Rinaldo Zardini (1902–1988) and his legacy – 121 after his birth and 35 after his death

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ABSTRACT

Rinaldo Zardini (1902–1988) was an Italian palaeontologist and botanist born in Cortina d'Ampezzo. Having a background as a professional photographer, he was able to illustrate his collection of mostly tiny fossils in high definition. For his significant contributions to the field of palaeontology he received an honorary degree from the University of Modena. Here we highlight the extent of his scientific interest and his enduring scientific legacy in geology, palaeozoology and palaeobotany.

KEY WORDS

Triassic, Carnian, Ladinian, bibliography, scientific legacy, plant fossils, marine fossils.

INTRODUCTION

Rinaldo Zardini (1902–1988) was an Italian palaeontologist and botanist born in Cortina d'Ampezzo (or simply Cortina). During World War I, he attended school in Switzerland and returned to Cortina only in 1920. His father, Raffaele Zardini, was a teacher, and his mother, Antonia Verocai, was the first war photojournalist in Cortina d'Ampezzo. The Zardini family, involved in photography, opened Cortina's first photographic shop. Rinaldo worked in the family optical business and participated in alpinism (with his sister Olga Zardini), ice hockey (Italian champion in 1932), and skiing. During World War II, he worked as a cinematographer for the Istituto Luce.

In the 1930s, Rinaldo Zardini initiated botanical studies, creating an herbarium of more than 1000 plant species from around Cortina d'Ampezzo. He published works like "La flora montana e alpina di Cortina d'Ampezzo" [The mountain and alpine flora of Cortina d'Ampezzo] (1939), and "Flora di Cortina d'Ampezzo" [The flora of Cortina d'Ampezzo] (Pampani & Zardini, 1948). From 1951 to 1959, he cataloged 500 butterfly and beetle species, concluding his botanical studies in 1959.

In 1935, Zardini collected his first fossil (a fossil coral). His passion for palaeontology led to the biggest and most significant collections of his time, of about one million fossils. His studies focused on Middle and Upper Triassic fossils, particularly gastropods, bivalves, corals and sponges, and other marine organisms. Notable publications include "Fossili del livello di S. Cassiano" [Fossils of the San Cassian level] (1966), "Geologia e fossili delle Dolomiti di Cortina e dintorni" [Geology and fossils of the Dolomites of Cortina and surroundings] (1988) and the "Fossili cassiani" catalogues [Fossils of the S. Cassian Formation] (1978–1981). Some of these became important reference papers in Italian, European and American universities.

Rinaldo Zardini received several awards, served as the President of the Istituto d'arte di Cortina, and earned an honorary degree from the University of Modena. Recognized for his contributions, he was honored the position as honorary researcher at institutions like the University of Washington and the Smithsonian Institution. In 1988, Rinaldo Zardini passed away, leaving an enduring legacy in various scientific fields.

The aim of this paper is to provide an overview on this scientific legacy more than 120 years after his birth and 35 years after his death.

1. Rinaldo Zardini's GEOLOGICAL LEGACY

Although Rinaldo Zardini was not a formally trained geologist, he demonstrated a profound understanding of the geology and palaeontology of the Dolomites, particularly of the mountains surrounding Cortina d'Ampezzo. Although he did not publish detailed scientific papers specifically on the geology of the Cortina d'Ampezzo area, he incorporated his extensive knowledge of the origin and distribution of various geological formations in works such as "Geologia e fossili attorno a Cortina d'Ampezzo" [Geology and fossils surrounding Cortina] (Zardini, 1973, 1980b, 1983). Additionally, he contributed to the study of landslides, evident in publications like "La frana in località Cinque Torri" [The landslide of the Cinque Torri] (Zardini, 1979) and "La frana su cui sorge Cortina d'Ampezzo" [The landslide on which Cortina d'Ampezzo is build] (Panizza et al., 1986; Panizza & Zardini, 1986).

FIG. 1: The mountains surrounding of Cortina.

In subsequent years, the Comprehensive Geological Mapping Project (CARG), a nationwide initiative involving regional and autonomous administrative bodies, academic institutions, research entities, and the Italian Geological Survey (ISPRA) continued the geological investigations initiated by Rinaldo Zardini in the region. The comprehensive geological survey led to the publication of the 1:50,000 scale geological sheet "F029 Cortina d'Ampezzo" (Neri et al., 2007). The meticulous geological studies conducted during this and other geological mapping endeavors in the Dolomites, such as the "F016 Dobbiaco" (Gianolla et al., 2018) and "F046 Longarone" (Gianolla et al., 2022) geological sheets, facilitated the revision and modernization of the stratigraphic framework of the Dolomite region. This endeavor significantly advanced our comprehension of the territory by providing a more detailed and higher-resolution account of its geological history.

