied to the floras and to the whole Younger Series.

The first series comprises five sedimentary cycles of the Older Series, numbered from 1 to 5, with the so called „Limnische Süßwasserschichten“ as zero. Within this range four faunal groups have been distinguished: Group A, corresponding to cycle 0, the latest fauna of MN 4 age, group B, without typical elements of MN 4, comprising the first cycle, forming the base of the real Upper

Freshwater Molasse, group C and group D both comprising two sedimentary cycles with rich faunas.

The Middle Series, also with five sedimentary cycles, has so far been divided into two faunal groups, but some additional information may be forthcoming. Two of these cycles are anterior to the Ries impact; the second one, being very incomplete, may be due to the pre-Riesian erosion. This forms a big hiatus at the northern margin of the Molasse basin with the formation of a relief of more than 100 m. Within the basin it is split into two gaps, one separating the Older and the Middle Series, the other immediately preceding the Ries impact. As the fauna of these two cycles is not exactly the same, they should be taken as subgroups E and E' (Table 1). Subgroup E has a fauna of the same composition as the reference locality of MN 5, Pont Levoy-Thenay. The three cycles after the impact, number 8 – 10, are considered as faunal group F with a fauna containing the first immigrant, characterising MN 6. The question whether E' belongs to MN 5 or MN 6 is not yet resolved.

The time of the Ries impact is, therefore, near, or at, the base of MN 6.

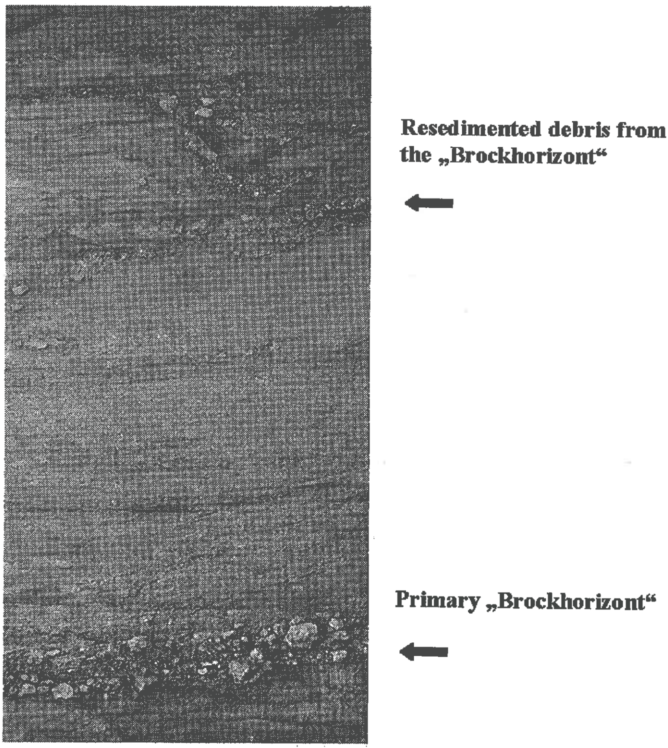

Fig. 2. Profile of the immediately post-Riesian sediments at the locality Ziemetshausen (65 km south of the Ries impact crater) showing the Ries debris in the primary "Brockhorizont" and re-sedimented debris (Section is about 2 m high)

Table 1. Sedimentary cycles and faunal groups of the Older and Middle Series of the Upper Freshwater Molasse (OSM) of Bavaria

MN-zone	OSM-units	Sedimentary cycles	Region Günz-Iller	Region Lech-Paar	Region Ilm-Isar	Eastern Bavaria
MN 6	none	none	Hiatus	Hiatus	Hiatus	Hiatus
type						
	OSM F?	OSM 10		Laimering 4b, 5		
	OSM F	OSM 9	Bentonite Thannhausen Ziemetshausen 1e	Bentonite 14,6 MA Laimering 2,3, 4a Stätzling	Bentonite 14,6 MA Sallmannsberg Göttschlag	Stürming
	OSM F	OSM 8	Ziemetshausen 1b Ries-boulders	Gallenbach 2a Unterneul 1c Ries-boulders	Unterzolling Streitdorf Ries-boulders	
			Hiatus	Hiatus	Hiatus	Hiatus
	OSM E'	OSM 7		Derching 1b		
MN 5 type	OSM E	OSM 6	Ziemetshausen 1c Ebershausen Mohrenhausen Altenstadt	Unterneul 1a Bentonite	Eberstetten	
			Hiatus	Hiatus	Hiatus	Hiatus
	OSM D	OSM 5	Oggenhof	Oberbernbach	Affalterbach Bentonite	
		OSM 4	Betlinshausen		Unterempfenbach 1b,d	
	OSM C	OSM 3	Burtenbach		Sandelzhausen Unterempfenbach 1c	Maßendorf
		OSM 2	Schönenberg Roßhaupten		Puttenhausen	
MN 5 base	OSM B	OSM 1	Bellenberg 2 Bellenberg 1	Langenmoosen	Wörth a. d. Isar	Niederaichbach
MN 4b	OSM A	OSM 0	Günzburg			Forsthart Rembach Rauscheröd

