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MIDDLE TRIASSIC AMBER ASSOCIATED WITH VOLTZIALEAN CONIFERS FROM THE SOUTHERN ALPS OF ITALY

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*Abstract***.** Amber from the Carnian succession of the Dolomites and Julian Alps (northeastern Italy) represents one of the most ancient and quantitatively substantial Triassic fossil resin records in the world. So far, the Carnian appeared to be the only Triassic stage with findings of amber remains. However, the recent reappraisal of historical collections of plant fossils led to the discovery of even older Triassic amber, found on a rock slab from the "*Voltzia* beds" of the Recoaro area (Anisian) and on a sample from the "Wengener Schichten" of Wengen/La Valle (Ladinian), respectively. Both specimens are associated with conifer shoots of Voltziales. To date, they are the oldest known Triassic fossil resins, demonstrating that the preservation of amber was not restricted to the sediments deposited during the Carnian as suggested before. These finds contribute to partially fill the gap in the amber record between the Carboniferous and Upper Triassic.

Introduction

Identification of the botanical origin of the fossil resin represents one of the main questions in amber study, and extensive literature, by using both physico-chemical analysis and paleobotanical evidence, tries to give an answer. As an example, starting from the pioneering papers of Langenheim and Beck (Beck et al. 1964, 1965; Langenheim & Beck 1965; Langenheim 1969) and arriving to more recent surveys (Weitschat & Wichard 2002; Langenheim 2003; Wolfe et al. 2009, 2016), the botanical affinity of the most famous fossil resin, Baltic amber, still remains unresolved. In this view, the discovery of amber directly associated with fossil plants, as in case of the Carnian amber of the Dolomites (Roghi et al. 2006) and the amber illustrated in this paper, improves our knowledge of the main resin producers through geologic time.

The oldest amber record dates back to Paleozoic (Carboniferous), while findings of Mesozoic amber are very patchy, with abundant material coming mainly from the Cretaceous (e.g., Penney 2016). The discoveries of Triassic amber are so far restricted to the Carnian (Upper Triassic), whereas until now only few localities yielded Jurassic amber (Philippe et al. 2005; Azar et al. 2010; Nohra et al. 2013; Neri et al. 2017. The possible producers of the Mesozoic amber include several conifer groups such as Cheirolepidiaceae, Araucariaceae, Pinaceae and Cupressaceae (Kosmowska-Ceranowicz et al. 2001; Knight et al. 2010; Schmidt et al. 2012; Sidorchuk et al. 2015).

Upper Triassic amber from Italy has been mainly recovered from the Heiligkreuz Formation in the eastern Dolomites and in the Rio del Lago Formation in the Julian Alps (Koken 1913; Zardini 1973; Wendt & Fürsich 1980; Gianolla et al. 1998b; Roghi et al. 2006). European Upper Triassic amber outside of Italy comes from the Schilfsandstein of Switzerland and Germany (Soom 1984; Kelber 1990), the Raibler Schichten and the Lunzer Schichten of Austria (Pichler 1868; Sigmund 1937; Vávra 1984) and the Sándorhegy Formation of Hungary (Budai et al. 1999). Here we document for the first time the presence of amber in the Middle Triassic of the Southern Alps (Fig. 1). Specifically, we report two fossil plant specimens bearing fossil resin, and recently recovered in old paleontological collections. These findings testify to the relevance