This revision also had profound implications for the nomenclature and interpretation of stratigraphic units studied and discussed in detail by Rinaldo Zardini. Presently, stratigraphic terms such as the Wengen, San Cassiano, Heiligkreuz, and Travenanzes formations have replaced the historical designations like "strati di La Valle", "strati di San Cassiano", "Infraraibliano", "formazione di Dürrenstein", or "strati di Raibl", which were used by Rinaldo Zardini but have been deemed imprecise in characterizing their respective stratigraphic units. However, many names employed by the geologist to delineate rock successions have remained unchanged. This includes for example Dolomia Cassiana or the Dolomia Principale. These adjustments, while respecting historical priorities (e.g., Wengen and Heiligkreuz formations) and considering the Dolomites as a geological unity, further underscore the geological significance of the region.

Rinaldo Zardini perceived the Dolomites surrounding his hometown Cortina, through the eyes of the photographer and the scientist. To him, these mountains likely were always the most beautiful and significant mountains in the Earth's history. In June 2009 the Dolomites achieved UNESCO World Heritage Site status, earning a place on the World Heritage List based on criteria VII (aesthetic and landscape value) and VIII (scientific importance in geology and geomorphology). The Seville declaration states "*The nine components of the Dolomites World Heritage Site protect a series of highly distinctive mountain landscapes that are of exceptional natural beauty. Their dramatic vertical and pale-coloured peaks in a variety of distinctive sculptural forms is extraordinary in a global context. This property also contains an internationally important combination of earth science values. The quantity and concentration of highly varied limestone formations is extraordinary in a global context, whilst the superbly exposed geology provides an insight into the recovery of marine life in the Triassic period, after the greatest extinction event recorded in the history of life on Earth. The sublime, monumental and colorful landscapes of the Dolomites have also long attracted hosts of travelers and a history of scientific and artistic interpretations of its values.*" (www.dolomitiunesco.info; Gianolla et al., 2009)

Among the numerous geological attributes that endow the Dolomites with global significance, the prominence of the area stands out as one of the finest examples worldwide of Triassic carbonate platform-basin systems. The extensive biodiversity of the cliffs or fossil atolls, forming the archipelago of tropical islands between 240 and 230 million years ago, has been documented meticulously by Rinaldo Zardini through his tireless

FIG. 2: The Dibona section.

fossil collection efforts. The declaration further underscores the extensive history of seminal scientific studies conducted in the region. And the meticulous work carried out by Rinaldo Zardini rightfully aligns with the scientific contributions and understanding of the territory, establishing the Dolomites as an open-air laboratory, frequented by countless researchers worldwide.

The mountains surrounding Cortina are particularly renowned for rock successions deposited during the late Ladinian, Carnian and Norian. Rinaldo Zardini devoted special attention to the study of what he referred to as the "San Cassiano" (Zardini, 1966, 1973, 1976a, 1976b, 1978, 1980a, 1980b, 1981a, 1981b, 1983, 1988, 2023; Dieci et al., 1968; Vermeij et al., 1982). Today, a portion of what he identified as "San Cassiano" has been delineated into two distinct lithostratigraphic units, the San Cassiano and the Heiligkreuz formations (Neri et al., 2007; Breda et al., 2009; Pecorari et al. 2023). The Heiligkreuz Formation preserves a crucial time interval marked by a significant climate change that profoundly impacted carbonate and sediment deposition in tropical regions.

This stratigraphic interval corresponds to the so called "Carnian Pluvial Episode" or CPE, a phase documenting the demise of the lower Carnian carbonate platforms (Cassian Dolomite) and the flattening of palaeotopography due to a rapid infilling of the basins by terrigenous sediments. This interval is documented in the ravines between the Cassian carbonate platforms and the Dolomia Principale across the Dolomites, including areas around Cortina, such as the base of the Tofane and the Cinque Torri, the roof of the Lastoni del Formin, creating the characteristic ledge at the base of the Tre Cime di Lavaredo. In adjacent basins, such as Misurina, Lago Antorno, Rifugio Dibona, Milieres, Ru Merlo, Boa Grande di Mietres, Costalaresc, and Rio Specie, it is the stratigraphic interval in the uppermost part of the San Cassiano Formation and in the Heiligkreuz Formation (Pecorari et al., 2023 et references therein). All these places Rinaldo Zardini knew very well having collected and studied thousands of fossils in these areas (e.g., Zardini, 1966, 1976b, 1978, 1980a, 1981a, b).

