The Carnian (Upper Triassic) Raibl Cataclysm and its impact on the plant world

Michael Wachtler
P. P. Rainerstrasse 11, 39038 Innichen, Italy; E-mail: michael@wachtler.com
Collaboration: Nicolas Wachtler; E-mail: nicolas@wachtler.com

The Raibl-Formation of the Eastern Alps offer one of the most interesting palaeobotanical possibilities to resolve the enigma of immense catastrophes. We encounter an almost paradisiacal tropical coexistence of cycads, horsetails, ferns and conifers from the beginning of the Triassic. Till the Late Triassic Carnian geological stage. Especially in the Eastern Alpine Lienz Dolomites for many chilometres rich plant lenses crop out, but with only a reduced, desertic till stressed vegetation. No ferns were recorded in these Raibl sediments, no cycads, seed ferns, rarely horsetails occur. But a plethora of different lycopods like leafless *Selaginellites perneri* and *Sigillcampeia blaui* form vast plant-carpets. Additionally, common and well preserved are the conifers, but they have a reduced and extremely prickly character like *Araucarites spinosa* n. sp., *Voltzia carinthica,* or shrubby cypresses (*Pusteria maribelae*) and sometimes larch progenitors *(Wachtlerolarix weissii)*. After this "Raibl-Cataclysm" the vegetation recovered in a short time leading to a normally tropical wet climate on the Triassic-Jurassic border. And strangely now the dinosaurs experienced its full bloom and dominated the Earth for about 150 million years and together with them also the birds and later the flowering plants. This publication deals with the strange plant assemblage during the Raibl Cataclysm and attempts to provide explanations regarding what happened in this time.

Online: May 2021

Key words: Conifer evolution lycopods, Carnian, Raibl Cataclysm, palaeoclimatology, Carnian Pluvial Event

A Late Triassic (Carnian) offshore clubmoss landscape of the Lienz Dolomites (Raibl cataclysm)

The area is dominated by the lycopod ***Selaginellites perneri.*** In the background grow the conifers ***Voltzia carinthica, Araucarites spinosa*** and ***Pusteria maribelae*** additionally to some isolated clubmoss ***Sigillcampeia blaui.***

Several Upper Triassic (Carnian) floras are known from Europe: some, like Raibl (Eastern Italian Alps) and Lunz (Austria), also the Neue Welt near Basel (Switzerland), were just described in the 19th century, other like the Mount Pora (Northern Italy) and the Lienz Dolomites (Austria) were discovered recently. Additionally, some belong to the Southern Alpine Raibl Group (Raibl, Monte Pora, Lienz Dolomites), other to the Northern Alps Raibl Formation (Lunz, Neue Welt-Basel, Seefeld). Although they all were inserted in the general term Raibl-Formation it can be supposed that they were not deposited so contemporaneously as it seems, but washed into the Tethys-ocean at different time intervals. They are also a result of a wide spectrum of different sedimentation features including limestones, dolomites, marls and clastic deposits and caused by multiple sequences of sea retreat and re-emerging flooding. The lenses were deposited in shallow sea areas, as well formed as deep ocean deposits. But in this time succession we have the historic opportunity to follow an extraordinary climate change as seldom in the Earth evolution. In the last decade several authors tackle with a big extinction event that was defined as the "Carnian Pluvial Event" or CPE a global climate change in the ocean but also on the continents in the Early Late Triassic (Preto et al., 2019).

Historical overview

The name giving hamlet Raibl was for centuries a famous mining region, especially for zinc sulphide, lead and iron. Raibl, today called in Italian Cave del Predil, is located near the city Tarvisio, in the Northern Italian region of Friuli Venezia Giulia, but was till 1866 part of the Austro-Hungarian Empire. The Austrian geologist **Franz Foetterle** was in 1856 the first to introduce the name "Raibler Schichten" to science. He collected also some plants that in 1868 were described by the Austrian-Slovakian palaeontologist **Dionys Stur.**

Raibl (Cave del Predil)

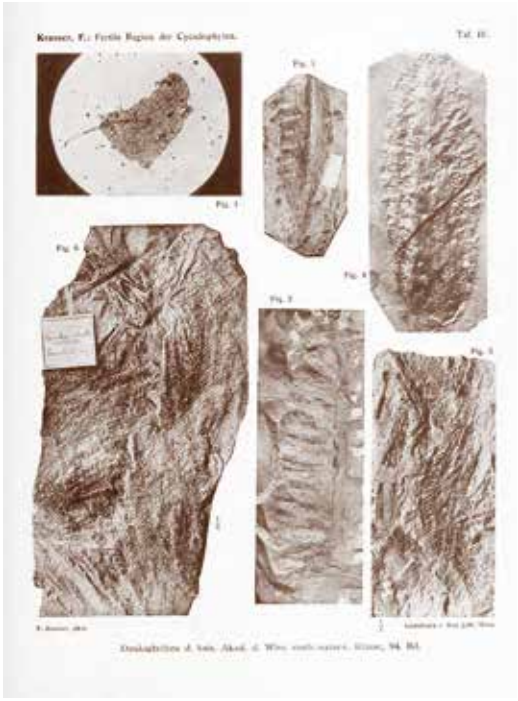
The Raibl layers consist predominantly of thin sand and limestone deposits which can reach a considerable thickness, deposited in anoxic marine conditions, thought to be of lower Julian age (Roghi, 2004). They are distinguished by their richness in plants, fishes, crustaceans bivalves and vertebrates. A first exhausting description about the fauna and flora from Raibl (*Beiträge zur Triasischen Fauna und Flora der Bituminösen Schiefer von Raibl*) was edited in 1858 by **Heinrich Georg Bronn** (1800–1862), Professor from Heidelberg in which he focused additionally to some gymnosperms like *Voltzia heterophylla, Pterophyllum, Taeniopteris*