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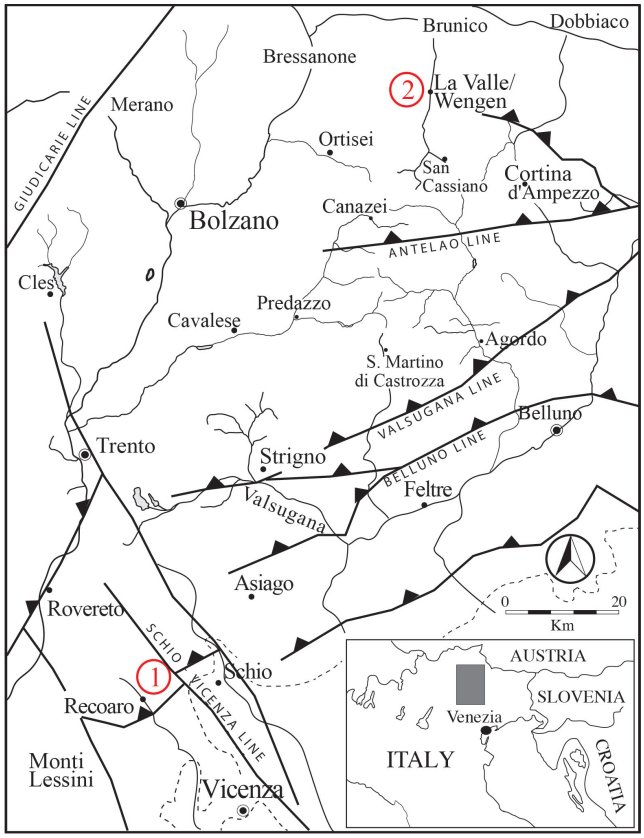

Fig. 1 - Map showing the original sites of discovery of Middle Triassic amber from Northern Italy. 1) Anisian Recoaro site; 2) Ladinian La Valle/Wengen site.

to carefully reappraise historical material coming from museums and academic institutions.

Material and methods

The two rock slabs with plant fossils and associated amber are housed in the collections of the Museum of Natural History of Venice (MSNVE 23292) and of the Museum of Natural History of Vienna (NHM 2007B0004-0001). Plant remains on both slabs are compressions/impressions, partly with organic material preserved. Amber droplets are closely associated with conifer stems and leaves but, in addition, dispersed amber pieces occur in the sediment matrix. Unfortunately, the amount and quality of amber material is insufficient for detailed physico-chemical analyses.

The Anisian specimen MSNVE 23292

A small collection of fossils, originally belonging to the botanist Abramo Massalongo (1824-1860), is presently housed at the Museum of Natural History of Venice, probably donated in the 19th century to the "Istituto Veneto di Scienze, Lettere ed Arti". Most of these specimens are invertebrates and plants from the Recoaro area (Vicenza provin-