Thorough investigations of the successions led to the discovery that the rocks bear witness to a climatic disturbance of the past linked to a sudden variation in the carbon cycle, likely associated with a rapid and substantial CO_2 emission related with significant volcanic eruptions, leading to an increase in temperature, an enhance in the hydrological cycle (resulting in increased rainfall), and likely simultaneous acidification of oceanic waters (Dal Corso et al., 2012, 2018, 2020). The consequence was a swift deterioration in living conditions, marked by extinctions among several marine groups documented across the Tethys Sea (e.g., Dal Corso et al., 2020 and references therein). The increasing rainfall enhanced the deposition of terrigenous sediments in the basins, flattening the palaeotopography and creating humid environments with forests and lush vegetation on the emerged lands (e.g., Dal Corso et al., 2020; Roghi et al., 2022 and references therein).

This upheaval was short-lived; already with the Travenanzes Formation, a return to an arid climate occurred (e.g., Breda et al., 2009), but its impact on the biosphere was significant, leading to a faunal turnover. The extraordinary collection of the Palaeontological Museum "Rinaldo Zardini" in Cortina preserves some of the first modern corals that appeared during

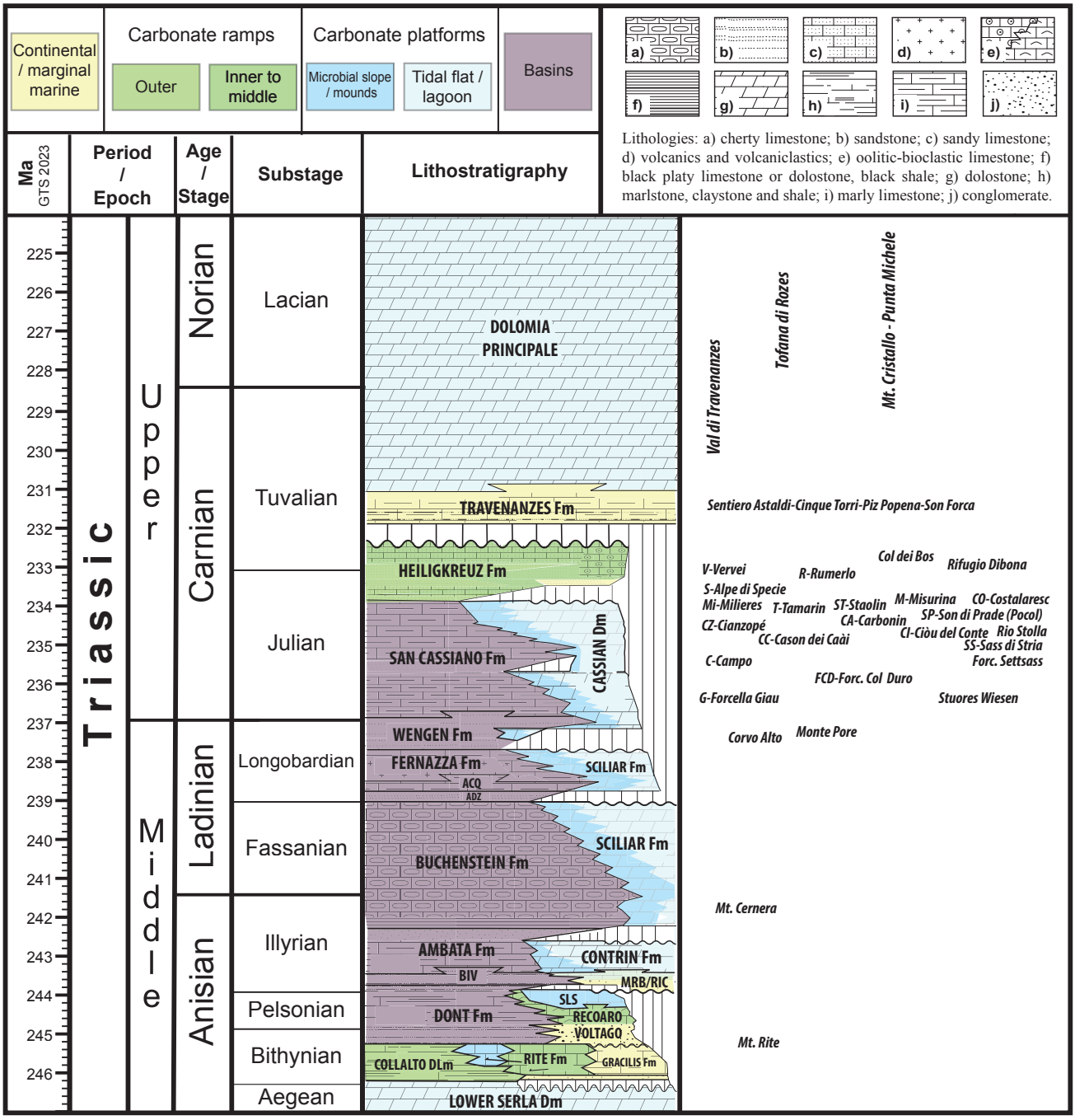

FIG. 3: Stratigraphic distribution of the Triassic fossiliferous localities positioned in a modern stratigraphic framework.

