The age of the first pulse of continental rifting associated with the breakup of Pangea in Southwest Iberia: new palynological evidence

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Abstract
In this work, we report the first palynological age for the base strata of the Silves Sandstones of the Silves Group in the Algarve Basin, located in Southern Portugal. The group is the oldest sedimentary unit of the Algarve Basin and was deposited unconformably over late Pennsylvanian turbidites of the Mira Formation, which were folded and faulted during the Variscan Orogeny. The Silves Group comprises a detrital red bed succession, representing the earliest phase of sedimentation associated with the initial rifting of Pangaea. Macrofossils are rare, occurring predominantly in the top layers of this group, and do not accurately constrain the age of the entire group’s deposition. From an outcrop exposed in the central Algarve, a grey mudstone bed positioned 2.5 m above the Variscan unconformity plane yielded palynomorphs that date the beginning of sedimentation in this basin to the early Carnian age (Late Triassic). The moderately well preserved and low-diversity palynological association comprises Aulisporites astigmosus, Enzonalasporites densus, Ovalipollis pseudoalatus, Samarapollenites speciosus, Tulesporites briscoensis and Vallasporites ignacii, among others, and is indicative of an early Carnian age.

Keywords Upper Triassic · Variscan unconformity · Palynology · Algarve Basin · Portugal

La edad del primer pulso de rifting continental asociado a la ruptura de Pangea en el suroeste ibérico: nueva evidencia palinológica

Resumen
Mediante datos de asociaciones palinológicas, describimos por primera vez la edad de los niveles de la base de la Formación Areniscas de Silves, del Grupo Silves, en la cuenca del Algarve, sur de Portugal. Este grupo representa la unidad sedimentaria más antigua del Mesozoico de la Cuenca del Algarve, y fue depositada discordantemente sobre las areniscas de edad Pensilvaniense superior de la Formación Mira, un registro sedimentario que fue plegado y fallado durante la Orogenia Varisca. El Grupo Silves muestra unos sedimentos detríticos rojos que representan la fase más temprana de la sedimentación y que está asociada a las primeras fases de la ruptura de Pangea. Los macrofósiles son escasos, se encuentran en los niveles superiores del grupo y no proporcionan una edad determinada. Una asociación palinológica ha sido encontrada y descrita
en un nivel de lutitas grises situado a 2,5 cm por encima de la discordancia varisca, y que proporcionan una edad Carniense (Triásico Superior) para el comienzo de la sedimentación de esta unidad. Se trata de una asociación moderadamente bien conservada y con baja diversidad de elementos, que contiene Aulisporites astigmaticus, Enzonalasporites densus, Ovalipollis pseudoalatus, Samaropollenites speciosus, Tulesporites briscoensis y Vallaspollites ignacii entre otros, y es indicativa de un Carniense inferior.

Palabras clave Triáesico Superior · Disconformidad Varisca · Palinología · Cuenca del Algarve · Portugal

1 Introduction

The Algarve Basin (Fig. 1a), located in the South of Portugal, is one of the Mesozoic sedimentary basins bordering the Iberian Massif. The origin of the Algarve Basin is related to the breakup of Pangaea and the following extensional tectonic episodes that led to the opening of the North and Central Atlantic oceans. Sedimentation in the Algarve Basin started with detrital continental red beds that unconformably overlie deep-marine Pennsylvanian strata, deformed, and metamorphosed during the Variscan Orogeny (Palain, 1976; Terrinha, et al., 2013). Overlying the red beds are variegated mudstones, interbedded with siltstones and dolostones, followed upwards by evaporites representing the first episodes of marine transgression in the Algarve Basin. The evaporites are covered by volcanics associated with the Central Atlantic Magmatic Province (CAMP) (Verati et al., 2007). The red sandstones, mudstones, evaporites, and the volcanics comprise the Silves Group (or Grés de Silves Group) and represent the first tectono-sedimentary cycle related to the initial phase of Pangaeian continental rifting. The following sedimentary cycles, ranging from Lower Jurassic to Lower Cretaceous, are dominated by carbonate sedimentation on a passive continental margin (Fernandes et al., 2013; Manuppella et al., 1988; Terrinha, et al., 2013).