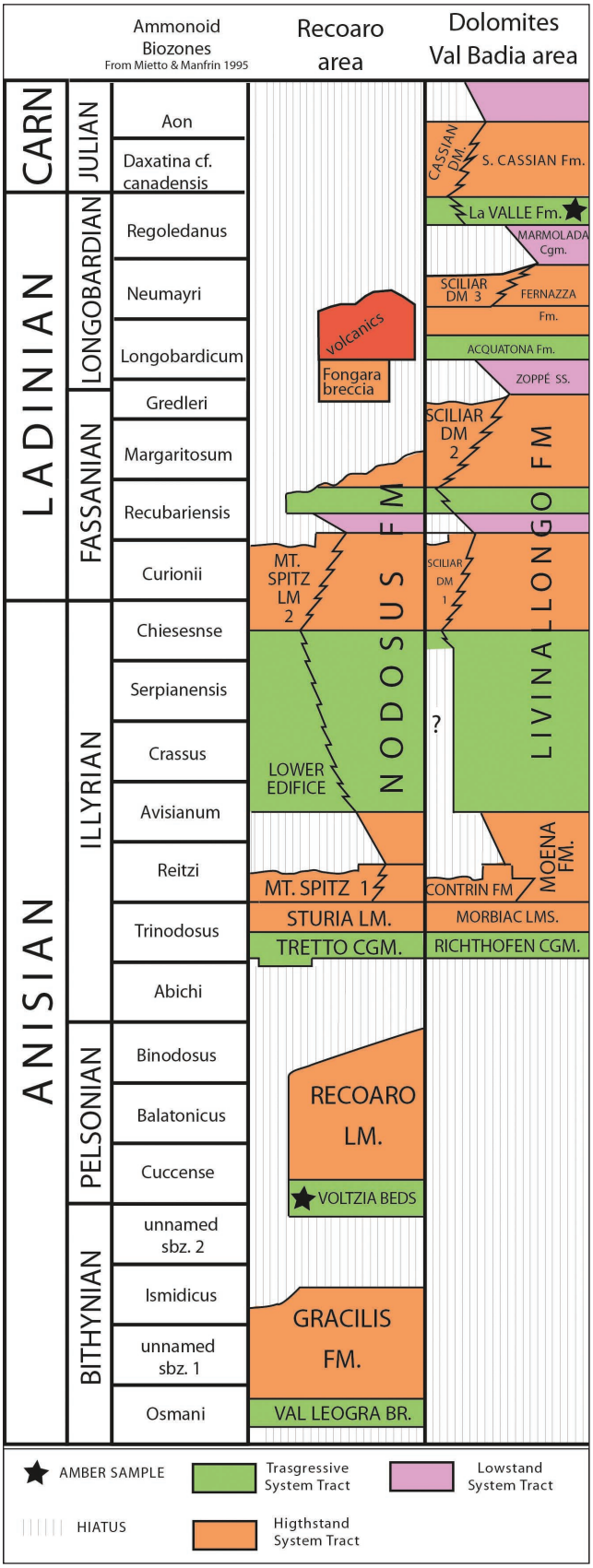

Fig. 2 - Correlations between Triassic Formations from the Dolomites (Val Badia Area) and the Recoaro area (modified from De Zanche et al. 1993; Gianolla et al. 1998a).

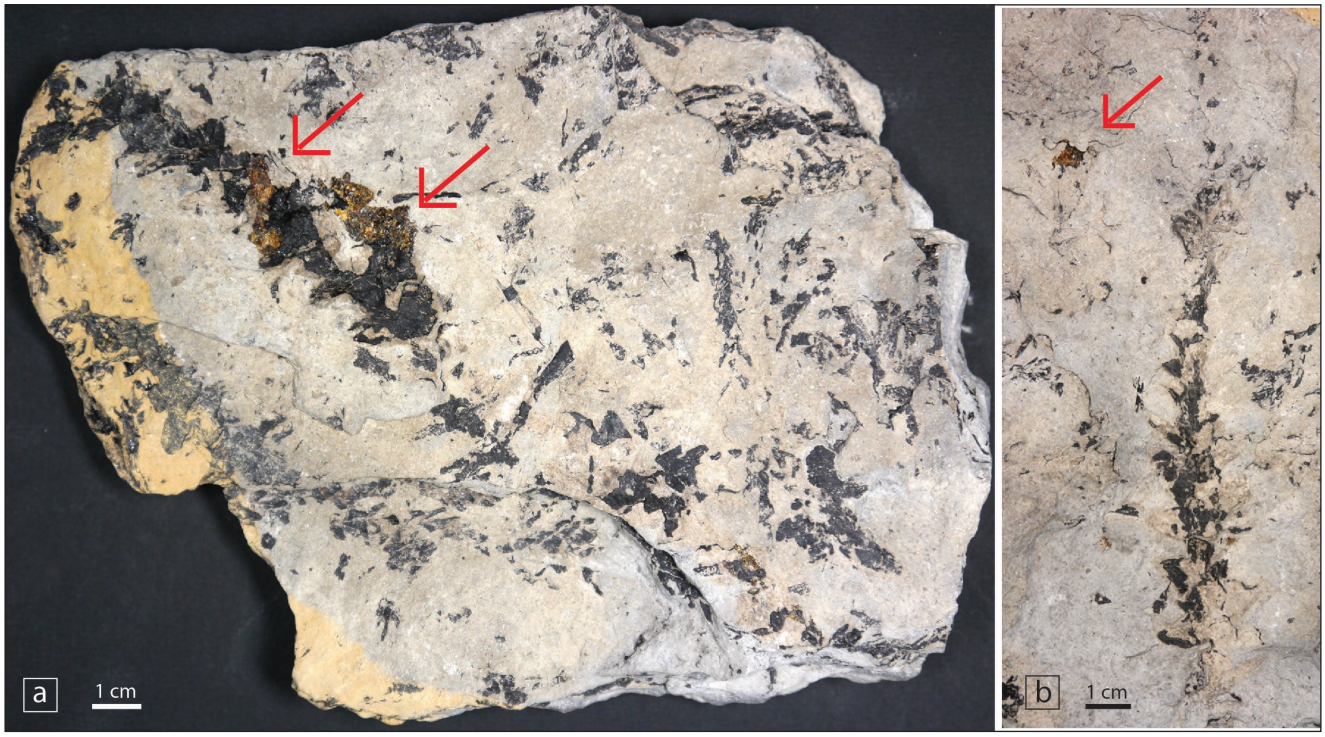

Fig. 3 - The Venice specimen of *Voltzia recubariensis* MSNVE 23292. a) Side A with the main shoot with attached fossil resin (red arrows); b) Side B with a drop of amber (red arrows) and a *Voltzia* shoot.