this interval. Changes in the ammonite faunas, in the flora composition, the spread of dinosaurs in Pangea, and other crucial evolutionary radiations characterize the Carnian Pluvial Episode (CPE), considered the dawn of the modern world. In this context, the patient and meticulous work of Rinaldo Zardini has played and continues to play a pivotal role in advancing our understanding of the geological history of the Dolomites, a fundamental piece in the reconstruction of Earth's geological history.

2. RINALDO ZARDINI'S LEGACY IN PALAEOZOOLOGY

Rinaldo Zardini's fossil collection originates mainly from the San Cassiano Formation sensu lato (including Heiligkreuz Formation, Carnian, Upper Triassic), with a primary focus on the Cortina d'Ampezzo basin. Collections from the Gadertal/Val Badia, including Stuores Wiesen/Prati di Stuores and Pralongia, are relatively limited, not mentioned his publications. Most outcrops of Rinaldo Zardini were either self-discovered or identified in collaboration with fellow collectors, such as, for example Rolando Lancedelli. These outcrops include Alpe di Specie (Seelandalpe, Plätzwiesen), Misurina Skilift, Campo di Sopra, and Costalaresc. Other localities also contributed significant fossils to his collection.

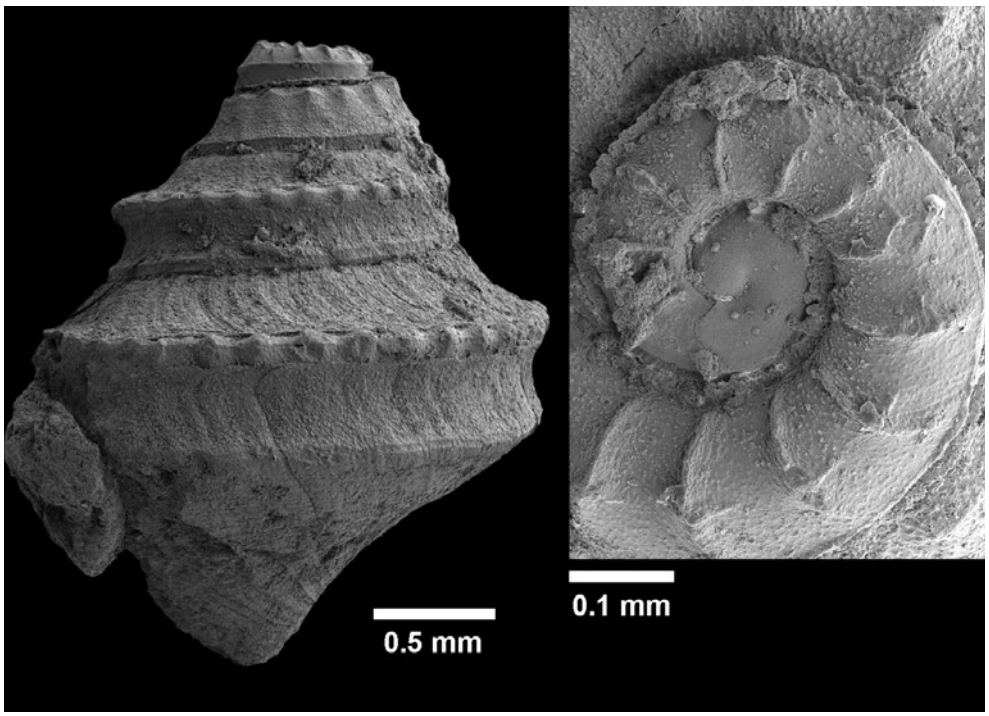

FIG. 4: *Bandelium ruedigeri* SCHWARDT, 1992, locality Campo near Cortina, an example for an extremely well-preserved gastropod form ZARDINI's collection at the Palaeontological Museum "Rinaldo Zardini" in Cortina; protoconch and fine ornaments are preserved (see also Karapunar & Nützel 2021).