4
Flora and Fauna before and after the Event

4.1
The Megafloras (Gregor)

The western and eastern parts of the Brackish Molasse became drier and drier, huge rivers succeeded the overall muddy area, and dense riparian forests evolved, very well known from the Günzburg area. In sand- and claypits from Burtenbach, Kirrberg (Riederle and Gregor 1997), etc., we find abundant leaves and fruits from different types of wetland, bottomland, and riparian forests (Gregor 1982, Gregor et al. 1989).

The main components were small-leaved *Gleditsia* and other legumes (often misinterpreted as arid or dry floras), of *Cinnamomum*-laurel-types, of *Zelkova*, waterelm, elmtree, beech, maple, spiny oaks, and many more. The floral composition was very similar in the whole of Europe at this time, some special stands excluded (Table A-C, appendix).

Spitzlberger (1984) postulated the extinction of plant and animal life between the Alps and Northern Germany for millions of years, due to the fact that for example an aceroid *Tilia* (from Goldern, MN5, before the event) vanished from this time on in Bavaria. But fossil leaves and fruits from *Tilia* are so rare in the molasse sediments that we can hardly conclude anything from the occurrence or absence of this taxon. It is a typical accompanying type of plant with an irregular behaviour. The presence or absence of *Tilia* type plants and other uncommon ones can be easily explained by special stands and habits in the Molasse region (the Goldern site is a high plateau), not by the impact.

The case of the palms is similar. We have real, well determinable palm remains only in the Lower Miocene and none in the Middle or Upper Miocene (Gregor 1980), in contrast to wrong determinations (see Jung 1981). It is not possible to say anything about the biotopes with palms around the time of the event. Many silicified wood remains in molasse sediments come from a secondary site and are not suitable for stratigraphical interpretations.

Concerning the vegetation of the time around the impacts it may be mentioned that in sediments of the Steinheim crater we find *Gleditsia, Populus, Celtis,* etc. (Gregor 1983, in the flora before the impact (e.g., Burtenbach site). In the Ries crater we find *Cedrelospermum, Gleditsia, Spondieaemorpha* etc., as formerly in the Randecker Maar or later in the Öhningen sites (Gregor 1982a).

In the Ries crater filling we find a certain *Zanthoxylum wemdingense* (Gregor 1977) as a single element, but it also occurs in the Lower Miocene of the Mainz basin. The small pine *Pinus aurimontana* is rare in the molasse (Gregor 1982b).

Typical pioneers also occurred in the Ries crater – *Ailanthus* – the Chinese Godtree, but no Chenopodiaceae as previously postulated (Jung in Dehm et al. 1977), today also typical pioneer herbs.

Around Augsburg we find post-Riesian sites with the common *Cinnamomum, Ulmus, Platanus* and *Hemitrapa*-flora, etc., as in pre-Riesian floras (Knobloch and Gregor, in prep.). Especially in the drill cores of the Steinheim crater these plants occur immediately after the impact (squeezed limestones, tectonically destroyed), which means perhaps a return within only years or tens of years. This shows clearly a rapid return of vegetation after devastation – such as after the Krakatau eruption of the last century (Ernst and Seward 1908, Thornton 1997). There, 50 years later half of the original plant- and animal life had come back. Also if we bear in mind that this was a volcanic eruption, it must have been somewhat similar to the Ries event and it is the greatest catastrophe that we can use for such a comparison.

All the mentioned data also allow the reconstruction of climates before and after the impacts - they were of the same Cfa-type (Virginia-climate sensu Köppen), only showing the normal cooling effect observed in the whole Tertiary.

Principally, the plant elements in the molasse were of exotic character, like *Ginkgo* (China, Japan), *Ailanthus*, *Corylopsis*, *Liquidambar*, *Celtis*, *Gleditsia*, *Glyptostrobus* or *Meliosma* (China), *Acer*, spiny oaks, *Taxodium*, *Magnolia*, *Zanthoxylum* or *Chionanthus* (North America). The wetland plants belong to native genera, such as *Ulmus*, *Alnus*, *Betula* or *Fraxinus*, but to Asian and American species (see Table A-C in the appendix). The palynological data give the same indication as the megaflora.