ce) that yielded one of the most famous Triassic macrofloras of northern Italy (e.g., Kustatscher & Roghi 2016). Plant remains from Recoaro have been described as early as the mid-19th century (Schauroth 1855; Massalongo 1857; De Zigno 1862; Schenk 1868; Gümbel 1879) and come from several Permian and Triassic sites (e.g., De Zigno 1862; Mietto 1988, 2003). Permian plants have been found in this area in Lopingian Gröden/Val Gardena Sandstones (Upper Permian), whereas the Triassic plants have been recovered from the Middle Triassic "*Voltzia* beds". The plant-bearing "*Voltzia* beds" (lower Anisian), extensively outcropping in the area (e.g., Barbieri et al. 1980), overlie the "*Gracilis* Beds" and include several lithologies (sandstones, siltstones, marls, marly limestones, etc.). The heterogeneous lithological association reflects a variety of depositional settings, ranging from alluvial plain to proximal marine (Fig. 2) (e.g., Mietto 1988, 2003; Gianolla et al. 1998a). Plant macroremains are generally preserved in gray siltstone and marly limestone and the plant assemblage is strongly dominated by conifers. Palynologically the "*Voltzia* beds" correspond to the *vicentinense-antonescui* subphase (*thiergartii-vicentinense* phase) characterized by the dominance of conifer pollen (Brugman 1986).

According to the original label, the rock slab housed in Venice (MSNVE 23292; Fig. 3) comes from "Valle del Prach" and is composed of grey mudrock characteristic of the "*Voltzia* beds". It preserves conifer remains on both sides (side A and side B; Fig. 3), identified by Massalongo as "*Araucarites athrotanoides* Msslg" (nomen in schedis). Several fossil resin fragments are associated with and partly cover the conifer shoot fragments (Fig. 3). The amber preserved on side A is associated with a conifer shoot of 90 mm length and 35 mm width (Fig. 3a). The amber is an unfractured, massive fossil resin, with resinous brilliance, yellow to reddish-brown in color with a conchoidal fracture. The fossil resin on side B (Fig. 3b) is isolated, with a diameter of 10 mm (arrow in Fig. 3b). The conifer shoot fragments on side A are badly preserved. The shoot fragment partly covered by amber is the biggest one (Fig. 3). Leaves are arranged in a loose helix and inserted perpendicularly to the 8 mm wide axis. The leaves are leathery, triangular to falcate, and 15–20 x 15–20 mm in size. Other shoot fragments preserved on this slab are smaller, in most cases less than 50 mm long, and even worse preserved. Nonetheless, they are falcate to triangular leaves, of which the upper margin is almost perpendicular to the axis. The conifer shoot fragments on side B are too poorly preserved for a precise determination.