RINALDO ZARDINI's interest in small fossils differs from many collectors' interests in large and spectacular specimens. His approach is crucial since most marine invertebrates are small. The study of small fossils is particularly valuable for identification and accurate classification, providing morphological characters from early ontogenetic stages of organisms such as larval shells in molluscs. Fieldwork photos depict ZARDINI in a kneeling or lying position during collection, essential for locating fossils of millimetre size range in the field, such as those abundantly present in the Palaeontological Museum "Rinaldo Zardini" in Cortina. Examination of the material in the Museo Rinaldo Zardini clearly revealed that RINALDO ZARDINI's careful approach involved washing and sieving sediments to extract very small fossils. Many fossils are so small that they could not have been spotted in the field but only in sediment residues under the binocular. This meticulous approach contributed to assembling his unique collection. Estimating the size of ZARDINI's collection from the San Cassiano Formation is challenging. However, considering the material still present in Cortina, along with what has given to other scientists like KLAUS BANDEL (Hamburg, published material commonly reposited in Vienna), it is reasonable to assume that several hundred thousand, perhaps even millions, of specimens were collected by him.

ZARDINI acquired a substantial collection, including exquisitely preserved corals and sponges, primarily through excavations on Seelandalpe, a locality that is now less productive. Other outcrops contributing to his vast collection, are also lost for scientific research for various reasons. The once fresh landslide of Costalaresc exposed fossil-rich rocks but is now largely overgrown. The once highly productive Campo site has been inaccessible for years. Therefore, a collection like ZARDINI's is unlikely to be replicated in dimension and diversity in the near future, underlining its uniqueness.

ZARDINI's importance as a collector and scientist is centered around his dedicated focus on the San Cassiano Formation. Fossils from this formation are exceptionally well-preserved for various reasons. Fossil preservation includes specimens of snails and clams with the original aragonite shells preserved, which is rare in such ancient rocks. Consequently, the San Cassiano Formation has earned global recognition as a *Fossillagerstätte*, yielding over 1400 scientifically described species (RODEN et al., 2020). These authors coined the term *Liberation Lagerstätte* for the San Cassiano Formation emphasizing its poorly lithified sediments that allow to extract tiny fossils with fine morphological details. In sediments of considerable geological age, this is usually impossible because lithification and diagenetic overprint are too strong. The fauna of the San Cassiano Formation is strongly dominated by molluscs, with gastropod and bivalves exhibiting high abundance and diversity across most of the fossil localities. Echinoderms are also a diverse group. Thus, the mollusc dominance in modern marine biota can be traced back at least 230 Ma. RINALDO ZARDINI himself described nearly 70 new snail species in his atlases, with some later designated as type species of new genera by other authors, notably KLAUS BANDEL. Thus, RINALDO ZARDINI scientifically described about 12% of the approximately 550 snail species from the San Cassiano Formation, ensuring his name will be remembered.

RINALDO ZARDINI's significance as a collector and scientist was notably enhanced by the publication of his atlases on the echinoderms, gastropods and bivalves of the San Cassiano Formation (Fossili Cassiani; ZARDINI, 1976b, 1978, 1980a, 1981a, b). These atlases feature numerous technically well-crafted photo plates. RINALDO ZARDINI was a professional photographer, adept at overcoming the issue of limited depth of field in the microphotography of small, often round fossils. The objects were well-illuminated, and Rinaldo Zardini coated them with magnesium oxide before photographing—a technique he elaborated on in the first snail atlas (ZARDINI, 1978). This significantly contributed to the high quality of the images. Fossils are predominantly depicted at five- or tenfold magnification, and as a result, ensuring a high definition. The original specimens illustrated in the atlases are curated in the Palaeontological Museum "Rinaldo Zardini" in Cortina.