In the accompanying diagram we try to correlate the occurrences of fossil fruits and seeds and of leaves by their coenocomplexes (Fig. 3). The laurophyllous forest in pre- and post-Riesian times was similar to that of today in SE-Asia (*Cinnamomum*) or elsewhere. All the forest types were similar to the evergreen broad-leaved forests, mixed mesophytic forests or deciduous broad-leaved forests of Asia and America, of the Indian Sholas and Littoral forests, the Japanese Oak-beech-forests, the Hardwood bottom formations of America and the Canarian Laurel forests.

The leaves from many different localities of the Molasse region are currently under study by Gregor and Knobloch, but a preliminary list can be given here (see appendix).

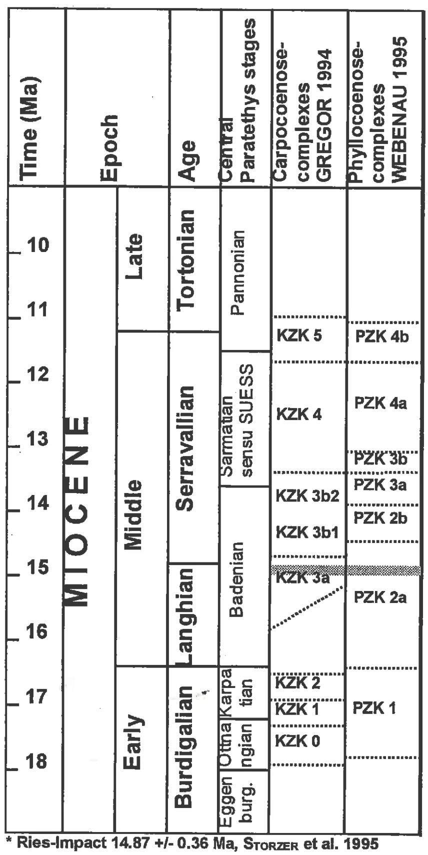

Fig. 3. Stratigraphic sequence of Carpocoeno- and Phyllocoenocomplexes. The data for this figure are given in tables A to C in the appendix. The grey line indicates the Ries impact event.

4.2 The Lower Vertebrates (Böhme)

Schleich (1984) characterised the Ries impact as a „faunal event“, postulating the extinction of large reptiles, such as *Diplocynodon* and *Geochelone*. He noted (Schleich 1985): „ein deutlich unterscheidbares präriesisches und postriesisches Herpetofaunenbild“ (a very distinct Herpetofauna before and after the Ries impact).

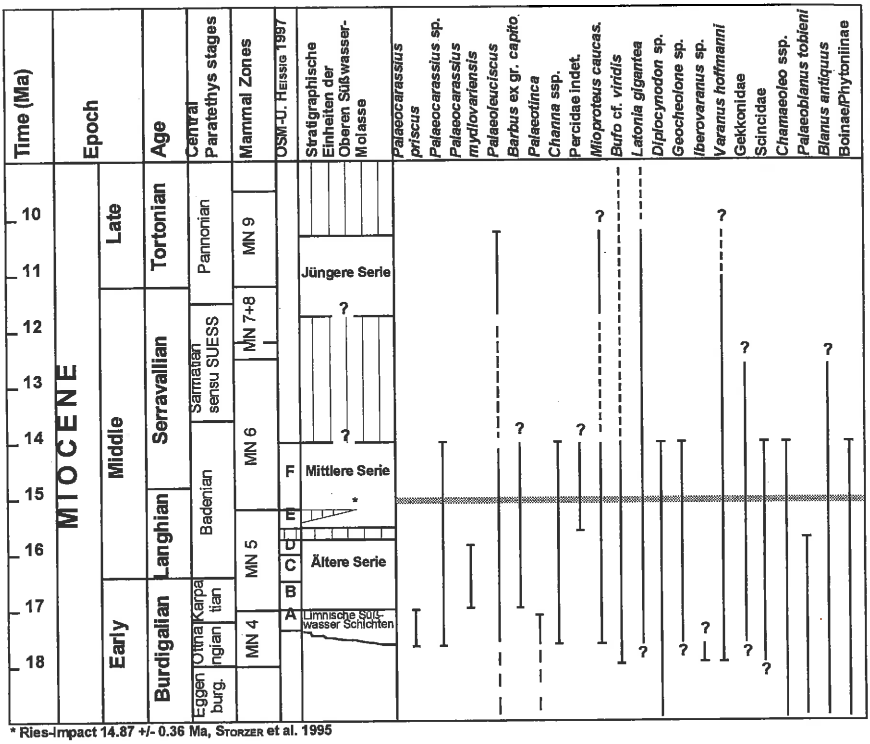

Fig. 4. Stratigraphical distribution of important fish and herpeto-taxa in Southern Germany. The grey line indicates the Ries impact

