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UPPER TRIASSIC AMBER FROM THE DOLOMITES (NORTHERN ITALY). A PALEOCLIMATIC INDICATOR?

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Riassunto. In strati terrigeno-carbonatici della Formazione di Dürrenstein delle Dolomiti è stata rinvenuta ambra sotto forma di goccioline di colore giallo-rossastro. Il ritrovamento di ammonoidi e di palinomorfi permette di assegnare l'età dell'ambra al più alto Julico, in prossimità del limite con il Tuvalico (circa 225 Ma). Sono state determinate le caratteristiche fisico-chimiche dell'ambra; la spettroscopia all'infrarosso (IR) evidenzia le tipiche bande delle resine fossili. L'area caratterizzante dello spettro mostra peculiarità riferibili ad un'unica specie, diverse da quelle delle resine fossili conosciute. La grande abbondanza di microspore teniate bisaccate, nei campioni contenenti ambra (41%), suggerisce una relazione con la specie produttrice di resina, probabilmente una conifera. Oltre a quelli delle Dolomiti, sono noti ritrovamenti di ambra anche nel Triassico superiore della Svizzera, delle Alpi Calcaree Settentrionali e dell'Arizona. La sostanziale isocronia dell'intervallo stratigrafico in cui è stata trovata l'ambra e la costanza delle caratteristiche paleoambientali dei siti (fluviale, marino marginale) suggerisce una possibile relazione tra la produzione e conservazione dell'ambra e un evento climatico umido verificatosi in tali regioni durante il Carnico, al passaggio tra Julico e Tuvalico.

Abstract. Amber in Triassic deposits in the Dolomites is demonstrated for the first time. The amber-bearing deposits belong to the middle part of the Dürrenstein Formation, referred to uppermost Julian (Lower Carnian, about 225 My). Chemico-physical features of amber, which occurs as small yellow to reddish droplets, have been determined. Infrared (IR) spectroscopy shows typical bands of fossil resins; the "fingerprint" region of the spectrum presents a unique pattern that cannot be referred to any other known fossil resin. Palynological investigation of amber-bearing layers shows a large prevalence of bisaccates and circumpolles. Particularly, the taeniate bisaccates are frequent (41%) and suggest a correlation with the amber-producing species. Amber production and preservation is possibly related to a humid climatic event.

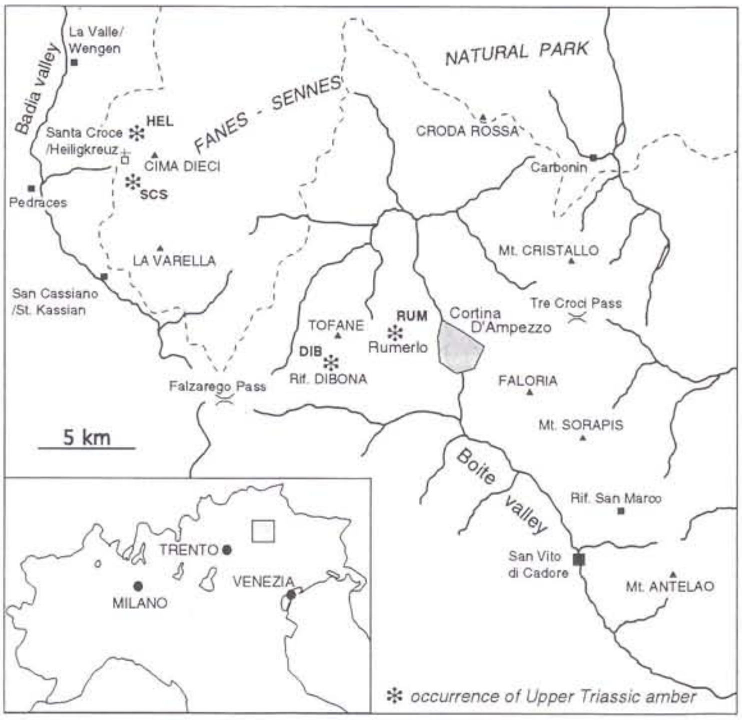

Fig. 1 - Location map of Upper Triassic amber investigated in the present study.

Introduction.

In the past, Upper Triassic amber has only been reported in Northern Calcareous Alps (Pichler, 1868; Vávra, 1984; Poinar et al., 1993), in Switzerland (Soom, 1984) and in Arizona (Litwin & Ash, 1991). As far as we know, amber has never been described in Triassic deposits in Italy, except for a generic mention of "fossil resin" by Zardini (1973). In the present study, we report the occurrence of amber in the Dürrenstein Formation in the Dolomites (Fig. 1). The age of the amber-bearing rocks is latest Julian (early Carnian). Since amber can embed and preserve organisms, such as arthropods and soft-body animals, as well as parts of plants and pollen, it provides a reliable tool for paleontological studies. The possibility of preserving nu-