Fossil plants figured by August Schenk (1866): They comprise conifers, ferns (middle *Cyatheites pachyrhachis*), horsetails right above middle *Calamites raibelianus*, now classified as *Phylladelphia strigata) and Bennettitales (right above Ptilozamites sandbergeri*). Right: *Phylladelphia strigata* (Fig. 2-3), an enigmatic plant

an interesting plant naming it *Phylladelphia strigata*. It represents an enigmatic leaf, till now not classified in one of the existing flora elements.
After Bronn followed in 1866 **August Schenk** with well done drawings about some conifers, ferns and cycads, whereas **Dyonis Stur** published a voluminous work about the "*Kenntniss der geologischen Verhältnisse der Umgegend von Raibl und Kaltwasser*", describing some plants, but without adding drawings of them. It was in 1893 **Freiherr Sydney von Wöhrmann** who analyses well the geology of "*Die Raibler Schichten nebst kritischer Zusammenstellung ihrer Fauna*", bringing them in a coeval time-context with the Lunzer Schichten. He baptized that the Lunzer Flora was different due to the fact that it was younger in age. A reduced mining activity led to the result that after a highlight of research in the 19th century only a few authors focused in the following decades their studies on the Raibl Flora (Arber 1907, Dobruskina et al., 2001) and therefore the interest declined largely, only interrupted sometimes by some private collector (Umberto Venier).

Lunz

Only rarely we can record exactly the exact time of a fossil site discovery as Lunz, located in the Northern Calcareous Alps, approximately 100 km west of Vienna. On 26 August 1842 the famous geologist **Wilhelm Haidinger** accompanied by the mineralogist **Adolph Patera** visited some places near this locality. They collected various fossil specimen especially plants, that till the present are stored in several Museums. Due to a disorderly storage at the begin in the Geologische Bundesanstalt at Vienna (GBA), other floras like those of the Pechgraben in Bayreuth have been viewed as coeval regarding all as "*Flora liasso-keuperiana*" (Stur 1885). Only after a restudying it was obvious that the Flora of Lunz was of Upper Triassic, Carnian age, whereas Bayreuth was deposited in the Late Triassic till Early Jurassic and being therefore younger. Nevertheless, the Lunz Flora can just be more compared with a Rhaeto-Liassic plant assemblage than to a typical Middle Triassic vegetation.
After that the Lunz plant fossils were intensely studied by several authors (Krasser 1917, 1919; Kräusel 1948, 1949, 1953) due to its richness in Cycadales, Bennettitales (also many reproductive structures), ferns, sphenophytes and conifers. Remarkable is the striking difference between other Triassic plant assemblages. Unfortunately, most of the plant fossils has been collected during the highday of the coal mining activity in the 19th and beginning of the 20th century.



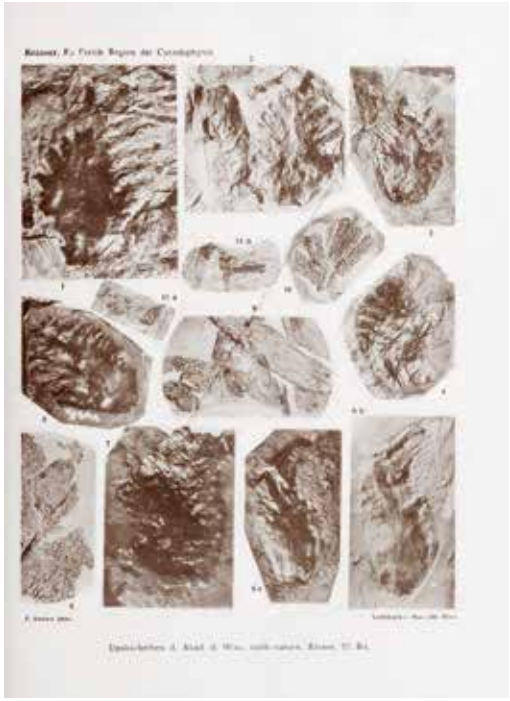
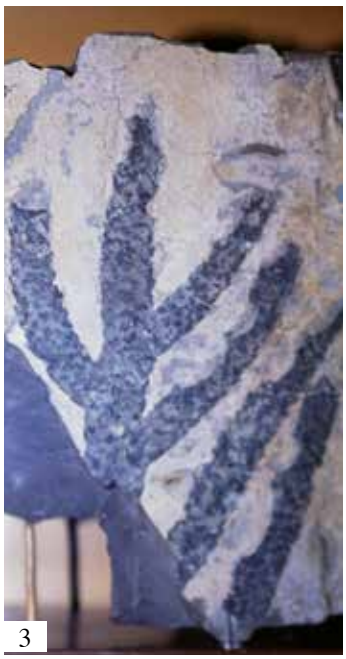


Plate from Fridolin Krasser (1916) "Über die Fertile Region der Cycadophyten aus den Lunzer Schichten" with a male cycad cone (*Lunzia austriaca*) and a female cycad organ (*Pseudoptilophyllum titzei*).