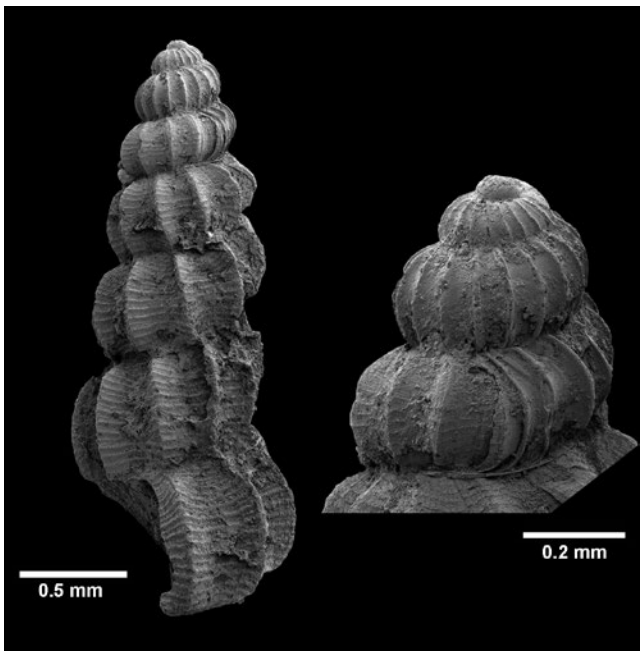

FIG. 5: *Striazyga zardinii* Nützel, 1998, locality Campo near Cortina, another example for a well-preserved gastropod form Zardini's collection at the Palaeontological Museum "Rinaldo Zardini" in Cortina; protoconch and fine ornaments are preserved (named in honour of Rinaldo Zardini).

Zardini's scientific impact includes his collaboration with other researchers. His name is mentioned in numerous acknowledgments in scientific papers, some of them are partially or entirely based on fossils from his collection (e. g., Leonardi & Fiscon, 1949, 1959; Bandel, 1991, 1992, 1993, 2007). He also co-authored several publications (e.g., Allasinaz & Zardini, 1977; Vermeij et al., 1982; Dieci et al., 1986). Many genera and species have been named after Zardini in gratitude for providing fossils or accompanying researchers in the field. Rinaldo Zardini was therefore not only a collector for aesthetic reasons but also played a key role in science and as networker. For instance, Kier (1977) wrote in his significant work on Triassic sea urchins: "An extraordinary collection of these sea urchins was assembled by Rinaldo Zardini from Cortina d'Ampezzo. He described many of these specimens in 1973, generously allowed me to study this material."

3. RINALDO ZARDINI'S LEGACY FOR PALAEOBOTANY

Rinaldo Zardini collected plant fossils in 1935, during a time when there were only a limited number of scientific papers on plant fossils from the Dolomites available. The earliest figure of a fossil fern fragment from the Dolomites dates to 1841, illustrated by Heinrich Ludolf Wissmann and Georg Graf von Münster. Edmund Mojsisovics von Mojsvàr provided the first fossil list in 1879, enlisting plant fossils from the Ladinian of the Dolomites in his work "Die Dolomit-Riffe von Südtirol und Venetien" [The dolomitic reefs of South Tyrol and Venice province]. Maria Ogilvie Gordon published the first detailed descriptions and illustrations of plant fossils from the Dolomites in her seminal book "Das Grödener, Fassa- und Enneberggebiet in den Südtiroler Dolomiten" [The area of Gröden, Fassa, and Enneberg in the Dolomites of South Tyrol] in 1927. Specimens from her work are stored today in the palaeobotanical collection of the Staatssammlung für Geologie und Paläontologie in Munich. In 1932, Georg Mutschlechner reported fossil plants in the Wengen Formation in Val Badia.

Piero Leonardi (1953) re-evaluated the fossils mentioned by Mojsisovics, Ogilvie Gordon, and Mutschlechner and described plant fossils collected by Heinrich (Enrico) Moroder (St. Ulrich/Ortisei) and himself in his work "Flora continentale Ladinica delle Dolomiti" [The continental flora of the Ladinian of the Dolomites] (Leonardi, 1953). In 1968, Leonardi wrote in his work "Le Dolomiti – Geologia dei Monti tra Isarco e Piave" [The Dolomites – Geology of the mountains between the Eisack/Isarco and Piave], that "the occurrence of plant fossils in the La Valle Strata underlines that the presence of plant remains in formations of marine origin indicates the proximity to landmasses (cliffs and volcanic islands)."

Rinaldo Zardini's interest in fossils was not restricted to marine invertebrate fossils (e.g., bivalves, ammonites, brachiopods, gastropods, corals) but also included plant fossils. He collected them from the Ladinian strata (Wengen Formation) of Corvo Alto and Mondeval in the Passo Giau area. Today, the collection preserves the historical labels with determinations written by Rinaldo Zardini, providing valuable insights into his work with these specimens.