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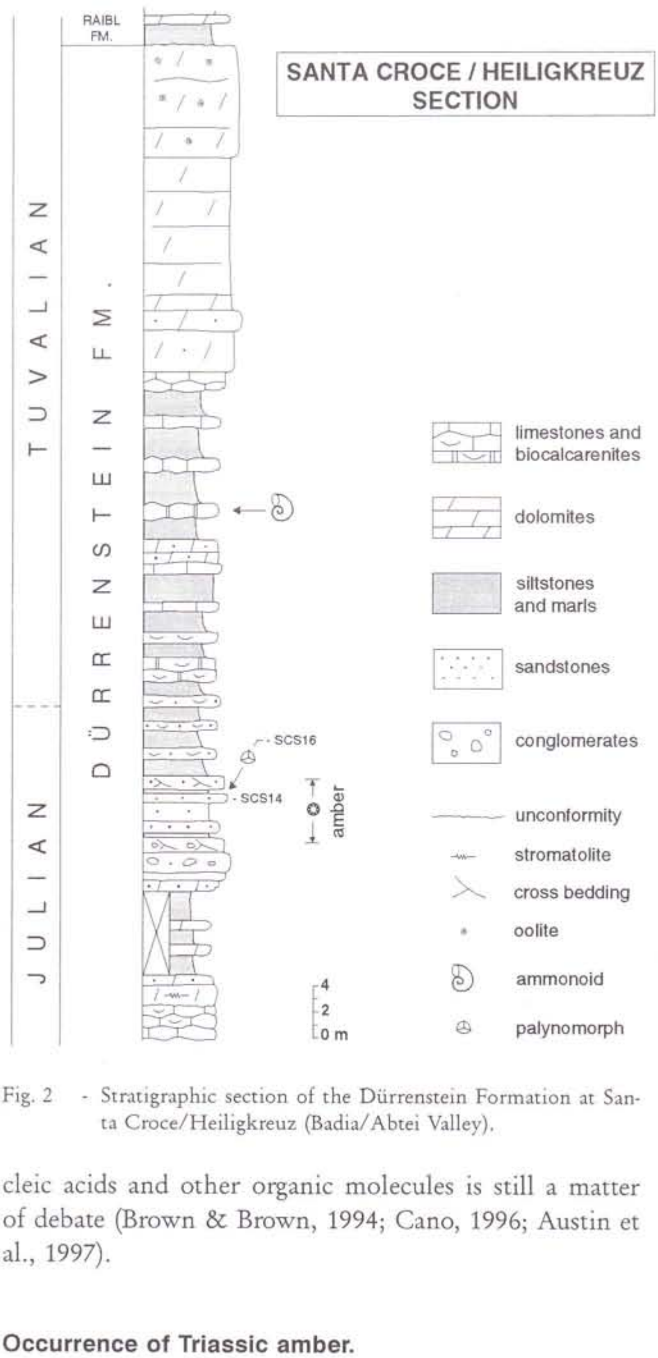


Fig. 2 - Stratigraphic section of the Dürrenstein Formation at Santa Croce/Heiligkreuz (Badia/Abtei Valley).

cleic acids and other organic molecules is still a matter of debate (Brown & Brown, 1994; Cano, 1996; Austin et al., 1997).

Occurrence of Triassic amber.

Triassic amber was first collected in 1823 in the fossil plant-bearing beds in the Schilfsandstein at Neuewelt, near Basel. The sample was described by Soom (1984) and is kept at the Museum of Natural History in Basel. The Schilfsandstein is a fluvial deposit, widespread throughout continental Europe, that deeply cuts the underlying sequences (Aigner & Bachmann, 1992). A re-interpretation of palynological data by Leschik in Kräusel & Leschik (1956) and Scheuring (1970), suggests a latest Julian age for the amber-bearing layers.

The first published report on Triassic fossil resin is by Pichler (1868), who described small resin droplets in the "oberen Schichten der *Cardita crenata*" of Kochental (Tyrol, Austria). The author gave this resin the name "Kochenit" and produced a complete chemico-physical analysis. The fossil plant-bearing beds belong to the 1st shale (Jerz, 1966; R. Brandner, pers. comm.) of the Raibler Schichten in the Northern Calcareous Alps (NCA), which typically includes important plant remains associated with coal layers. As far as we know, these amber-containing levels correspond to those in Mt. Leitnermoos, near Schliersee (Bavaria, Germany), in which amber collected and studied by Poinar et al. (1993) was found. The amber-bearing beds were deposited in a marginal fluvial environment (Bechstädt & Schweizer, 1991). According to Kavary (1966, 1972) and Jelen & Kusej (1982), these beds are Julian in age. As the 1st shale of the Raibler Schichten bears *Carnites floridus* (Wulfen) and a microflora including *Patinasporites justus* Klaus, in our opinion its age is latest Julian.

Triassic amber was also reported near Lunz (Niederösterreich, Austria) by Sigmund in 1937 (quoted by Vávra, 1984) and was named "Copalin". The amber-containing strata belong to the Lunzerschichten, interpreted as pro-delta and delta deposits (Tollmann, 1976), directly correlated to the Schilfsandstein (Behrens, 1973; Aigner & Bachmann, 1992). Once again this unit is particularly rich in fossil plants (cf. Kräusel, 1949; Dobruskina, 1988) and is late Julian in age (Klaus, 1960; Dunay & Fisher, 1978).

Litwin & Ash (1991) also pointed out Upper Triassic amber in the lower member of the Petrified Forest Formation (Chinle Group) in the Petrified Forest National Park (Arizona). The amber is not associated with petrified wood, but rather with carbonized leaf debris in paper coal. According to Litwin et al. (1991), the age of the amber-bearing strata is Late Carnian.

Amber in the Dolomites.