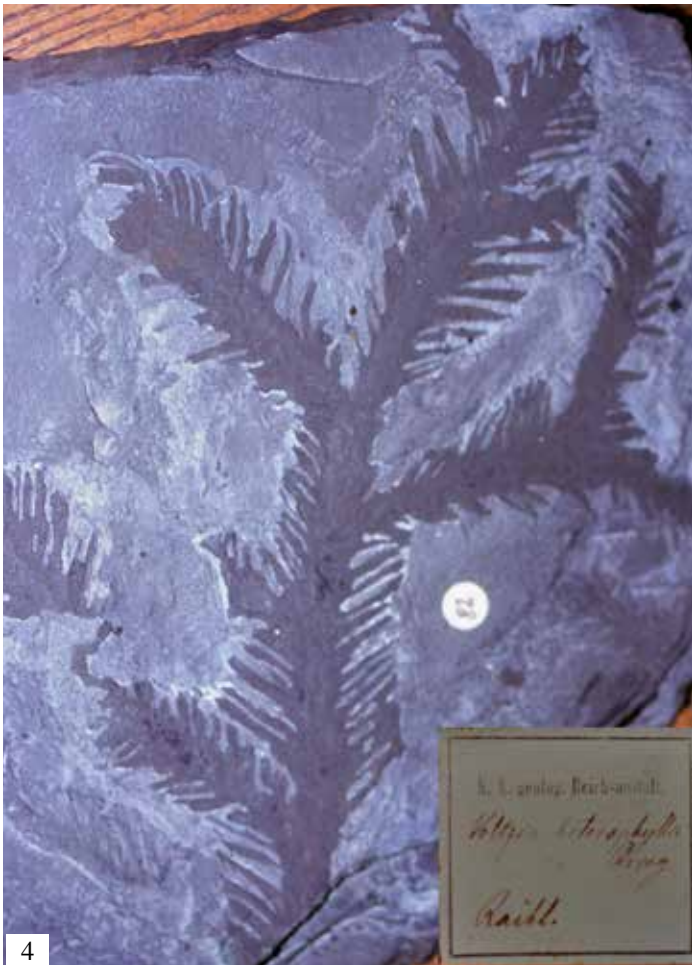
Other plate from Krasser 1919 "Studien über die Fertile Region der Cycadophyten aus den Lunzer Schichten: Makrosporophyle" with *Haidingeria krasseri*.

1

2



3

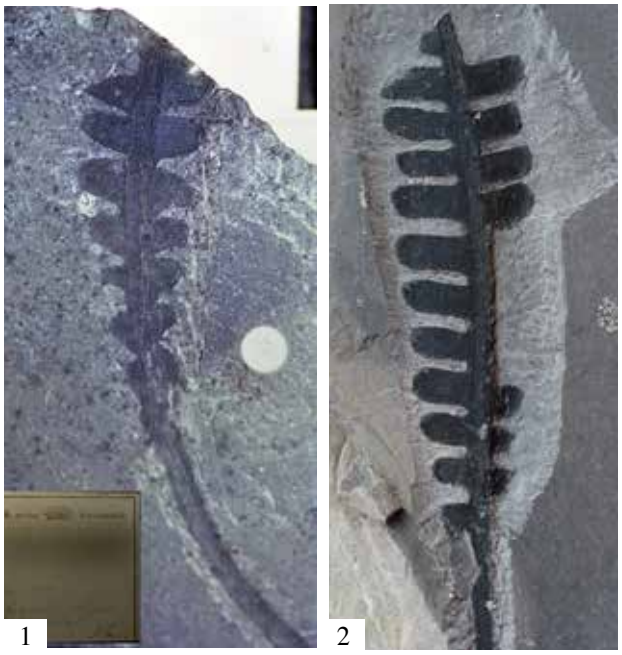


4

5

Plants from the Carnian Raibl beds in Raibl

1. *Macropterygium bronnii*, Raibl Coll. Venier); 2-3. Plants classified as *Voltzia heterophylla, R*aibl; 4. *Voltzia heterophylla (raiblensis*), described by D. Stur in 1885; 5. *Voltzia haueri*, Raibl. All Geologische Bundesanstalt (GBA), Vienna. The names were mentioned as described in the old labels. It is obvious that the conifers belong to different genera or species. But due to the poor fossil record further classifications are vague.



1. *Ptilozamites sandbergeri* (former *Pterophyllum sandbergeri)*, label from D. Stur, locality: Südflanke des Königberges im Kaltwasser Thal, GBA, Vienna; 2. *Ptilozamites sandbergeri*, Raibl, Coll. U. Venier, Domanins

After their closure further discoveries are limited, especially for excellently preserved, never to weathering exposed material. Apart from many miners the local naturalist **Josef Haberfelner** (1830–1913) collected and sold many plant fossils to various European museums (Aschauer, 2013).
Just from the beginning, the Lunz Formation, was regarded as coeval with the Raibl layers. Especially Stur who had just published an exhausting work about the fossils of the Southern-Alpine Raibl-beds (1868) classified in his work (*Die obertriadische Flora der Lunzer-Schichten und des bituminösen Schiefers von Raibl - The Upper Triassic Flora of the Lunz-layers and the bituminous slate of Raibl,* 1885) the fossils as being deposited at the geological same time in the Upper Triassic. An exact dating of the Lunz Formation can be regarded till now as problematic due to the lack of convincing markers, but a late Julian (Port & Krings, 2013) is now accepted, meaning that they are younger than the Early Julian aged Italian Raibl-sediments (Roghi, 2004). This is also demonstrated by the completely different fossil flora record having more affinities with the Triassic-Jurassic Bayreuth-flora.