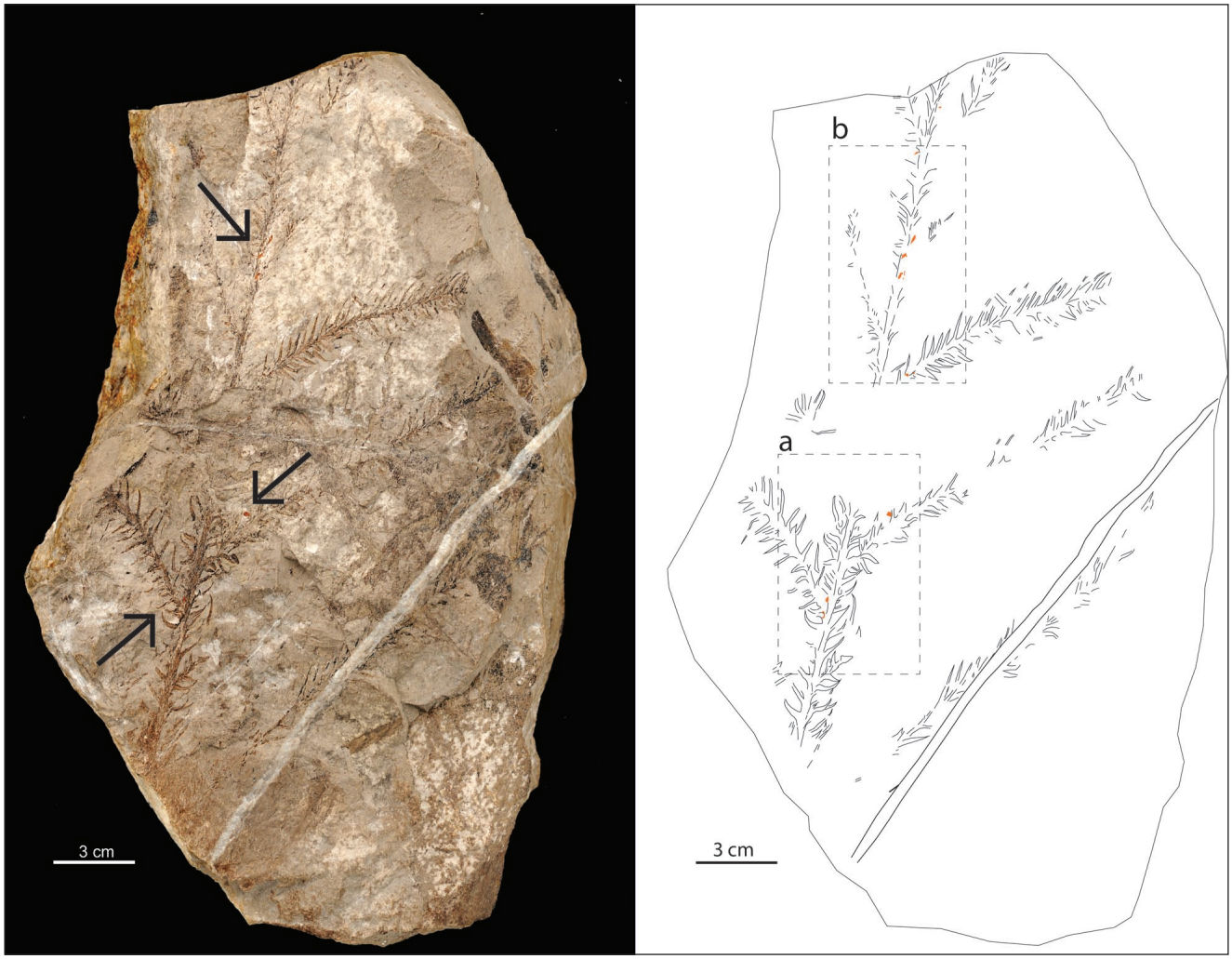

Fig. 4 - Amber and plant remains from the Vienna specimen of *Voltzia ladinica* NHM 2007B0004-0001; a and b in the drawn plant represent areas shown in detail in Fig. 5a and 5c, respectively.

Robust falcate to triangular leaves with the upper margin positioned almost perpendicularly on the axis are characteristic of *Voltzia recubariensis* (De Zigno 1862) Schenk, 1868, a typical Anisian taxon so far not reported outside the Southern Alps (Brack & Kustatscher 2013). Apart from the *Voltzia* beds of the Recoaro area (e.g., Schenk 1868), this species was also described from the Agordo Formation of the San Lucano Valley (Kustatscher et al. 2011), the Dont Formation of Kühwiesenkopf/Monte Prà della Vacca (e.g., Broglio Loriga et al. 2002; Kustatscher 2004), the Richthofen Conglomerate of Piz da Peres (Todesco et al. 2008), the Angolo Limestone of the Bagolino succession (Brack & Kustatscher 2013), and a not precisely defined Anisian locality of Vallarsa Valley (Selli 1938). The fact that the amber has been found not only dispersed in the sediment but also tightly associated with shoots of *Voltzia recubariensis* strongly suggests that this Triassic conifer was the producer of the amber preserved on MSNVE 23292.