The Silves Group is poorly studied from a biostratigraphic point of view, perhaps due to its sparse macrofossil content. In western central Portugal, the Lusitanian Basin (Fig. 1a) is another important sedimentary basin related to the breakup of Pangaea. In this basin the Silves Group has been subdivided into four formations, from the oldest to the most recent; the Conraria, Penela, Castelo Viegas and Pereiros formations (Soares et al., 2012). These units were previously described by Choffat (1894, 1903) and Palain (1976, 1979), and dated as Carnian–Norian age, through the first palynostratigraphic studies carried out by Doubinger et al. (1970) and by Adloff et al. (1974). This last study, at the time, did not permit accurate dating of this interval in the Lusitanian Basin, but it did provide the first evidence of Carnian–Norian age palynomorphs in the Silves Group. According to Palain (1976), the base of the Silves Group is of Carnian age. More recently, palynological data from these formations allowed better detailing the age, thus dating the Conraria Formation and the base of the Silves Group as Norian, (late Triassic), and the Pereiros Formation at top of the group, as Hettangian (early Jurassic; Vilas-Boas et al., 2021a).

In the Algarve Basin, the Silves Group's fossil record is scarce (Palain, 1976) and characterised by the lack of important age-diagnostic index fossils. Thus, the relative ages of the constituent formations are poorly constrained. However, the presence of bivalves of the genus Euestheria sp. (Palain, 1976), vertebrate remains of Phytosauria (Mateus et al., 2014) and a new Metoposaurus species (Brusatte et al., 2015), all found in beds stratigraphically above the basal red sandstones, strongly suggests a Late Triassic age for this part of the stratigraphic succession of the Silves Group. Regarding the upper part of the Silves Group lithologies, the CAMP volcanism is dated 198.1 ± 0.4 Ma based on the radio-isotopic ages for the basalt flows determined from on 40Ar/39Ar data. This age attribution is consistent with a palynological assemblage found in mudstones ca. 50 m below the CAMP (Cirilli oral commun. in Verati et al., 2007). It is also close to the late Hettangian age assigned to the microfloral assemblage from the evaporites (Fechner, 1989). New palynological studies recently confirmed this age determination in the Triassic basins of the Betic Cordillera in southern Spain and the Algarve Basin (Peréz-López et al., 2021; Vilas-Boas et al., 2021b). These data show that new studies are needed to ascertain the age of the Silves Group.

Since the age of the strata of the Silves Group may encompass the record of important changes of Earth’s history that occurred during Late Triassic to Early Jurassic times (i.e. the Late Triassic Extinctions), the precise biostratigraphic scheme for the Silves Group is necessary to unlock its stratigraphic record. This work contributes to this last part; we report palynological assemblages from the Silves Group's basal beds.

2 Location and description of the studied outcrop

The studied section is located in the central Algarve, in a road cut of the CM1054 road, near the International Race-track of Algarve (Fig. 1b). The road cut provides good exposures of the Variscan angular unconformity and a ca. 24 m thick sequence assigned to the Silves Group’s lowermost unit, the Silves Sandstones (Figs. 1c and 2). The lithologies below the unconformity plane consist of folded greywackes...
Fig. 1 Map of the studied area with location of studied sections. a Map of Portugal with the Lusitanian and Algarve basins represented. The star symbol represents the studied outcrops; b detailed geological map of the area where the studied outcrop is located, geological map and inferred ages for formations adapted from Manuppella et al., (1992); c photography of the outcrop, with the Variscan unconformity and the bed that yielded palynomorphs marked.
and shales belonging to the Mira Formation of Serpukhovian to middle Bashkirian age (Fernandes et al., 2019; Oliveira & Wagner-Gentis, 1983).

Above the unconformity, the Silves Sandstones include a ca. 2.5 m thick succession consisting mainly of red mudstones, interbedded with a 20 cm thick bed of fine- to medium-grained sandstone showing reduction spots. Above the basal beds is a 25 cm thick bed of coarse to medium-grained sandstone showing current ripples, cross-lamination and diagenetic calcite nodules. This unit is followed upwards by a 3 m thick bed of grey mudstones with common small plant impressions and parallel lamination. Towards the top of this bed, the colour of the mudstones changes from grey to red. The sedimentary features observed in this latter bed suggest deposition in either a shallow lake or the fill of an abandoned river channel, where fine-grained sediments gradually accumulated by successive river floods. All of the palynological productive samples were collected from this latter bed. Above the grey mudstones, and until the end of the road cut exposure, the succession is dominated by fine-grained red sandstone beds. The sandstone beds show a range of massive-bedding, normal graded-bedding, tabular and trough cross-bedding, and contain diagenetic concretions. These sedimentary features suggest fluvial channel fill successions. Between 14 to 16 m above the unconformity plane, the sandstones are interbedded with a red mudstone interval, which may relate to floodplain deposition.