4.2.1 The Lower Vertebrates before the Ries Impact

The lower vertebrates of the Older and the Middle Series before the Ries impact come from sediments of fluviatile ecosystems (braided and meandering rivers, riparian waters). The fish fauna of the still water is dominated by species of the families Channidae und Cyprinidae, which tolerate a low oxygen content, especially some species of the air-breathing snakehead *Channa* and three species

of the genus *Palaeocarassius*. A *Channa/Palaeocarassius*-association is typical for flat, muddy, oxygen deficient, in exceptional cases temporary waters in the riparian zone (Böhme 1999a). The fish fauna of the running water systems is dominated by barbels closely related to *Barbus capito* and a species of the genus *Palaeoleuciscus*.
The amphibians reach, with 14 species, a very high diversity at this time (Böhme 1999a). The characteristic forms of the riparian waters are newts of the genus *Triturus* (*T. vulgaris*, *T.* cf. *marmoratus*) and the frogs *Rana* (*ridibunda*) sp., *Latonia gigantea* and *Pelobates* nov. sp.. The waterdog (*Mioproteus caucasicus*) and the salamandrids (*Salamandra sansaniensis*, *Chelotriton paradoxus*) are the typical elements in the running water systems.

The reptilian fauna of the fluviatile ecosystems is mostly thermophilic. Apart from the common crocodile *Diplocynodon styriacus* and the giant turtle „*Geochelone*“, the Chamaeleonidae, Scincidae, Amphisbaenidae, and diverse taxa of the Lacertidae and Anguidae are present with several species (Böhme 1999a, b). Gekkonidae and two genera of the Varanidae (*Varanus*, *Iberovaranus*) appear in the drier habitats of the Franconian and Swabian Alb (fissure fillings).

These reptiles are characteristic from the Eggenburgian until the Middle Badenian, indicating a climate optimum. All taxa (especially *Chamaeleo* ssp., „*Geochelone*“ and *Diplocynodon*) refer to a „thermal window“ with a mean temperature during the year of at least 17-18° C, a mean temperature of the coldest month not lower than 8° C, and a mean temperature for the warmest month about 25-30° C (inferred from the recent distribution of the most closely related taxa and there hibernation, reproduction, and activity temperatures; cf. Haller-Probst 1998).

4.2.2
The Lower Vertebrates after the Ries Impact

In contrast to Schleich (1984, 1985), who postulated a „faunal event“ character of the Ries impact, I could not find in my survey any hints of a palaeontologically verifiable regional extinction event. All taxa of fishes, amphibians, and reptiles in the sediments of the Older and Middle Series before the Ries impact (OSM-units A to E; Fig. 4) also occur in the sediments of the Middle Series after the Ries impact (OSM-unit F), particularly the giant turtle „*Geochelone*“ (Griesbeckerzell 1a, Ziemetshausen 1b, Haberskirch) and the crocodile *Diplocynodon* (Griesbeckerzell 1a, Derching „Blauer Ton“ (blue clay), Göttschlag 1b, Kirrberg, Unterneul 1b). However, these taxa, like other ecologically sensitive reptiles, such as chameleons (Laimering 2a) and skinks (Griesbeckerzell 1a), are documented after the Ries event. It is not possible to made a distinction between the herpetofauna before and after the Ries impact event. The extinction of thermophilic taxa took place between the Middle Series and the Younger Series in the Late Badenian and Sarmatian. But at this time we have a sedimentary hiatus in the Molasse Basin (Fig. 4). This extinction was caused by a climatic change during the Middle Miocene (increasing seasonality, decrease of the mean temperature).

4.3
The Mammals (Heissig)

4.3.1
The Mammal Fauna before the Ries Impact

Due to some erosion and relief formation just before the impact event we know the mammalian fauna immediately preceding the Ries impact only from one locality, "Derching 1b" (OSM-unit E', Table 1). This fauna is not yet thoroughly studied, but seems to be similar to the preceding ones, except for one stratigraphically important hamster species, which was replaced by another one (Fig. 5).

Generally, the mammal fauna corresponds to the type of the MN 5 mammal unit, characterised by the lack of the old rodent genera *Melissiodon* and *Ligerimys* and the presence of modern hamsters of the genera *Cricetodon, Democricetodon* and *Megacricetodon.* The numerous small mammal sites, covering most of the times of sedimentation in a rather dense succession, allow a more detailed subzonation than in any other region of Central Europe. It is controlled by superposition.