During the revision of the Upper Triassic stratigraphy in the Dolomites, some layers bearing small amber droplets were discovered. All of the material was collected in the Dürrenstein Formation (Pisa et al., 1980; De Zanche et al., 1993) in various localities: Santa Croce/Heiligkreuz in Badia Valley, Rumerlo and Rifugio Di Bona near Cortina d'Ampezzo. The Dürrenstein Formation is a complex carbonate-terrigenous stratigraphic unit consisting of two distinct interfingered lithozones. The carbonate one is the most typical and widespread, made up of intra-supratidal well-bedded dolomites with stromatolitic, birds-eye and tepee structures. The terrigenous lithozone is characterized by sandstones, conglomerates and hybrid arenites; coquinas are widespread in this part of the unit. The vertical evolution of this lithozone shows a decrease in siliciclastic content and consequent increase in carbonate supply.

The depositional environment is mostly a wide tidal flat, sometimes interrupted by lagoons (Pisa et al., 1980; De Zanche et al., 1993). From these facies, reptile footprints have been reported (De Zanche et al., 1993), suggesting the existence of a nearby emerged land. The terrigenous sediments are restricted to ephemeral distributor channels, controlled by tidal currents, and represent the dispersal of fluvial supply in a marginal marine setting. The Dürrenstein Formation corresponds to the ultimate phases of the Carnian regression: in fact, at that time, Triassic basins in the Dolomites were more or less completely filled. According to the sequence stratigraphic interpretation by De Zanche et al. (1993), the whole Dürrenstein Formation corresponds to the Car 3 3rd-order depositional sequence.

Amber has only been found in a narrow interval of siliciclastics lying in the middle portion of the Dürrenstein Formation (Fig. 2). Although different in details, the amber-bearing layers consist of grey-yellowish hybrid sandstones, rich in plant remains and coal. Marine invertebrates, mainly large bivalves and gastropods, are abundant. Teeth of fossil fish and fragments of terrestrial reptile bones have been detected. On the whole, the environment can be interpreted as marginal marine.

The age of these layers is latest Julian, possibly close to the Julian/Tuvalian boundary (about 225 My according to Gradstein et al., 1994). In the upper part of the Dürrenstein Fm., in correspondence to the maximum flooding surface of the Car 3 depositional sequence, the ammonoid *Shastites* cf. *pilari* (Diener) has been found (Fig. 2), belonging to the lower Tuvalian Dilleri Zone (Krystyn, 1973). In the amber-bearing beds, cropping out about 10-15 m below, the miospores *Spiritisporites spirabilis* Scheuring and *Patinasporites justus* Klaus, have been found. *S. spirabilis* is assumed to be a typical Tuvalian element (Scheuring, 1970; Blendinger, 1987), as it has never been found in Julian layers. However, as far as we know, a direct fitting with ammonoids does not exist. Therefore, we don't know if the appearance of *S. spirabilis* coincides with the base of the Tuvalian or if it is a little older. Help is given by a sequence stratigraphic correlation between the Dolomites and the NCA. As the Car 3 depositional sequence at Lunz (Fig. 3) is partly Julian, due to the presence of ammonoids of the Austriacum Zone (Krystyn, 1991), it is highly probable that the lower part of the Dürrenstein Formation is also upper Julian.

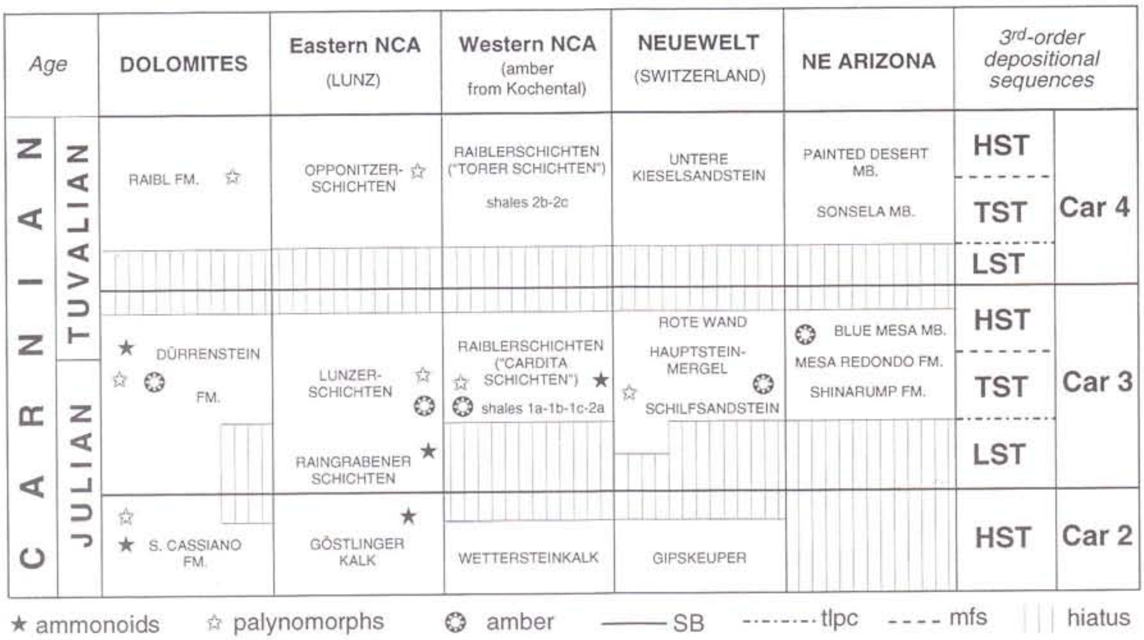


Fig. 3 - Sequence stratigraphic correlation of the Upper Triassic amber-bearing units.