The Ladinian specimen NHM 2007B0004-0001

According to its label, the specimen of the Museum of Natural History of Vienna (NHM 2007B0004-0001; Fig. 4, 5) has been found in the "Wengener Schichten" of Wengen (Badia Valley) in the Bolzano Province (Fig. 1). This area is well known for its upper Ladinian plant fossils (e.g., Kustatscher & Van Konijnenburg-van Cittert 2005; Kustatscher & Roghi 2016 and references therein). Starting with the first illustration by Wissmann & Münster (1841), a high number of different plant remains was subsequently described from the upper Ladinian of the Dolomites (e.g., Mojsisovics

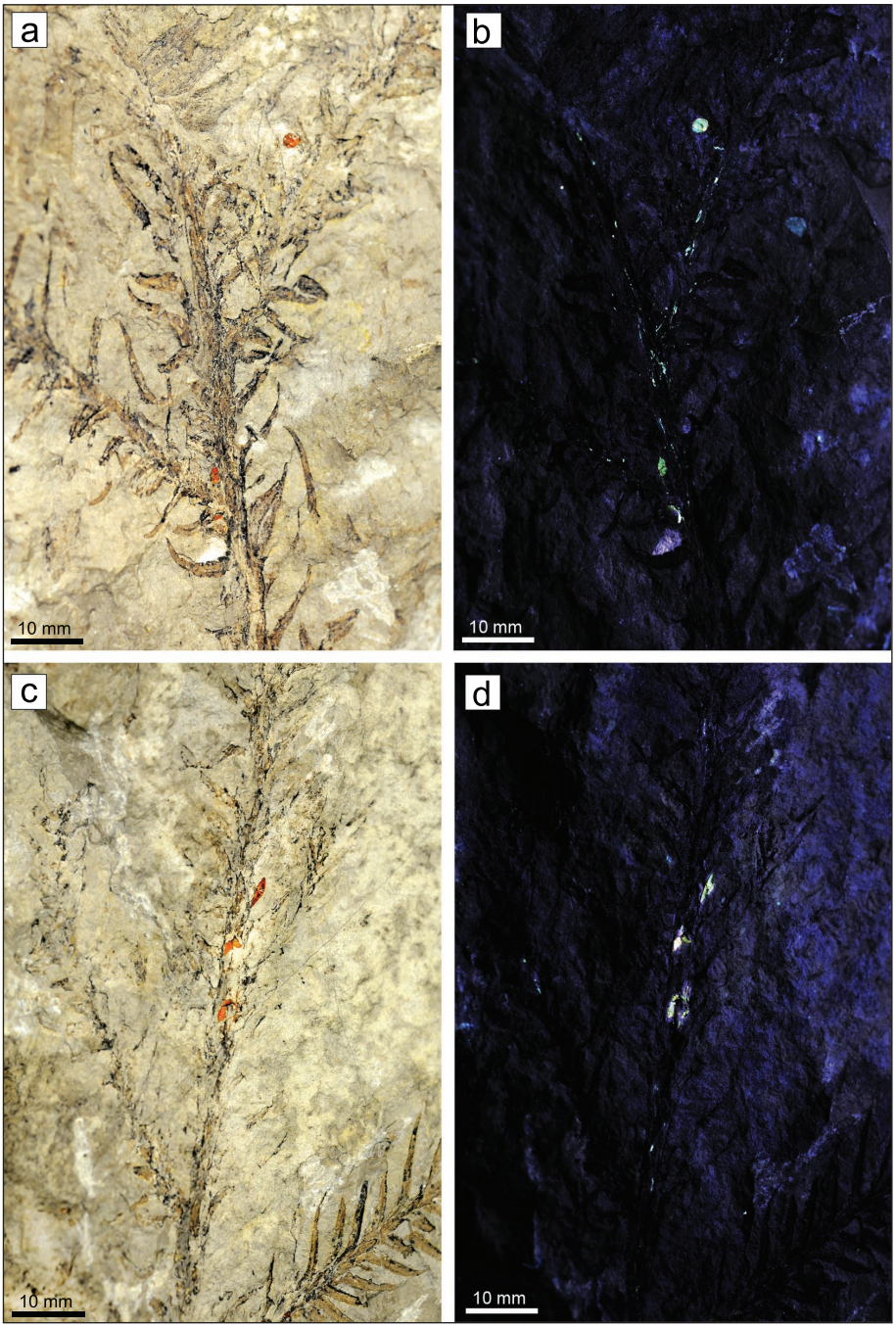

Fig. 5 - (a-c) Detail of the amber specimen from Vienna NHM 2007B0004-0001. 5b and 5d: same portions of the Vienna specimen under UV light. The fossil resin covers and, in some cases, fills the spaces inside the main branches.