Within the MN 5 unit, a faunal turnover occurred throughout Western and Central Europe that can be followed in the faunal succession of the Upper Freshwater Molasse of Bavaria and Switzerland. This turnover antedates the Ries impact and is contemporaneous with a stratigraphic gap between the units OSM D and OSM E (Table 1, Fig. 5). Above this gap several immigrants are found, partly replacing older representatives of the same genus or family. The immigrants probably came not exactly at the same time, but the hiatus has condensed the first occurrence of most of them into one line of erosional discordance. Thus, we can observe the first immigrants already before the gap: the flying squirrel *Albanensia*, two dormice of the genera *Myoglis* and *Eomuscardinus* and the small ruminant *Micromeryx*. Most of the immigrations falls within the time of non-sedimentation: the primate *Pliopithecus*, the big hamster *Cricetodon,* the pig *Conohyus* and the deer *Dicrocerus* and *Stehlinoceros* have their first appearances. At the species level the hamster *Eumyarion bifidus* is replaced by the immigrating *Eumyarion medius*. There is one newcomer later than the gap: within the larger-sized lineage of the hamster genus *Megacricetodon* there appears a medium-sized species, *Megacricetodon* aff. *gersi* just a few meters below the „Brockhorizont" in Derching 1b. It is related to the slower increasing lineage of Western Europe and replaces the very large *Megacricetodon lappi*, the final species of the rapidly increasing *M. bavaricus* lineage of Central Europe, which had survived the main turnover for maybe a hundred thousand years.

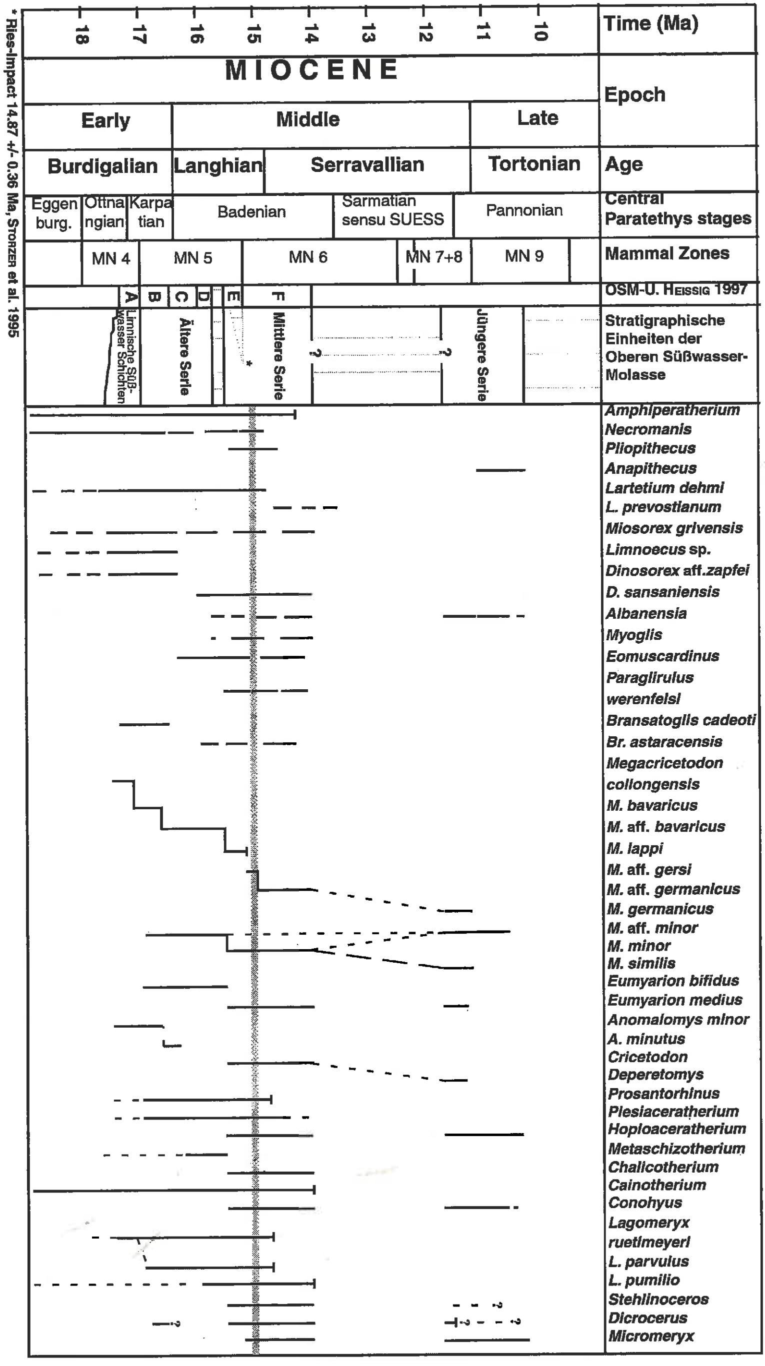

Fig. 5. Stratigraphic distribution of mammalian taxa in the Upper Freshwater Molasse (OSM) of Southern Germany. The grey line indicates the Ries impact event.