Morphology and chemico-physical properties of amber of the Dolomites.

Amber found in the described Triassic formation occurs as spherical-ovoidal granules (Fig. 4), generally with diameter of about 2-5 mm; occasionally specimens of a larger size (up to 3 cm) have been found. The colour is from light yellow to reddish, with resinous luster, and conchoidal fracture. The amber droplets are minutely and pervasively fractured. Microscopic observation of the droplets shows a rough surface. Hardness is 2-3 and specific gravity slightly greater that 1 (about 1.08). Exposed to flame, amber burns producing a resinous odour. Particulate samples are almost insoluble in alcohol or ether, and slightly soluble in acetone. After

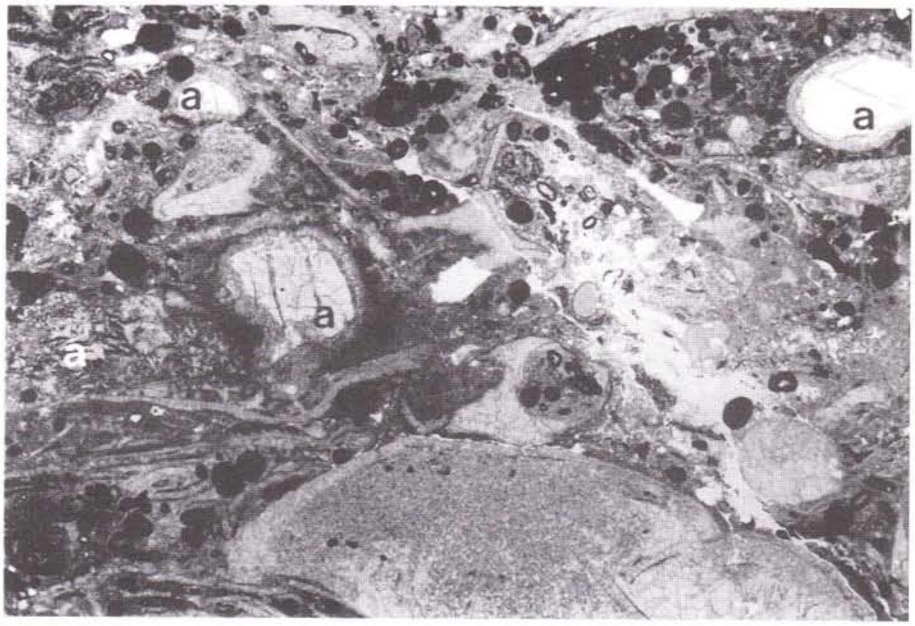


Fig. 4 - Amber droplets (a) in hybrid arenite (Rumerlo area). Thin section (6, 3x).

evaporation of the acetone, amber fragments are covered by a whitish crust.

Infrared (IR) spectroscopy.

IR spectroscopy has been suggested as a method to characterize fossil resins (Beck et al., 1964; Langenheim & Beck, 1965). In the present study, small specimens of amber droplets obtained from different localities were removed from their matrix, avoiding contamination with matrix particles. Spectra were obtained in the solid state: after grinding in agate mortar, samples were included in potassium bromide pellets. IR determinations were made just after the preparation of the pellets, to avoid an increase of hydroxyl stretching and bending absorptions due to KBr hygroscopicity (Beck, 1986). A Perkin Elmer 1600 Series FTIR spectrophotometer, within a range of 2.5-15.5 μm (4000-645 cm^{-1}), was used.

Typical IR spectra of two samples of amber are shown in Fig. 5. Additional spectra of samples from different localities in the Dolomites ranged between the two in the figure. The observed differences were of quantitative type and possibly due to different degrees of preservation. The prominent carbonyl band near 5.8 μm (about 1700 cm^{-1}), which is recognized as uniformly typical of all fossil resins and due to the stretching of carbon-oxygen double bonds (Langenheim & Beck, 1968; Beck, 1986), is present at 5.9 μm (1690 cm^{-1}) (Band B). The stretching of carbon-hydrogen bonds produces absorptions near 3.4 μm (2950 cm^{-1}) (Langenheim & Beck, 1968) (Band A); bending motions of these same bonds produce absorption near 6.8 μm (1470 cm^{-1}) and 7.2 μm (1380 cm^{-1}) (Langenheim & Beck, 1968) (Bands C and D).

However, the spectrum does not show a sharp band near 11.3 μm (885 cm^{-1}), characteristic of out-of-plane bending of the two hydrogen atoms of a terminal methylene group, also considered as a feature of resin acids (i.e. agathic and copalic acids) isolated from recent resins (Langenheim & Beck, 1968; Beck, 1986). On the other hand, Langenheim & Beck (1968) suggest caution when interpreting the absence of this band in fossil resins, since terminal methylene groups are easily oxidized. The region between 8-15 μm shows a unique morphology, with a main band at 8 μm (Band E in Fig. 5) and other minor bands, which may include those of carbon-oxygen single bond(s) at 8-10 μm (1250-1000 cm^{-1}) (Langenheim, 1969). The absence of the shoulder, known as "Baltic shoulder" (Beck et al., 1964; Beck, 1986), in the "fingerprint" region between 8 and 8.5 μm (1250 and 1175 cm^{1}), excludes a similarity with Baltic amber spectra.