Monte Pora

Another newly discovered Carnian plant fossil site is located on the border between the Italian provinces Bergamo and Brescia on the Monte Pora (Colle Vareno) (Passoni & Van Konijnenburg-van Cittert, 2003). It is characterised by a predominance of the fern *Pseudodanaeopsis aberi,* probably better classified as *Danaeopsis aberi*, additionally to cycadophyta or Bennettitales (*Sphenozamites bronnii* and *Sphenozamites angustipinnatus*), conifers and one interesting lycopod (*Porastrobus bergomensis*), probably sporophylls with a close affinity to *Lepacyclotes,* a small growing clubmoss being present all over the Triassic like Anisian *Lepacyclotes bechstaedtii* or Ladinian *Lepacyclotes zeilleri* (Wachtler, 2016).

Lienz Dolomites

The first brief introduction about the geology of the Lienz Dolomites we have to thank the tireless German researcher **Leopold von Buch** (1824), followed in 1843 by **Alexander Petzhold** and in 1850 by **Heinrich Credner.** For the first more exhausting work we have to wait till 1903, with **Georg Geyer**'s *"Zur Geologie der Lienzer Dolomiten"*. He made just a distinction between the fossiliferous horizons of the Raibl-Sediments, sometimes calling them *Cardita*-layers, where he recorded plant-debris, without being able to recognize special plant families.
Surprisingly these Carnian flora assemblage—although frequent in the Lienz Dolomites—were overlooked for a long time. The reasons are not fully comprehensible, because the plant fossil strata can be followed over many chilometres from Oberdrauburg till the Kerschbaumer-Alm over Lienz.
In 2015, **Michael Wachtler** began his research recognizing a rich lycopod-conifer flora with several new species and genera. In a short time, the Lienz Dolomites became one of the richest Carnian paleobotanical places in the world. The rich plant lenses sprout out just near the Hochstadel-Hut and stretch than over a length of more than six chilometres crossing the Schwärza Törl, prosecuting under the Lavanter Alm, the Lavant-Luggauer Törl, reaching the Seekofel and the Zochenpass – situated over the Kerschbaumer Alm. The Raibl-

1

2

3

4

Plants from the Carnian Raibl-beds in Lunz

1.Big slab of *Pterophyllum brevipenne*, belonging to the Bennettitales; 2. *Asterotheca merianii*, a fern; 3. *Danaeopsis marantacea*, belonging to the Danaea-ferns; 4. *Macrotaeniopteris (Bjuvia) haidingeri,* a cycad frond. All Lunz, stored in the Natural History Museum, Vienna.

1

2

3

4

5

6

Plants from the Carnian Raibl-beds in Lunz

1. *Williamsonia wettsteini*, fruit of a Bennettitales, first described by Krasser in 1912; 2. *Ginkgoites lunzensis*, leaf of a Ginkgo-tree; 3. *Pterophyllum brevipenne; 4. Lunzia austriaca*, probably a cycad male cone, first described by Krasser in 1917; 5. *Haidingeria krasseri,* fruit of a Bennettitales; 6. *Stachyotaxus lipoldi*, a conifer twig. All Lunz, stored in the Geologische Bundesanstalt GBA, Vienna.

Plants from the Carnian Raibl-beds from Monte Pora (Bergamsc Alps, Northern Italy

1. *Pseudodanaeopsis aberi* (better *Danaeopsis aberi).* Big slab with several fern fronds; 2. *Pseudodanaeopsis aberi.* Fertile frond; 3. *Porastrobus bergomensis,* probably sporophylls of a lycopod having close affinities with Triassic *Lepacyclotes*; 4-5. Isolated twigs described as *Brachyphyllum* and *Pagiophyllum,* but probably belonging to *Araucarites* and *Voltzia.* All Monte Pora, Valle Seriana, Bergamo, Northern Italy, Coll. Aber, Museo Civico di Scienze Naturali, Bergamo

Group (Carnian) is there underlain by older Anisian shallow water carbonates and the Ladinian to Carnian platform carbonates of the Wetterstein Formation and are overlain by lagoonal Dolomites of the Hauptdolomit Formation (Norian) and basinal shales of the Kössen Formation (Late Norian to Rhaetian). Three prominent and different carbonatoclastic sequences of the Raibl Formation can be encountered, that hold an alternation of bituminous dolomites, limestones and marls. But only the middle one held good preserved vegetal remains and occasional bone-beds.

The flora is not variegated, ferns are missing, horsetails are rare, whereas the lycopods (*Sigillcampeia blaui, Selaginellites perneri*) are frequent. Additionally, common and well preserved are conifers, especially *Araucarites spinosa, Voltzia carinthica*, the Cupressaceae *Pusteria maribelae* and the larch progenitor *Wachtlerolarix weissii.*

Interesting is the fact that the vegetation of the Carnian Lienz Dolomites is totally different from other Carnian deposits. Whereas the Raibl beds in the original Cave del Predil area resembles in their appearance and habitat the Ladinian plant-assemblages of the Dolomites with abundant recoveries of conifers, cycads, horsetails and ferns, and the Lunz flora remembers late Triassic-Jurassic (Rhaeto-Liassic) Bennettitales-cycad-vegetation, the Lienz-Flora otherwise is characterised by their extremely thorny aspect, composed of prickly conifers and low growing lycopods. The reasons are not easy to interpret. It seems that a catastrophic event influenced in this time considerably the climate, reduced the temperatures and changed the landscape—although being ocean near—into a desertic landscape.