4.3.2 The Mammal Fauna after the Ries Impact

The first mammal faunas after the impact are found within the first reworked horizon above the autochthonous „Brockhorizont" (Figs. 1 and 2). This horizon still contains lots of angular blocks and fragments coming from the Ries area, as well as single silicified Jurassic microfossils, which have probably been transported within blocks of residual clay, dissolved in the first process of reworking. This means that the fauna came back into the devastated landscape within a time-span that was too short for a visible weathering of small calcareous debris.

The faunas after the impact are generally put into the mammal unit MN 6, because of the immigration of the rhinocerotid *Hoploaceratherium* at that time, but not because of a real turnover.

There is no faunal element that was wiped out by the catastrophe. Thus, we can conclude that the radius of destruction was less than the area of distribution of all the documented species. This result is corroborated by the fact that even those survivors of old genera, which became extinct rather soon after the impact, had survived over the event for several hundred thousand years. The European opossum *Amphiperatherium frequens* had its last occurrence at the end of MN 6. The smaller short legged rhino, *Prosantorhinus germanicus* still occurs in the first sedimentary cycle after the event, but becomes extinct before the second one. Even *Cainotherium*, a survivor of an old-fashioned praeruminant group of the Oligocene, survived the event for at least two sedimentary cycles. It is recorded also from the calcareous crater sediments of the Ries. *Pliopithecus*, a monkey that lived almost at the northernmost boundary of its range, came just before the event and disappeared from the molasse basin within the second sedimentary cycle. Any climatic deterioration on a larger scale would have wiped out this fastidious animal. Most of the fauna established by the faunal change before the Ries event remains constant during the Middle Series of the Upper Freshwater Molasse, i.e., within MN 6. The more important changes fall in the time of the next stratigraphic gap, spanning the upper part of MN 6, MN 7, and the lower part of MN 8. These units are partly recorded in Switzerland, where the sedimentation was more continuous.

5 Conclusions

The Ries impact event had no long-time effect on the composition of the fauna and the flora in Southern Germany. The radius of destruction was less than the area of distribution of all the documented species. The ecosystem was quickly reconstituted after the catastrophic impact. The probably fast reorganization of the fluviatile ecosystems of the Upper Freshwater Molasse is explained by their dynamic properties. The immigration of the faunal and floral taxa was accelerated by fluviatile drift from refugia. Species with a high colonization ability (plankton, benthos, riparian vegetation, fishes, and some amphibians) were the founders of a new succession.

This model of the Ries and Steinheim impact should be borne in mind when postulating an extinction of organisms by other impact events (e.g., at the Cretaceous/Tertiary boundary). We should be more critical when separating biological from geological events.

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Appendix

Table A. Distribution of carpofossils in the molasse sediments in Neogene times; the Carpocoenocomplexes (after Gregor 1982 and Gregor et al. 1989), (KZK= Karpozoenosenkomplex *sensu* Webenau 1995)

Fossil taxon	**KZK-0**	**KZK-1**	**KZK-2**	**KZK-3**	**KZK-4**	**KZK-5**
Acanthopanax solutus	-----------			----------		
Acer giganteum				----------		
Ailanthus confucii			--------------			--------------
Alnus kefersteini				----------	---	
Asimina brownii						--------------
Betula sp.					---------	
Brasenia victoria	-----------		-----------	----------	---------	
Calamus daemonorhops	-----------		----			
Caldesia cylindrica					---------	
Carex flagellata					---------	
Carpinus grandis					---------	--------------
Carpinus kisseri					---------	--------------
Cedrelospermum aquense			--------------	----------		
Celtis lacunosa		-----------	-----------	----------	---------	
Cephalanthus kireevskianus		-----------	-----------		---------	
Chionanthus kornii	-----------		-----------	----------		
Chionanthus rühlii		-----------				
Cladiocarya trebovensis		-----------		----------		
Cladium oligovasculare	-----------		-----------	----------		
Cladium palaeomariscus	-----------		-----------			
Cleome probstii		-----------				
Cordia mettenii	-----------	-----------	-----------	----------		
Coriaria collinsonae		-----------				
Cornus brachysepala				----------		--------------
Corylopsis urselensis	-----------	-----------		----------	---------	
Cyclocarya cyclocarpa				----------		
Decodon globosus	-----------		-----------	----------	---------	
Eoeuryale moldavica		-----------				
Eomastixia sp.	-----------	-----------				
Epipremnum cristatum			-----------			
Epiprmnum ornatum				----------	---	
Eurya stigmosa	-----------		-----------			
Fagus sp.						--------------
Gleditsia knorrii				----------		
Glyptostrobus europaeus	-----------	-----------	-----------	----------	---------	--------------
Hartziella rosenkjaeri		-----------		----------		

Table A. Continued.