Palynology.

Black siltstones without amber and biocalcarenites including amber from different localities within the Dürrenstein Formation have been processed. The palynological methodology consisted of a standard preparation procedure (HCl, HF, HNO_3 and 15 μm-mesh sieving).

The samples supplied a rich palynoflora consisting of spores (levigate, verrucate), pollen (monosaccate, bisaccate and circumpolles) and abundant cuticular fragments. The assemblage includes typical uppermost Julian-Tuvalian elements, such as *Spiritisporites spirabilis* Scheuring, *Vallasporites ignacii* Leschik, *Patinasporites justus* Klaus, *Pseudoenzonalasporites summus* Scheuring, *Samaropollenites speciosus* Goubin, *Infernopollenites parvus* Scheuring, *"Paracirculina" verrucosa* Praehauser-Enzenberg, *Duplicisporites continuus* Praehauser-Enzenberg, *Paracirculina maljawkinae* Klaus, *Duplicisporites verrucosus* (Leschik) Scheuring, *Duplicisporites granulatus* (Leschik) Scheuring (Pl. 1).

As shown in Fig. 6, amber-bearing sandy biocalcarenites (sample RUM7) and black siltstones without amber (samples HEL1 and SCS16) underwent a quantitative palynological analysis. A large amount of alete bisaccate pollen has been detected in all samples; other forms show different percentual distribution. The taeniate bisaccate pollen *Lunatisporites acutus* Leschik and *Lueckisporites* sp. present an unexpectedly high peak of frequency (a total of 41%, being single values 38% and 3%,

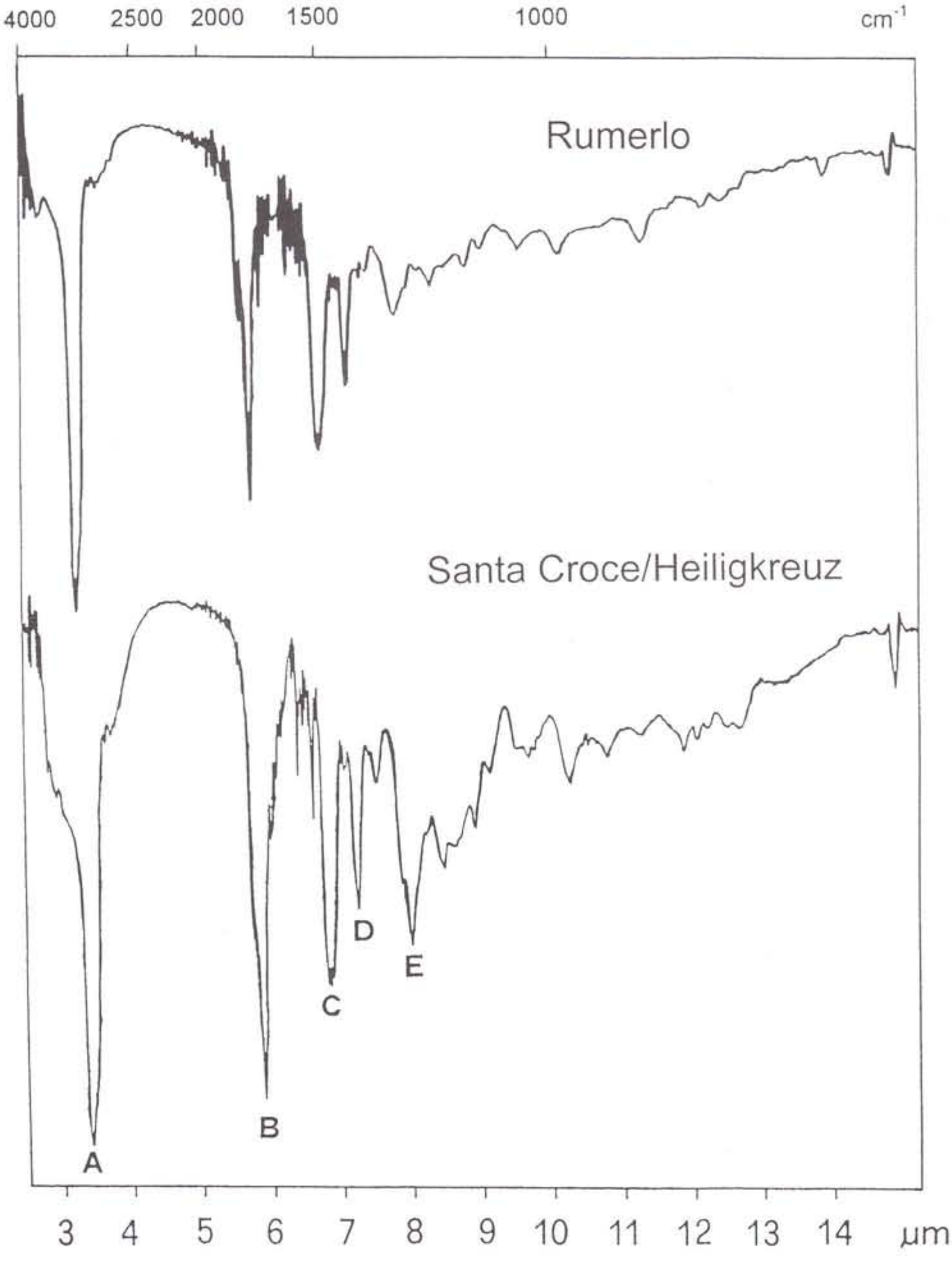


Fig. 5 - Infrared spectra of amber in the Dolomites. Upper spectrum from Rumerlo area; lower spectrum from Santa Croce/Heiligkreuz section. A-E: main bands (see text for details).

respectively) in correspondence to amber level (sample RUM7), thus suggesting a link with the amber-producing species.