An immense catastrophe: the Raibl Cataclysm

The question is now which of all this fossil outcrops can be regarded as older or younger? From the main Carnian plant assemblages probably all belonging to the Julian stage of the Carnian, we have the Cave de Predil-Raibl area which has close affinities to the Ladinian (Wengen) flora, whereas Lunz and Monte Pora have striking resemblances in their biotic community with the Bennettitales-cycad-rich Rhaeto-Liassic-floras. But one—the Lienz Dolomites are characterised by an extremely reduced, desertic till stressed vegetation. Another small area with the same characteristics of the Lienz-Dolomites can be found in the Julian Alps in the locality Dogna, pertaining to the Rio del Lago Formation (Preto et al., 2005).

The Lienz-outcrops lie in the middle of the Julian period. The Carnian spans for about 10-12 million years from 237.0 ± 2.0 to 226.5 ± 2.0 Ma (Gradstein et al., 2012) and is divided in two (Julian, Tuvalian) till three (Cordevolian, Julian, Tuvalian) main stages. But why do we have in the Julian period ranging for only a few million years such reduced vegetation? No cycads, no ferns, no seed ferns, sparse horsetails, only a plethora of low growing lycopods and thorny, dwarfish conifers?

The Lienz Raibl-Formation constitutes one of the most interesting paleobotanical sites to resolve the enigma of an immense catastrophes. The continents in the Carnian were still united in the supercontinent Pangaea, with a single global ocean, Panthalassa, and a western branch at tropical zones, the Paleo-Tethys. These areas

The dwarfing of the *Voltzia* seed scales

1. *Voltzia rietscheli,* Anisian, Piz da Peres, Dolomites.

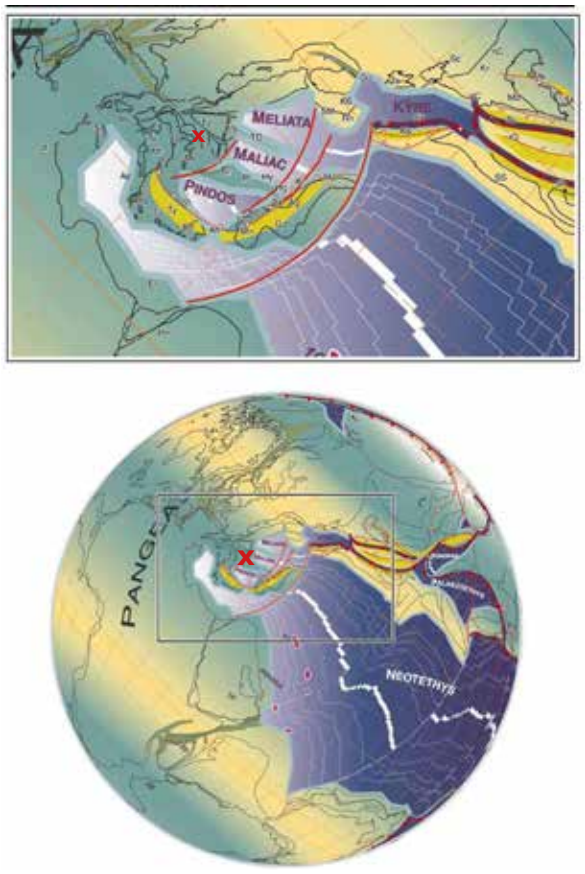
2. *Voltzia carinthica,* Carnian, Lienz Dolomites. The size decreased by half.

A bed of the lycopod *Selaginellites perneri.* Over chilometres the layers are covered by the same club-moss. Raibl beds, Lienz Dolomites Schwärza Törl. (Coll. Wachtler - Dolomythos, LAV 60)

Rarely *Voltzia* or *Araucarites* twigs were deposited between the *Selaginellites* beds (LAV 56).

of the Eastern Alps were located at latitude of about 20° in the Northern hemisphere and influenced by marine conditions. Moreover, today these latitudes include rainy landscapes like Hawaii-Island, the Southern part of Cuba, Vietnam, Taiwan but also the desertic landscapes of Qatar or Mauritania with the Sahara Desert, the Atacama Desert or the Australian Outback.

The Late Triassic Lienz-Flora, that can be followed over a full length of more than six chilometres, was miserable in all parts, not meaning the conservation, but the richness and flourishing. We encounter lenses extending for hundreds of meters like those from the Schwärza Törl till the Lavanter Alm where mainly exclusively one mimicry and leafless *Selaginellites perneri* species can be encountered; sometimes interrupted by some dehydrated, thorny conifers like *Araucarites* and *Voltzia,* or low growing *Pusteria*-cypresses.