3 Materials and methods

Twenty-five samples were collected from the Silves Sandstones (lowermost Silves Group) on an outcrop along the studied section in the CM1054 road towards the International Roadtrack of Algarve, located in Portimão. The outcrop consists of two facing road cuts on the eastern and western sides of the road (Figs. 1 and 2). The layer was sampled every 30 cm on the western side of the road (positive samples: B5(+ 0,30), B5(+ 0,60), B5(+ 0,90), B5(+ 1,20), B5(+ 1,50), B5(2,10), B5(+ 2,40) and B5(+ 2,70)) and every 50 cm on the eastern side of the road (positive samples: A5 and C5(+ 1,50)). In this last road cut, this bed was sampled in both the hanging wall and footwall blocks of a reverse fault (Fig. 2). Standard palynological laboratory techniques were used for extraction and concentration of organic matter, with treatments with hydrochloric (HCl) and hydrofluoric (HF) acids, as described by Wood et al. (1996) and Riding and Warny (2008).

The residues were sieved using a 15 μm sieve and were mounted on microscope slides using Entelan®, a commercial resin-based mounting medium. The slides were analysed using a Leica ICC50W microscope equipped with a camera. Biostratigraphically significant taxa are illustrated in Plate I. All samples, residues, and slides are held at the University of Algarve and the Palynological Collection of LNEG, Portugal.

4 Palynology

Palynomorph recovery was obtained only in samples collected from a 3 m thick layer, starting at about 2.5 m above the Variscan unconformity plane. The resulting residues contained palynological material that was moderate to well-preserved, which allowed the identification of some age-diagnostic palynomorphs.

The assemblage is characterised by the common to abundant presence of the pollen taxa Aulisporites astigmosus and Tulesporites briscoensis, and by the spores Calamospora sp., Conbaculatisporites sp., Converrucosisporites sp., Deltoispora sp., Lycopodiacidites rugulatus, Nevesisporites cf. vallatus and Verrucosisporites sp. Other rarer taxa present in the assemblage include the pollen Alisporites sp., Cycadopites sp., Enzonalasporites vigens, Klausipollenites sp., Ovalipollis pseudoalatus, ?Protodiploxypinus sp., Samaropollenites speciosus, Triadispora sp. and Vallasporites ignacii. The recovered palynomorph assemblage is of low taxonomic diversity and is impoverished relative to coeval assemblages from similar palaeolatitudes, e.g.: Cantabrian Mountains, northern Spain (Juncal et al., 2020); Catalian Coastal Ranges, northeast Spain (García-Avila et al., 2020); Paris Basin, France (Juncal et al., 2018); northwest Sicily, Italy (Buratti & Carrillat, 2002; Martini et al., 2007; Visscher & Krystyn, 1978); Western Dolomites, Italy (Van der Eem, 1983); Julian and Southern Alps, northeast Italy (Mietto et al., 2012; Roghi, 2004); Central Atlas of Tunisia and Gulf of Gabes, southern Tunisia (Buratti et al., 2012; Mehdi et al., 2009); Moroccan High Atlas (Coussminer & Manspeizer, 1976). The reason for the low diversity is presently unclear, but may be the result of either ecological or taphonomic controls.

5 Biostratigraphic discussion

The stratigraphic range of some key taxa recorded in the palynological preparations from the Silves Sandstones in the Portimão section sheds new light on the age of this lithostratigraphic unit, and provide important age constraints for the opening Algarve Basin. Specifically, the co-occurrence of Aulisporites astigmosus, Enzonalasporites vigens, Samarpollenites speciosus and Vallasporites ignacii is strongly suggestive of a Carnian age. In Germanic Basin and Alpine realm, Aulisporites astigmosus has its first occurrence in the Ladinian, but reaches an acme in the lower Carnian (Julian) (Kürschner & Hergreen, 2010). At the Carnian GSSP at Prati di Stuores/ Stuores Wiesen, Aulisporites cf. astigmosus,
Samaropollenites speciosus and Vallasporites ignacii have their first occurrences in the canadensis Subzone and are thus firmly dated as earliest Carnian (early Julian) (Cirilli, 2010; Cirilli & Roghi, 1999; Mietto et al., 2012; Roghi, 2004). In the circum-Mediterranean areas similar Carnian microfloral assemblages were recorded from independently dated strata in Sicily (Visscher & Krystyn, 1978), and in southern Albany (Cirilli & Montanari, 1994), north-western Libya (Muttoni et al., 2001), southern Israel (Cirilli & Eshet, 1991) highlighting a microfloristic provincialism referable to the Onslow Microflora (Buratti & Cirilli, 2007). Similarly, in the Boreal Realm, the first occurrences of A. astigmosus and V. ignacii...
occur in beds independently-dated as early Carnian (Paterson & Mangerud, 2020; Vigran et al., 2014). Collectively, the first occurrences of these taxa indicate the basal Silves Sandstones at the Portimão section is no older than early Carnian.