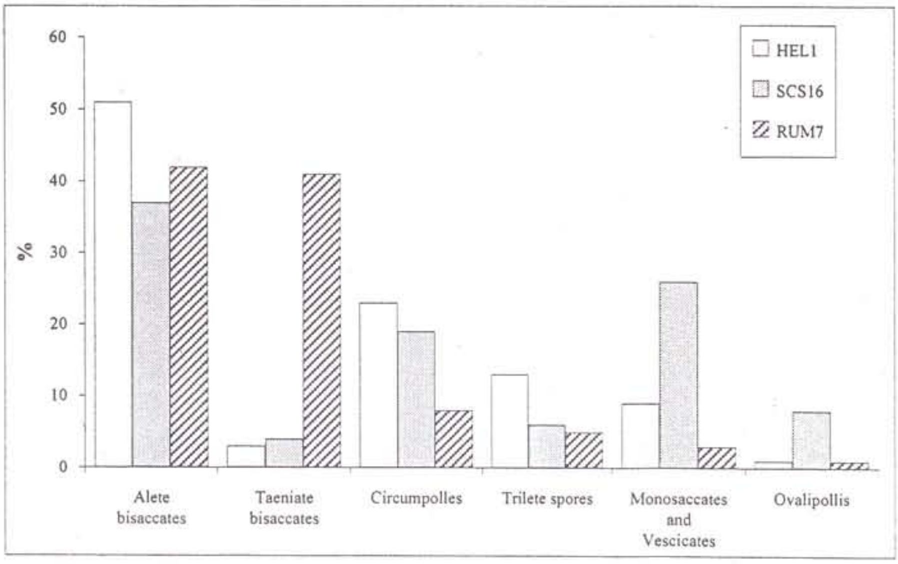
Discussion.

Comparison of the IR spectrum of our samples to spectra of other fossil resins (Langenheim & Beck, 1965, 1968; Langenheim, 1969; Beck, 1986) suggests that this resin is a unique kind of amber, in spite of the fact that the spectrum has similarities (band at 8 µm, 1250 cm-1) with those of present-day Pinaceae resins (Langenheim & Beck, 1965). A similarity can also be found with spectra of Cretaceous amber in Washington, D.C. and Alaska, interpreted as deriving from a complex forest of Coniferales, including Podocarpaceae, Araucariaceae, Pinaceae and Cupressaceae-Taxodiaceae (Langenheim & Beck, 1968).

A comparison with the Triassic amber found in Arizona (Litwin & Ash, 1991) shows, in turn, marked differences. The authors suggest that the botanical source of the Arizona fossil resin could be araucarian gymnosperms, because of Araucariaceae-like IR spectrum. Their spectrum however has very few diagnostic bands, which may be the result of a different taphonomic history rather than of a different botanical source. Amber in the Dolomites also displays a wide range of band amplitude, possibly as a result of different degrees of preservation.

Regarding the botanical source of amber in the Dolomites, quantitative palynological data support the possibility of a conifer origin. The unusual abundance of *Lunatisporites acutus* and *Lueckisporites* sp. corroborates this hypothesis. In Australian Triassic sediments, *Lunatisporites acutus* has been found associated *in situ* with gymnosperm cones (Townrow, 1967; Balme, 1995) and tentatively referred to the genus *Rissikia*, which represents the oldest certain podocarpacean remains (Stewart, 1983). *Lueckisporites* sp. is associated with the conifer *Majonica alpina* Klement-Westerhof, a Permian Majonicaceae found in the Butterloch area (Balme, 1995); another affinity is between this pollen and the conifers *Pramelrauthia hoberfelneri* (Krasser) found in the Triassic at Lunz. However, attribution of a Triassic fossil resin to a specific taxon is hazardous, because during that time the major groups of Coniferales had just begun to differentiate from Voltziales (Miller, 1977; Stewart, 1983).

Palynostratigraphic and sedimentological analysis of amber-bearing layers (Dunay & Fisher, 1978; Klaus, 1960; Jelen & Kusej, 1982; Praehauser-Enzenberg, 1970; Scheuring, 1970) suggests a narrow correlation between amber occurrence in several Triassic localities (Fig. 7) along 10°-30° paleolatitudinal belt (Gilbert Smith et al.,