The Dolomites in the Carnian. The latitude was about the 20th latitude, corresponding today's Hawaii or Jamaica. But the vegetation was much more reduced than today on the close to the see lying areas. (After Stampfli et. al. 2002)

The *Araucarites weissi* twigs were leathery and prickly. Zochenpass Lienz Dolomites (Coll. Wachtler - Dolomythos, ZOC 105 and ZOC 120)

Rarely can be encountered some gastropod. (Coll. Wachtler - Dolomythos, Lavant Luggauer Törl LAV 104)

A catastrophic event can effectively be a good explanation! It is imaginable and plausible that climate changes occurred several times in the million years of Earth history. From huge ice-ages till volcanic eruptions till cometary impacts, all happened and changed the life circumstances.
But what caused this megaevent? Several authors suggested (Simms & Ruffell, 1989; Preto et. al, 2019) that the origin was an episode of extremely wet tropical climate with intense mega-monsoons, calling it "*Carnian Pluvial Event*" (CPE) or "*Raibl event*", beginning between the latest early Carnian (Julian) and the late Carnian (Tuvalian) about 232 million years ago. This catastrophe lasted between one and two million years. Another totally contrary theory (Visscher et al., 1994), rejected this and sustained that large parts of Europe in that time were dominated by xerophytic vegetations indicators of arid climatic conditions.
Theories about catastrophes in the past are always highly speculative. First, as exact term can be instituted the name Raibl Cataclysm to avoid the fixation on a not proven pluvial catastrophe. The palaeobotanical fossil record for a not very long period during the Carnian sustained a dry and extremely arid climate on the Paleo-Tethys beaches of this region. Whereas before and after this is not ascertainable. But also, no disasters based on extreme rainfall can be encountered in the Ladinian or later on the Triassic-Jurassic border. Whether this Raibl Cataclysm is to attribute to cold sea currents triggering a dry climate in this time

Equisetites sp. Seekofel, Carnian, Dolomites, Coll. Wachtler

The plant fossil rich Raibl beds in the Lienz-Dolomites

Forest road to the Hochstadel hut. The outcrop hold the cypress *Pusteria maribelae* and *Selaginellites.* Only a few *Voltzia* or *Araucarites*-twig can be found.

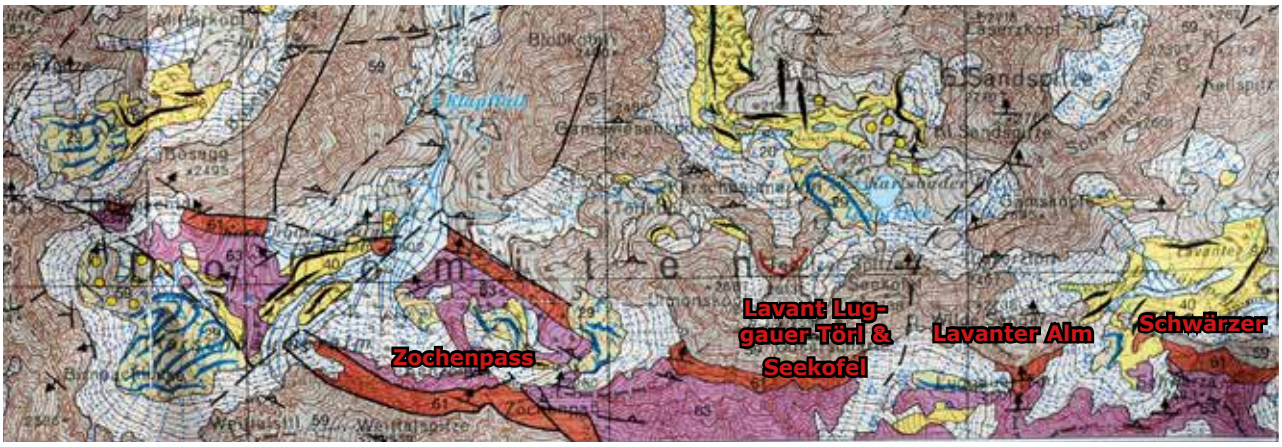
Lavanter Alm in direction to the Schwärza Törl. The outcropping layers on the alp are rich on *Selaginellites perneri* and *Pusteria maribelae.*

Schwärza Törl. The layers contain almost exclusively abundant *Selaginellites perneri* carpets. Only a few *Voltzia* or *Araucarites*-twig can be found.

Lavant Luggauer Törl. The layers contain *Araucarites spinosa* and *Pusteria maribelae*. Less frequent is *Selaginellites perneri.*

Seekofel mountain. The layers are the richest in vegetation, especially *Wachtlerolarix weissii* and the lycopod *Sigillcampeia blaui.* But also *Voltzia carinthica* and *Araucarites spinosa* can be recorded in good samples. Less frequent are the conifer *Pusteria maribelae* and the lycopod *Selaginellites perneri*. A few *Equisetites* stems can be found.

Zochenpass. The long outcrops are rich in *Voltzia carinthica* and *Araucarites spinosa*. The lycopods *Sigillcampeia blaui,*and *Selaginellites perner*i can be found in fair amounts. Also the conifer *Pusteria maribelae i*s abundant.



The geological setting of the Raibl beds in the Lienz Dolomites

Nr. 61(red) represents on the geological map the Raibl-Formation in the Lienz Dolomites. All the layers are rich in plant fossils (Blau, J., Schmidt, T. 1988; Blau, J., Blind, W., Grün, B., Schmidt, T., Senff M., 1990.)

or volcanic eruptions that were responsible for the climate change is difficult to answer. Certainly at high elevation, lying freshwater lakes with a cold climate are to be excluded. It was supposed (Simms & Ruffell, 1989) that the cataclysm was created by massive basalt formations in British Columbia (Wrangellia Terrane), spewing out huge volumes of lava over hundred thousands of years, around 232 million years ago. They could have released enough carbon dioxide to warm the globe. In the geological record, theories about intense and large volcanism with release of CO^2 in the atmosphere or the ocean are often correlated to episodes of major climate changes and extinctions like the Permo-Triassic cataclysm.