Among the plant fossils he collected, a particularly noteworthy specimen stands out – a cycad leaf belonging to the species *Bjuvia dolomitica* Wachtler et Van Konijnenburg-van Cittert (2000). This fossil, approximately 70 cm long and 22 cm wide, represents the largest leaf fragment of this species discovered so far. It is an almost complete leaf, cut apically and along one side, suggesting possible transport from the terrestrial environment where the plant lived to the marine depositional setting. Rinaldo Zardini originally identified this specimen as *Paleocycas*, an italianized version of the original name *Palaeocycas* Florin, a Late Triassic species from Sweden. It is uncertain whether Zardini was aware of the papers by Rudolf Florin (1894–1965), but none of the publications on plant fossils from the Dolomites before Zardini mentioned

FIG. 6: Leaf fragment of *Bjuvia dolomitica*, MDR 2645, Palaeontological Museum "Rinaldo Zardini" in Cortina.

FIG. 7: Leaf fragment of *Ptilozamites sandbergeri*, MDR 2655, Palaeontological Museum "Rinaldo Zardini" in Cortina.

this genus. This choice of nomenclature reflects Zardini's meticulous research during fossil determination and underscores his robust network of international contacts in the scientific community.

Preserved in the collection are also fern fragments identified as belonging to the Osmundaceous *Cladophlebis leuthardtii* Leonardi. Rinaldo Zardini labelled these specimens as *Neuropteridium*, but subsequent analysis revealed that the pinnules are smaller and more sickle-shaped than the species typically assigned to this genus (Van Konijnenburg-van Cittert et al., 2006). Today, these fern fragments are assigned to the species *Cladophlebis leuthardtii*. Although Leonardi (1953) had already reported the presence of *Neuropteridium* in the Ladinian of the Dolomites, the genus is rare in Ladinian layers, being more abundant in the Anisian sediments, as demonstrated in studies by Kustatscher & Van Konijnenburg-van Cittert (2005) and Kustatscher et al. (2010, 2019).

Another pinnate leaf fragment was labelled by Rinaldo Zardini as *Pterophyllum venetum* De Zigno (Zardini, 1988, pl. 6, fig. 8; Fig. 7). Achille De Zigno (1873) established this species based on fossil leaf fragments from the Calcari Grigi Group of the Jurassic in the Vicenza Province. This species has been rarely mentioned in literature of the time, suggesting that Zardini was aware of De Zigno's paper. The leaf fragment, resembling the drawings of Achille De Zigno (1873), was interpreted by Zardini as a fern leaf. Interestingly, Maria M. Ogilvie Gordon (1927) had previously assigned a similar specimen to the genus *Pterophyllum*, albeit to a different species, *Pterophyllum brevipenne* Kurr. Modern taxonomic understanding identifies these specimens as belonging to the seed fern species *Ptilozamites sandbergeri* (Schenk) Kustatscher et Van Konijnenburg-van Cittert (2007).

In the first edition of "Geologia e Fossili delle Dolomiti di Cortina e dintorni" in 1973 Rinaldo Zardini reported the presence of amber from the successions in the Cortina area. This remarkable

FIG. 8: Rock sample with plant debris and amber droplets, Palaeontological Museum "Rinaldo Zardini" in Cortina.