1879; Ogilvie-Gordon 1927, 1934; Leonardi 1953, 1968; Wachtler & Van Konijnenburg-van Cittert 2000; Kustatscher et al. 2004; Kustatscher & Van Konijnenburg-van Cittert 2005). This also includes the surroundings of Wengen/La Valle, the type locality of the so-called "Wengener Schichten" (for more details, see Kustatscher & Van Konijnenburg-van Cittert 2005).

The "Wengener Schichten", nowadays including several units (see Gianolla & Neri 2006), testifies to the beginning of the basic volcanic activity in the Dolomites. This volcanic activity was mostly submarine, although locally (e.g., Predazzo area) subaerial eruptive centers existed (Hoernes 1912; Leonardi 1968). The "Wengener Schichten" comprises several formations, two of which are known for their content in plant fossils: the Fernazza and the Wengen/La Valle formations (Fig. 2). The Fernazza Formation is a volcano-turbiditic succession with tuffites, hyaloclastites, pillow lavas and pillow breccias. During the breaks in the volcanic activity, debris flows and submarine avalanches occurred (Gianolla 1993). This succession, characterized by marked lateral variations, was deposited in a basinal setting. Based on its ammonoid content, it has been dated as late Longobardian (Fig. 2) (late Middle

Triassic; e.g., Viel 1979a, 1979b; Gianolla 1993; Mietto & Manfrin 1995). The Wengen/La Valle Formation is characterized by terrigenous–carbonatic successions overlying the volcano-arenites of the Fernazza Formation and is overlaid by the St. Kassian/San Cassiano Formation. The formation was dated by ammonoids as latest Longobardian. Palynologically, the Wengen/La Valle Formation corresponds to the upper part of TrS-F palynological zone sensu Hochuli et al. (2015).

The rock sample containing the amber fragments is composed of a gray marly limestone with a branching conifer shoot bearing well-preserved leaves. Based on the lithology, sample NHM 2007B0004-0001 likely comes from the uppermost part of the Wengen/La Valle Formation (latest Middle Triassic; e.g., Viel 1979a, 1979b; Fois 1982; Gianolla 1993; Mietto & Manfrin 1995). The Ladinian amber occurs in association with and partly covers a conifer shoot fragment. The use of UV-light revealed that the amber is attached to the upper side of the leaves (Fig. 5). The amber is massive, yellow to orange in color and with conchoidal fracture. The conifer shoot is about 180 mm long and 80 mm wide. The main axis is 2–3 mm in diameter and bears alternating incomplete up to 70 mm long and 10 mm wide lateral shoots. Both the main shoot and the lateral shoots are covered with narrow, triangular to slightly falcate leaves with a pointed apex. The leaves are inserted in a loose helix and arise at an angle of 40–60°; the leaves are 6–10 mm long and 1–2 mm wide. Globally the shoot represents a very delicate conifer branch.

Typical conifers of the Ladinian of the Dolomites are the broad-leaved *Pelourdea vogesiaca* (Schimper & Mougeot, 1844) Seward, 1917 and conifers with needle-like leaves such as *Voltzia dolomitica* Wachtler & Van Konijnenburg-van Cittert, 2000, *Voltzia pragsensis* Wachtler & Van Konijnenburg-van Cittert, 2000 and *Voltzia ladinica* Wachtler & Van Konijnenburg-van Cittert, 2000. The leaves of *V. dolomitica* and *V. pragsensis* are much robust, thicker and the shoots stouter, whereas *Voltzia ladinica*, which is characterized by heterophyllous leaves that can become also thin and needle-like, strongly resembles our specimen (Fig. 4). *Voltzia ladinica* was previously described from Prags/Braies, Gröden/Val Gardena and Wengen/La Valle (Wachtler & Van Konijnenburg-van Cittert 2000; Kustatscher & Van Konijnenburg-van Cittert 2005). The fact that also in this specimen amber droplets were found both dispersed near the shoot fragment and associated with some of the leaves strongly suggests that a voltzialean conifer, *Voltzia ladinica* was the producer of this amber.