SPECIES	HEL1	SCS16	RUM7
TRILETE SPORES	C	R	R
Calamospora sp.		R	
Todisporites sp.	R	R	
Concavisporites toralis Leschik in Kräusel & Leschik, 1956	R	R	R
Retusotriletes hercynicus (Mädler, 1964) Schuurman, 1977		R	
Concavisporites sp. 2 (*sensu* Schuurman, 1977)		R	
Uvaesporites gadensis Praehauser-Enzenberg, 1970	R	R	R
Spiritisporites spirabilis Scheuring, 1970		R	
MONOSACCATES AND VESCICATES	C	A	R
Enzonalasporites vigens Leschik in Kräusel & Leschik, 1956	C	A	R
Vallasporites ignacii Leschik in Kräusel & Leschik, 1956	R	A	R
Patinasporites justus Klaus, 1960		C	R
Pseudoenzonalasporites summus Scheuring ,1970		R	R
Kuglerina meieri Scheuring, 1978		R	
ALETE AND TAENIATE BISACCATES	A	A	A
Ovalipollis pseudoalatus (Thiergart 1949) Schuurman, 1976	R	C	R
Samaropollenites speciosus Goubin, 1965	R	R	
Lunatisporites acutus Leschik in Kräusel & Leschik, 1956		R	A
Infernopollenites parvus Scheuring, 1970		R	
Lueckisporites sp.			R
CIRCUMPOLLES	A	A	C
Paracirculina verrucosa Praehauser-Enzenberg, 1970	R	R	
Duplicisporites continuus Praehauser-Enzenberg, 1970	R	R	
Paracirculina scurrilis Scheuring, 1970	C	C	R
Paracirculina maljawkinae Klaus, 1960	C	C	
Paracirculina tenebrosa Scheuring ,1970		R	R
Camerosporites secatus Leschik in Kräusel & Leschik, 1956	R	R	
Partitisporites novimundanus Leschik in Kräusel & Leschik, 1956	C		C
Duplicisporites verrucosus (Leschik in Kräusel & Leschik, 1956) Scheuring, 1970	R		R
Duplicisporites granulatus (Leschik in Kräusel & Leschik, 1956) Scheuring, 1970		R	
Praecirculina granifer Klaus, 1960	C	C	R

Fig. 6 - Quantitative palynological analysis of 3 samples from the amber-bearing interval: HEL 1 and SCS 16 from Santa Croce/Heiligkreuz area; RUM 7 from Rumerlo (Cortina d'Ampezzo). Samples HEL 1 and SCS 16 do not bear amber. R = rare, from 0 to 5%; C = common, from 5 to 15% and A = abundant, 15%.

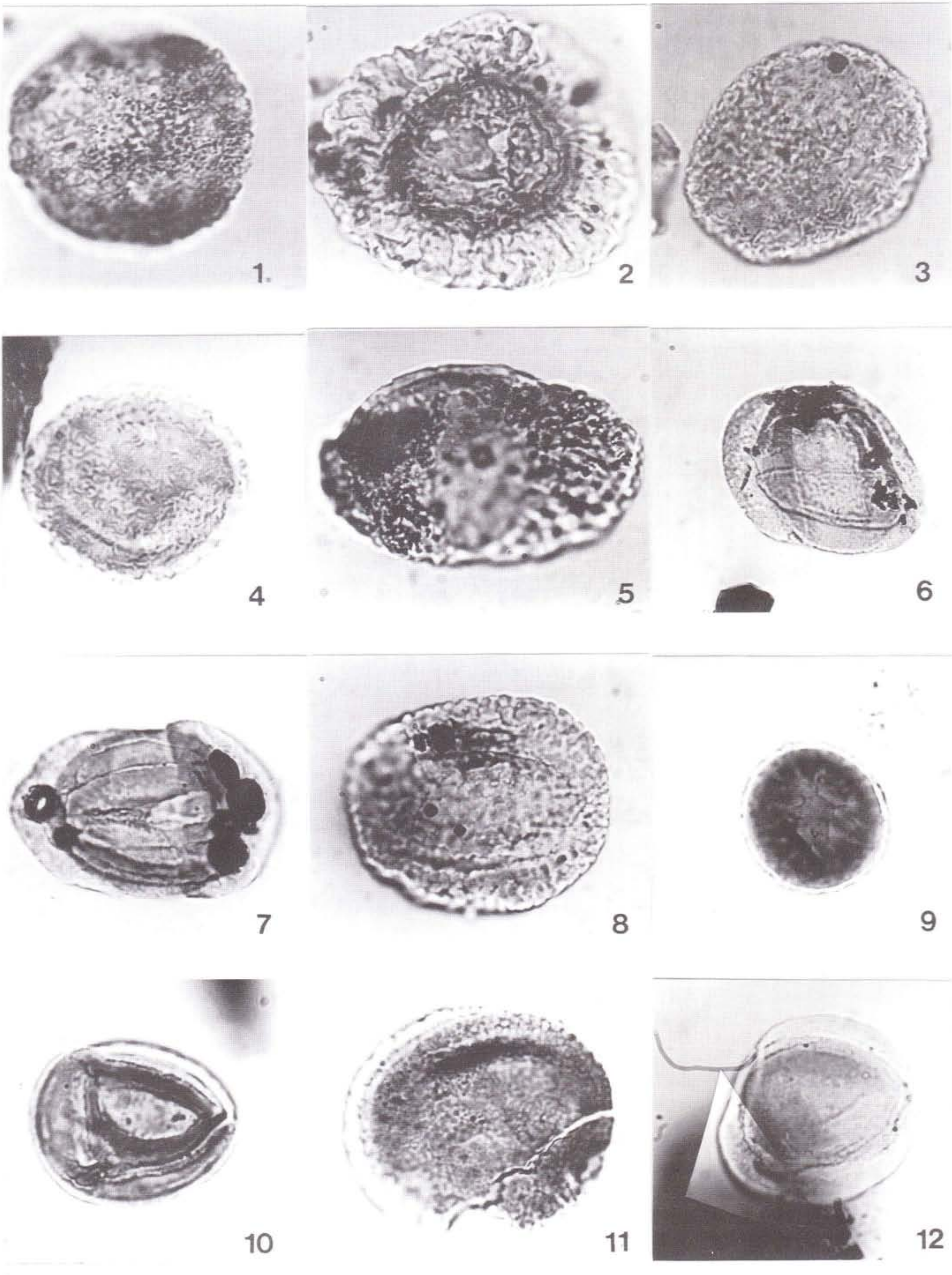
1973; Veevers, 1994). The first surprising result is the substantial synchroneity of the amber-bearing interval. Secondly, the consistency of the correlation is enhanced by a similar depositional typology (fluvial, marginal-marine) throughout different Triassic basins, attesting to a sudden and strong increase in immature siliciclastics, in turn documenting an increase in runoff and therefore in rainfall.