In the palaeobotanical fossil record of the Alps catastrophes can be observed several times. One occurred between the Carboniferous-Permian border with the vanishing of the huge *Lepidodendron* and *Sigillaria*-trees and the arising of the gymnosperms like conifers, cycads and gingkos. The next we encounter on the Permian-Triassic with a short disappearing of the gymnosperms and the spreading of arborescent lycopods like *Pleuromeia* in the Early Triassic, followed by a plethora of lycopods (Wachtler, 2016) till the Early-Middle Triassic (*Lycopia, Sigillcampeia, Eocyclotes, Lepacyclotes, Selaginellites)*. After that we have again a wet tropical climate with a heavenly together of cycads, horsetails and ferns for about 20 million years. Till the Carnian!

There effectively—especially in the plant rich sediments, that allow statistical conclusions due to the fact of the recovery of thousands and thousand of specimen—it is proven that the nature was infected by an extraordinarily event. It was probably a long-lasting stormy aridity that brought the growth of plants to the most extreme survival fighting or near the extinction. Especially *Selaginellites perneri* is sometimes so common to form vast plant-carpets. This *Selaginella*-species was mostly leafless and in the same manner also the conifer *Pusteria maribelae*, a small cypress with dwarfish cones. The Voltziaceae hold only small seed scales, whereas the *Araucarites* species were characterized by reduced and extremely prickly leaves.

Interesting is that in all these cataclysms clubmosses play an outstanding role. As giant *Lepidodendron* trees, as arborescent lycopods in the Early-Middle Triassic, and as wide areas covering small-sized carpets in the Late Triassic Carnian. The reasons for the dominance of the clubmosses during the catastrophes are till now unclear.

After this period the vegetation recovered in a short time to lead to a normally tropical wet climate, as recorded immediately after in the Lunz-Formation with a plethora of cycads, ferns, horsetails and other plants and after that on the Triassic-Jurassic border with the Rhaeto-Liassic Bayreuth-flora. Fact is also that after this period the dinosaurs experienced its full bloom and dominated the Earth for about 150 million years and together with them also the birds and later the flowering plants.

References

Arber, E.A.N.(1907. On Triassic species of the genera Zamites and Pterophyllum types of fronds belonging to the Cycadophyta. The Transactions of the Linnean Society of London 7(7): 109–127

Aschauer B. 2013. Die Lunzer-Flora-Sammlung des Stiftes Seitenstetten. Eine Lehrsammlung von Josef Haberfelner, Berichte der Geologischen Bundesanstalt, ISSN 1017-8880, Band 103, Wien

Blau, J., Schmidt, T. 1988. Tektonisch kontrollierte Sedimentation im Unterlias der Lienzer Dolomiten (Österreich, Osttirol, Kärnten). - Mitt. Ges. Geol. Bergbaustud. Osten-., 34/35, 185-207, Wien.

Blau, J., Blind, W., Grün, B., Schmidt, T., Senff M., 1990. Bericht über geologische Aufnahmen in den Lienzer Dolomiten auf den Blättern 178 Hopfgarten, 178 Lienz, 195 Sillian und 196 Obertilliach- Jb. Geol. B.-A., 134 (3), 527-530, Wien 1991.

Bronn, H.G. 1858. Beiträge zur Triasischen Fauna und Flora der bituminösen Schiefer von Raibl, nebst Anhang über die Kurr'sche Sippe *Chiropteris* aus dem Lettenkohlen-Sandsteine. 63 pp., E. Schweitzerbart'sche Verlagshandlung und Druckerei, Stuttgart.

Buch, L. v. 1824. Über die Karnischen Alpen. - Leonhards Miner. Taschenb., 18, 2. Abt., 396-437, Frankfurt/Main

Fötterle F. 1872. Raibler und Bleiberger Schichten Verh. geol. R.-A., pag. 372

Dobruskina, I.A. 1994. Triassic Floras of Eurasia. 422 pp., Springer Verlag, Wien.

Dobruskina, I.A., Jurkovsek, B., Kolar Jurkovsek, T. 2001. Upper Triassic Flora from „Raibl beds" of Julian Alps (Italy) in Karavanke Mts. (Slovenia). Geologija, 44(2): 263-290

Dobruskina, I. A. 1989. The alpine Lunz-Flora – a standard flora for the Carnian stage of the Triassic. – International Geological Review, 31: 1209–1215.

Geyer G 1903. Zur Geologie der Lienzer Dolomiten, Verh. geol. R.-A., 1903, 165-196, Wien

Petzholdt A. 1843. Beiträge zur Geognosie von Tyrol. Leipzig, pag. 132

Credner H., 1850. Geognostische Bemerkungen über die Centralkette der Alpen in Ostkärnten. Neues Jahrbuch für Mineralogie, pag. 513

Gradstein, F.M.; Ogg, J.G., Schmitz, M.D. & Ogg, G.M., 2012. The Geologic Time Scale, Elsevier.

Krasser, F. 1909a. Die Diagnosen der von Dionysius Stur in der obertriadischen Flora der Lunzer Schichten als Marattiaceenarten unterschiedenen Farne. – Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften Wien, Abt. 1, 118: 13–43.