Discussion

The Anisian and Ladinian amber were deposited in marginal marine sediments, just like part of the Carnian amber material of the Dolomites and the Julian Alps (Roghi et al. 2006). Moreover, the amber is preserved physically connected with conifer shoots that permit to assign the amber to their respective resin-producing plant species. Our data suggest that the amber of the Middle Triassic of Northern Italy was produced by representatives of the Voltziales (*Voltzia recubariensis* and *V. ladinica,* respectively), whereas the Carnian amber of the Dolomites was mainly produced by cheirolepidiaceous conifers.

The Anisian macroflora from Recoaro is dominated by conifers of the *Voltzia recubariensis* type. Rare additional elements are, according to literature, horsetails (*Equisetites* sp.) and conifers belonging to the ?Cupressinae (*Taxodites saxolympiae* Massalongo ex De Zigno, 1862). The Ladinian plant association of the Wengen/La Valle area is composed of lycophytes (*Annalepis zeilleri* Fliche, 1910), horsetails (*Equisetites arenaceus* (Jaeger) Schenk, 1864), ferns (*Cladophlebis leuthardtii* Leonardi, 1953; *Gordonopteris lorigae* Van Konijnenburg-van Cittert et al., 2005; *Ptilozamites sandbergeri* (Schenk) Kustatscher & Van Konijnenburg-van Cittert, 2007), cycadophytes (*Bjuvia dolomitica* Wachtler & Van Konijnenburg-van Cittert, 2000; *Sphenozamites wengensis* Wachtler & Van Konijnenburg-van Cittert, 2000; "*Pterophyllum jaegeri* Brongniart, 1828") and conifers (*Pelourdea vogesiaca*, *Voltzia dolomitica* and *V. pragsensis*). The conifers are the dominant plant group, followed by seed ferns, while lycophytes, horsetails and cycadophytes are rare (e.g., Kustatscher & Van Koijnenburg-van Cittert 2005, 2007).

Palynological analyses of Anisian and Ladinian samples from both areas (Recoaro, Wengen/La Valle) revealed a rich and diversified microflora. The environment was probably characterized by more or less expanded carbonate or volcanic islands covered by a rich flora (Brack & Kustatscher

2013; Kustatscher et al. 2010). The dominance of the conifers in the macroflora is mostly due to a taphonomic effect (transport from islands to proximal marine environments) while the microflora suggests a humid environment (e.g., Kustatscher & Van Konijnenburg-van Cittert 2005; Kustatscher et al. 2010).

Unusual high abundance of amber in the fossil record may be linked to specific events of environmental stress for the plants, as it is is well documented for the Carnian Pluvial Event (Gianolla et al. 1998b; Roghi et al. 2006). Although rare, the presence of the fossil resin in the Recoaro area and in the Wengen/La Valle area suggests it is coeval with two Triassic humid events detected during the Bithynian/Pelsonian and Longobardian, respectively (Preto et al. 2010; Stefani et al. 2010; Trotter et al. 2015). Conifers may have reacted to stress provoked by environmental changes with increased resin production. Moreover, the "*Voltzia* beds" were deposited during a transgressive phase, which could also have created stressed conditions for the forest habitat while creating favorable conditions for the preservation of fossil plants and resin at the same time.

Conclusions

This paper documents for the first time the presence of amber in the Middle Triassic of the Southern Alps and expands our knowledge of the distribution of amber in the Paleo-Mesozoic fossil record (e.g., Bray & Anderson 2009; Penney 2016). The Venice and Vienna specimens here described and discussed are of great importance also because both represent amber closely associated with the resin-producing plants. Moreover, these findings represent the oldest known Triassic occurrence of amber and provide clear evidence that also Middle Triassic voltzialean conifers secreted resin.

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