Although rejected by some researchers, on the basis of a detailed quantitative palynological analysis (Visscher et al., 1994), in our opinion the idea of a time-limited humid event, which during late Triassic broke the prevalent and generalized arid climate (Simms & Ruffel, 1989; Manspeizer, 1994; Simms et al., 1995) could be once more taken into consideration. In the Dürrenstein Formation, the presence of spores belonging to different species suggests the existence of a vegetation of hygrophitic type, thus corroborating the idea of a humid event.

Above data pose new problems which require further investigations. Why does amber only occur in such deposits? Why are they so relatively abundant? What are the relationships between amber and the assumed humid climatic event? Can amber production and/or fossilisation be tentatively related to it? The abundance of amber droplets in the sediments may be the consequence of litoraneal re-

PLATE 1

1) *Spiritisporites spirabilis*, Scheuring 1970, (42 μm); Slide SCS16 III, J45/3; 2) *Patinasporites justus*, Klaus 1960, (54 μm); Slide SCS16 I, K32; 3) *Vallasporites ignacii*, Leschik 1956, (36 μm); Slide SCS16 I, S28/3; 4) *Enzonalasporites vigens*, Leschik, 1956, (38 μm); RUM7 IX, N40; 5) *Samaropollenites speciosus* Goubin, 1965, (length 56 μm); SCS16 II, C32; 6) *Lueckisporites* sp., 1954, (length 72 μm); RUM7 X, P35; 7) *Lunatisporites acutus* Leschik, 1956, (length 47 μm); RUM7 IX, P28/2; 8) "*Paracirculina*" *verrucosa* Praehauser-Enzenberg, 1970, (45 μm); SCS16 I, N31; 9) *Paracirculina tenebrosa* Scheuring, 1970, (27 μm); SCS16 I, K30/3; 10) *Duplicisporites continuus* Praehauser-Enzenberg, 1970, (40 μm); SCS16 IV, K35; 11) *Pseudoenzonalasporites summus* Scheuring, 1970, (46 μm); SCS16 II, P48/4; 12) *Paracirculina maljawkinae* Klaus, 1960, (36 μm); SCS16 I, N33. Coordinates of the figured specimens were taken with the England Finder using Leitz Wetzlar n. 5345 with attached camera. All the slides housed in the Dipartimento di Geologia, Paleontologia e Geofisica of the University of Padova.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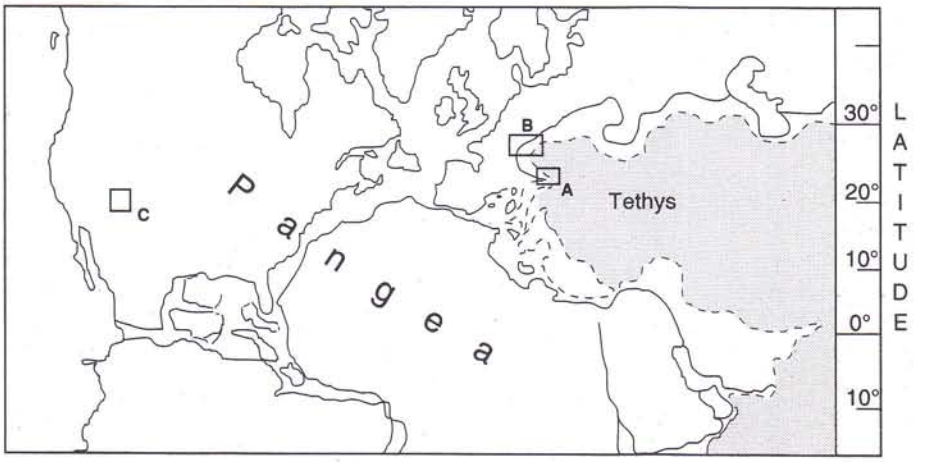

Fig. 7 - Occurrences of Upper Triassic amber. The distribution of the sites is scattered along the tropical belt. Carnian Pangea after Gilbert Smith et al. (1973). A) Dolomites; B) Northern Calcareous Alps and Switzerland; C) Arizona.

sin deposition due to a decrease of water salinity, following important rainfall events. The lowered density of marine water may have allowed sinking and deposition of the resin. Furthermore, a rapid change in climate may have induced stresses in the plants and therefore an increase in resin secretion.

Although in the other fluvial and/or marginal-marine Triassic deposits in the Southern Alps fossil resins have not yet been mentioned, the occurrence of amber in the Carnian cannot be a fortuitous event. Further investigations will establish the consistency of these considerations.

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