Krasser, F. 1909b. Zur Kenntnis der fossilen Flora der Lunzer Schichten – Jahrbuch der Kaiserlich-Königlichen geologischen Reichsanstalt, 59: 1–26.

Krasser, F. 1917. Studien über die fertile Region der Cycadophyten aus den Lunzer-Schichten: Mikrosporophylle und männliche Zapfen. Denkschriften der Kaiserlichen Akademie der Wissenschaften (Wien), Mathematisch-Naturwissenschaftliche Klasse, 94: 489–553.

Krasser, F. 1919. Studien über die fertile Region der Cycadophyten aus den Lunzer Schichten: Makrosporophylle. – Denkschriften der Kaiserlichen Akademie der Wissenschaften (Wien), Mathematisch-Naturwissenschaftliche Klasse, 97: 1–32.

Kräusel, R. 1921. Über einige Pflanzen aus dem Keuper von Lunz (Nieder-Österr.) – Jahrbuch der Preußischen Geologischen Landesanstalt, 41: 192–209.

Kräusel, R. 1943. Die Gingkophyten der Trias von Lunz in Niederösterreich und von Neue Welt bei Basel. – Palaeontographica Abt. B, 87: 59–93.

Passoni, L., Van Konijnenburg-van Cittert, J.H.A. 2003. New taxa of fossil Carnian plants from Mount Pora (Bergamasc Alps, Northern Italy). – Review of Palaeobotany and Palynology, 123: 321–346

Preto N., Roghi G., Gianolla P. 2005. Carnian stratigraphy of the Dogna area (Julian Alps, northern Italy): Tessera of a complex palaeogeography: Bollettino della Società Geologica Italiana, 124, 269-279

Preto N., Bernardi M., Dal Corso J., Gianolla P., Kustatscher E., Roghi G., Rigo M., 2019. The Carnian Pluvial Episode in Italy: History of the research and perspectives, Bollettino della Societa Paleontologica Italiana

Pott C., Krings M. 2010. Gymnosperm Foliage from the Upper Triassic of Lunz, Lower Austria: an annotated check list and identification key, Geo.Alp, 7: 19-38

Schenk, A. 1866. Über die Flora der schwarzen Schiefer von Raibl. Würzburger naturwissenschaftliche Zeitschrift, 6:10-20

Simms, M. J.; Ruffell, A. H. 1989. Synchronity of climatic change and extinctions in the Late Triassic. Geology. 17: 265–268.

Stampfli, G., Borel, G., Marchant, R., Mosar, J. 2002. Western Alps geological constraints on western Tethyan reconstructions. In: (Ed.) Gideon Rosenbaum, and Gordon Lister, Reconstruction of the evolution of the Alpine-Himalayan orogen, Journal of the Virtual Explorer, Electronic Edition, ISSN 1441-8142, volume 8, paper 5, doi:10.3809/jvirtex.2002.00057

Stur, D., 1868. Beiträge zur Kenntnis der geologischen Verhältnisse der Umgebung von Raibl und Kaltwasser. Jahrbuch der Geologischen Reichsanstalt, 18: 71-122.

Stur D., 1856. Die geologischen Verhältnisse der Thäler der Drau, Isel, Möll und Gail in der Umgebung von Lienz, Jahrb. d. KK. geol. R.-A. VII, 1856

Stur, D. 1885. Die obertriadische Flora der Lunzer-Schichten und des bituminösen Schiefers von Raibl. Sitzungsbericht der Kaiserlichen Akademie der Wissenschaften Wien, Mathematisch-Naturwissenschaftliche Klasse, Abt. 1, 88(1): 93-103

Stur, D. 1888. Die Lunzer (Lettenkohle-)Flora in den „older mesozoic beds of the coalfield of eastern Virginia". – Verhandlungen der Kaiserlich-Königlich Geologischen Reichsanstalt, 10: 203–217

Visscher, H., Van Houte, M., Brugman, W. A., Poort, P. R. 1994. Rejection of a Carnian (Late Triassic) "pluvial event" in Europe. Review of Palaeobotany and Palynology. Volume 83, Issues 1–3, Pages 217-226

Wachtler M., 2016. A strange rising of the lycophyta in the European Triassic. In: Wachtler M., Perner T., Fossil Triassic Plants from Europe and their Evolution, Volume 2: Lycopods, horsetails, ferns, Dolomythos Museum, Innichen, South Tyrol, Italy, p. 3-16

Wachtler M., 2016. Sigillaria-Lycopods in the Triassic. In: Wachtler M., Perner T., Fossil Triassic Plants from Europe and their Evolution, Volume 2: Lycopods, horsetails, ferns, Dolomythos Museum, Innichen, South Tyrol, Italy, p. 3-16

Wachtler M., 2016. Fossil Triassic *Selaginella* species from the Dolomites. In: Wachtler M., Perner T., Fossil Triassic Plants from Europe and their Evolution, Volume 2: Lycopods, horsetails, ferns, Dolomythos Museum, Innichen, South Tyrol, Italy, p. 3-16

The Upper Triassic Raibl Cataclysm and its impact on the plant world

Edited by
Michael Wachtler and Nicolas Wachtler

Published by Dolomythos Museum, 39038 Innichen, South Tyrol, Italy
First edition May, 2021 ISBN 978-88-944100-5-1

Softcover Euro 49
Pages 86