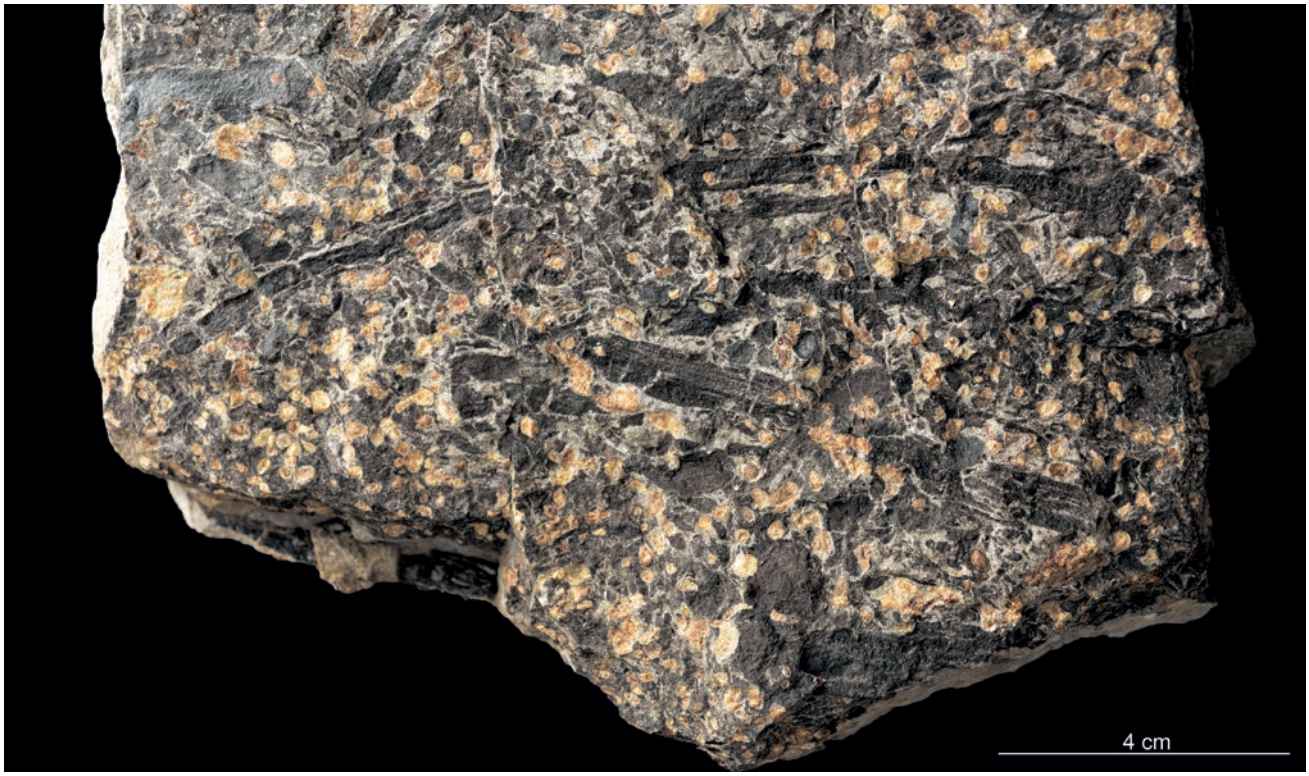

FIG. 9: Amber droplets from the Dibona section.

finding followed 60 years after the first description of amber in 1913 by Rudolf Karl von Koken (1860–1912). In the subsequent 25 years extensive examination of this fossil resin (Figs. 8, 9) has shed light on both its palaeobotanical origin and palaeozoological inclusions. The Carnian (Late Triassic) amber has revealed a unique microcosm including bacteria, protozoa, algal spores, nematodes, pollen grains, and spores (Gianolla et al., 1998; Roghi et al., 2006; Schmidt et al., 2006, 2012). The in-depth exploration of fossil resin droplets has led to the identification of multicellular organisms, including mites and insects. Rinaldo Zardini alongside collaborators such as Paolo Fedele (also from Cortina), has played a pivotal role in inaugurating an entirely novel realm in scientific studies. This research not only enhances our understanding of Late Triassic amber but also provides insights into a specific moment in Earth's biological history, the Carnian Pluvial Episode. The synergy between historical observations and contemporary investigations has opened a new chapter in our scientific comprehension of the ancient ecosystems encapsulated within the amber deposits near Cortina (Dal Corso et al., 2020; Roghi et al., 2022).

4. CONCLUSIONS

Rinaldo Zardini's enduring contributions have become the foundation for numerous palaeontological studies and scientific discoveries. His meticulous work, spanning geology, palaeozoology, and palaeobotany, has paved the way for a deeper understanding of the Dolomites' geological and paleontological significance. The scientific community continues to build upon his legacy, conducting studies on his fossil collections and the localities he identified.

Zardini's mountains, the Dolomites, have evolved into a global reference area for geology and for understanding the ancient Triassic world. His passion for these mountains, seen through the eyes of both a photographer and a scientist, has left an indelible mark. The UNESCO World Heritage designation in 2009 (Gianolla et al., 2009), based on aesthetic and landscape value as well as scientific importance in geology and geomorphology, further underscores the international recognition of the Dolomites' significance.

Rinaldo Zardini's imprint on the research of Mesozoic marine faunas is undeniably profound, and his legacy endures through the wealth of knowledge encapsulated in his collections. His meticulous approach, keen observation, and generosity in sharing his fossils have ensured that his collection remains a valuable resource for ongoing research and exploration. His passion for uncovering the hidden treasures in the

Dolomites, especially the beauty of small fossils, is a testament to the curiosity and strong desire to discover that drove his scientific pursuits. His spirit lives on not only through his collections and publications but also through the enthusiasts he inspired, creating a lasting impact on the study of nature and geology.

The torch has been passed on to subsequent generations, including scientists and collectors like Rolando Lancedelli, the Toscani sisters, Giorgio Zardini, Paolo Fedele, and many others. Their dedication to continue the exploration of the wonders of the territory and the mountains is a tribute to Zardini's enduring influence. The development of geological research in the Cortina d'Ampezzo area owes much to Zardini and those he inspired, ensuring that his legacy persists in the ongoing pursuit of understanding the Earth's geological history.

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