Hartziella vindobonensis					---------	
Hemitrapa heissigii				---------		
Koelreuteria macroptera				---------		
Leguminocarpum sp.				---------		
Limnocarpus eseri				---------		
Limnocarpus major				---------		
Liquidambar europaea	-----------			---------	---------	--------------
Liquidambar magniloculata	-----------			---------	---------	
Ludwigia ungeri						--------------
Microdiptera parva		-----------				
Mneme menzelii					---------	
Myrica ceriferiformis			-----------	---------	---------	
Myrica stoppii	-----------	-----------	-----------			
Nymphaea alba foss					---------	
Nyssa ornithobroma	-----------	-----------	-----------	---------	----	
Olea moldavica		-----------		---------		
Ostrya scholzii		-----------		---------	---------	--------------
Paliurus thurmannii					---------	
Passiflora heizmannii		-----------				
Pinus aurimontana				--		
Pinus tomasiana	-----------	-----------	-----------	---------	---------	
Polygonum leporimontanum		-----------	-----------			
Populus sp.				---------		
Potamogeton piestanensis					---------	--------------
Potamogeton schenkii		-----------	-----------			
Proserpinaca reticulata				---------	---------	
Pterocarya sp.				---------	---------	
Quercus sapperi					---------	--------------
Rhus cf. toxicodenron			-----------			
Ruppia maritima-miocenica				---------		
Ruppia palaeomaritima				---------		
Salix sp.				---------		
Sambucus pulchella					---------	
Sambucus pusilla		-----------	-----------			
Sapindoidea margaritifera	-----------	-----------	-----------	-----		
Sapium germanicum	-----------		-----------	---------		
Saururus bilobatus			-----------			
Schizandra moravica		-----------		---------		
Spirematospermum wetzleri	-----------	-----------	-----------	---------	---------	
Spondieaemorpha dehmii	-----------	-----------		--		

Table A. Continued.

Swida gorbunovii					---------	--------------
Symplocos lignitarum	-----------				---------	
Symplocos pseudogregaria	-----------	-----------	-----------			
Taxodium hantkei					---------	
Tilia praeplatyphyllos		------				
Toddalia latisiliquata	-----------			---------		
Toddalia thieleae	-----------	-----------	-----------			
Toddalia maii	-----------	-----------	-----------			
Ulmus sp.				---------		--------------
Umbelliferopsis molassicus			-----------			
Vitis teutonica	--------------					--------------
Zanthoxylum ailanthiforme	-----------	-----------				
Zanthoxylum wemdingense				---------		
Zanthoxylum ailantiforme	--------------					
Zanthoxylum giganteum	--------------					
Zanthoxylum müller-stolli		--------------				

Table B. Phyllocoenocomplexes of the molasse region in time, connected with the impacts of the Ries- and Steinheim meteorites (PZK=Phyllozoenosenkomplex after Webenau 1995 and Gregor et al. 1989)

Fossil taxon	**PZK 1**	**PZK 2a**	**PZK 2b**	**PZK 3a**	**PZK 3b**	**PZK 4a**	**PZK 4b**
Acer palaeocacharinum						------------	
Acer tricuspidatum		------------	------------	----------	------------	------------	------------
Alnus ducalis							------------
Alnus julianaeforms		------------	------------				
Berchemia multinervis		------------	------------	----------	------------	------------	
Betula subpubescens							------------
Carpinus grandis						------------	------------
Celtis begonioides					------------	------------	
Daphnogene bilinica	------------	------------	------------	----------	---------		
Daphnogene polymorpha	------------	------------	------------	----------	-----------		
Fagus attenuata							------------
Ginkgo adiantoides					------------	------------	
Gleditsia lyelliana		------------	------------		------------		
Liquidambar europaea				----------	------------	------------	------------
Monocotyledoneae	------------	------------	------------				

Table B. Continued.

Myrica sp.		-----------	-----------	----------			
Parrotia pristina		-----------			-----------		
Persea princeps		-----------				-----------	
Platanus leucophylla			-----------	----------	-----------	-----------	-----------
Populus balsamoides	-----------	-----------	-----------	----------	-----------	-----------	-----------
Populus mutabilis			-----------				
Populus populina		-----------	-----------	----------	-----------		-----------
Quercus cruciata	-----------						
Quercus ex gr. Kubinyi					-----------	-----------	-----------
Quercus gregori							-----------
Quercus pseudocastanea					-----------	-----------	-----------
Salix angusta	-----------	-----------	-----------	----------	-----------	-----------	-----------
Salix lavateri	-----------	-----------	-----------	----------	-----------	-----------	
Sapindus falcifolius		-----------	-----------	----------	-----------	-----------	
Smilax sagittifera		-----------				-----------	
Tilia atavia	---						
Tilia sp.				-------			
Ulmus pyramidalis		-----------	-----------	----------	-----------	-----------	-----------
Ulmus minuta		-----------		----------	-----------	-----------	-----------
Ulmus ruszovensis					-----------		-----------
Viscum morlottii	-----------					-----------	
Zelkova ungeri					-----------	-----------	
Zelkova zelkovaefolia		-----------		----------	-----------	-----------	-----------
"Palms"	---						

Table C. Palynomorphs in their time distribution in the molasse sediments (after Planderova in Gregor et al. 1989)

Taxa	**Ottnang**	**Karpat**	**Baden**	**Sarmat**	**Pannon**
Alnipollenites verus	-------------	-----------	-----------	-----------	-----------
Arecipites wiesenensis	-------------	-----------			
Caryapollenites ssimplex	-------------	-----------	-----------	-----------	
Engelhardtioidites microcorypheus	-------------	-----------	-----------	-----------	
Ephedripites treplinensis	-------------	-----------	-------		
Ginkgoretectina neogenica	-------------	-----------	-----------	-----------	-----------
Graminidites media	-------------	-----------	-----------	-----------	-----------
Liquidambarpollenites styracifluaeformis	-------------	-----------	-----------	-----------	-----------
Magnolipollis neogenicus			-----------		
Myricipites rurensis	-------------		-----------		
Pinus haploxylon typus	-------------	-----------	-----------	-----------	-----------
Pityosporites cedrisacciformis	-------------	-----------	-----------	-----------	-----------
Porocolpopollenites vestibulum	-------------	-----------	-----------		
Pterocaryapollenites stellatus	-------------	-----------	-----------	-----------	-----------

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E. Buffetaut · C. Koeberl (Eds.)

Geological and Biological Effects of Impact Events

with 85 Figures and 23 Tables

ESF IMPACT

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Preface

This book is the first volume of a new interdisciplinary series on "Impact Studies". The volumes of this series aim to include all aspects of research related to impact cratering – geology, geophysics, paleontology, geochemistry, mineralogy, petrology, planetolgy, etc. Future volumes will include monographs, field guides, conference proceedings, etc. All contributions in this book were peer-reviewed to ensure high scientific quality.

The thirteen papers in the present volume result from a workshop of the European Science Foundation (ESF) IMPACT programme ("Response of the Earth System to Impact Processes"). This programme is an interdisciplinary effort aimed at understanding impact processes and their effects on the Earth System, including environmental, biological, and geological changes, and consequences for the biodiversity of ecosystems. The goals of the programme, and details about our activities, can be found on the web at <http://pssri.open.ac.uk/ESF/>. The IMPACT programme has currently 15 member nations from all over Europe. The activities of the programme range from workshops to specific topics regarding impact cratering, short courses on impact stratigraphy, shock metamorphism, etc., mobility grants for students and young researchers, development of teaching aids, and publications.

The third IMPACT workshop was held in Quillan, in the foothills of the French Pyrenees, in September 1999. The theme chosen for the workshop was "Geological and biological evidence for global catastrophes", and the papers in this volume reflect the diversity of approaches that can be used to investigate the complex causal chains linking a catastrophic event to its ultimate environmental and biological consequences. It is now widely accepted that large impact events can have a considerable influence on the global environment of the Earth and on the biosphere. However, finding a chronological coincidence between an extraterrestrial impact and an extinction episode in the fossil record is only a first step in the elucidation of what may actually have happened at that particular time. The general question to be asked (and, ideally, answered) is: what are the causal links between the physical impact phenomenon and the extinctions of species or groups of species revealed by palaeontology? Unravelling those links can only be a multidisciplinary endeavour, including the fields of (among others) astrophysics, geophysics, geochemistry, stratigraphy, mineralogy, climate modelling, and palaeobiology. Only in this way can we expect to reliably identify global catastrophes on the basis of the (often difficult to interpret) geological and biological evidence they have left behind.

A taste of both the diversity of approaches and the common goal of impact researches is provided by the papers in this volume. Contributions cover a wide time span, ranging from the Late Devonian mass extinction to the Miocene Ries/ Steinheim impact (which did not cause any mass extinction, confirming the existence of a threshold in impactor size below which no global effects can be expected) and to the Tunguska event of 1908. Not unexpectedly, the K/T

Table C. Continued.

Quercoidites petraea			------------	------------	------------
Rhoipites pseudocingulum	--------------		------------		
Salixipollenites div. spec.			------------	------------	------------
Sapotaceoidaepollenites microrhombus	--------------	------------	------------		
Sciadopityspollenites serratus	--------------		------------	------------	------------
Sequoiapollenites polymorphosus	--------------	------------	------------	------------	------------
Trapa sp.			------------	------------	------------
Tricolpopollenites liblarensis	--------------	------------	------------		
Tricolporopollenites cingulum	--------------	------------	------------	------------	------------