The majority of the taxa present in the Silves Sandstones assemblage have relatively long ranges. Nonetheless, an upper age limit is provided by *A. astigmous*. In the Germanic and Alpine realms, Kürschner and Herngreen (2010, Fig. 3) indicate that the last occurrence of taxon corresponds with the Julian–Tuvalian boundary. However, ammonoid-calibrated occurrences from the Cave del Predil area of northeast Italy suggest that the taxon, and its acme, range into the
lower Tuvalian (Roghi, 2004). These observations, combined with the absence of characteristic Norian taxa in our assemblage, indicate an age no younger than late Carnian.

Our analyses provide the first documentation for Aulisporites astigmosus in the Grés de Silves Group. Crucially, this taxon has not been recorded in the Carnian age Manuel Formation, the Silves Group equivalent stratigraphic unit in Spain (Arche & López-Gómez, 2014, Diez work in progress).

Also registered for the first time in Europe, with a common to abundant presence, is the pollen species T. briscoensis. This taxon has previously only been recorded in North American assemblages. It was first described by Dunay and Fisher (1979) in assemblages from the Dockum Group in the Texas Panhandle region. It was subsequently recorded in the Chinle Formation of Arizona, Colorado, New Mexico and Utah (Baranyi et al., 2017; Scott, 1982), and from Carnian lacustrine deposits in North Carolina and Virginia (Robbins, 1982). We highlight that A. astigmosus is seemingly absent in North American assemblages, and it was not reported in the studies listed above. However, S. speciosus is present in the Carnian Zone I and E. vigens in the succeeding Zone II of Litwin et al., (1991).

Thus, the co-occurrence of T. briscoensis and A. astigmosus suggest the existence of a previously undescribed palynoflora, which combines elements typical of the North American and Central Europe Carnian. Other taxa present in our assemblage, such as E. vigens and S. speciosus are cosmopolitan, and are present both in North America and Europe are. These data are therefore consistent with the paleogeographic position of the Algarve Basin, Portugal, in the Late Triassic (Palain, 1976; Terrinha et al., 2013).

More detailed studies are in progress on the recorded sporomorphs and their palaeobotanical affinities for paleo-phytogeographic and climatic reconstructions, which will contribute to a better understanding of the local sedimentary environments.

6 Conclusions

The main results of this study are summarized below:

- The basal part of the Silves Sandstone of the Silves Group in the Algarve Basin yielded a biostratigraphically significant palynological assemblage including Aulisporites astigmosus, Enzonalasporites vigens, Vallasporites ignacii, and Samaropollenites speciosus and is referable to the early Carnian;
- The age attribution based on the recorded palynological assemblage represents a significant result as it constrains the beginning of sedimentation within the Algarve Basin to the early Late Triassic;
- The taxon T. briscoensis is recorded for the first time in Europe and in Iberia;
- The co-occurrence of taxa such as A. astigmosus, E. vigens, S. speciosus and T. briscoensis indicates a mixing of early Carnian palynofloral elements with Central European and North America affinities, which is consistent with the paleogeographic position of the Iberian Peninsula in the Late Triassic;
- The present study contributes to a more complete documentation and illustration of the palynoflora from Iberia.

List of taxa

Pollen:

Aulisporites sp.

Aulisporites astigmosus (Leschik, 1956) Klaus, 1960

Cycadopites sp.

Enzonalasporites vigens Leschik, 1956

Nevesisporites cf. vulatus Jersey & Paten, 1964

Ovalipollis pseudoalatus Krutzsch, 1955

?Protodiploxypinus sp.

Samaropollenites speciosus Goubin, 1965

Triadispora sp.

Tulesporites briscoensis Dunay & Fischer, 1979

Vallasporites ignacii Leschik, 1956 emend. Scheuring, 1970

Spores:

Calamospora sp.
Conbaculatisporites sp.
Converrucosisporites sp.
Deltiodospora sp.
?Klausipollenites sp.
Lycopodiacidites rugulatus (Couper) Schulz, 1967
Verrucosisporites sp.

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Cirilli, S., & Esabit, Y. (1991). First discovery of Samaropollenites and the Onslow Microflora in the Upper Triassic of Israel, and its phytogeographic implications. Palaeogeography, Palaeoclimatology, Palaeoecology, 85, 207–212. https://doi.org/10.1016/0031-0182(91)90160-S

Cirilli, S., & Montanari, L. (1994). The Carnian evaporites succession of Bistríc River (southern Albany). Palaeopelagos, 4, 107–118.

Cirilli, S., & Roghi, G., et al. (1999). Palynomorphs. In C. Loriga (Ed.), Comunicações Serviços Geológicos de Portugal, 199, 229–282. Memórias Serviços Geológicos de Portugal.

Cousminer, H. L., & Manspeizer, W. (1976). Triassic pollen date of a borehole in the Djebel Melita 1 borehole (Gulf of Gabes, South-eastern Tunisia). Micropaleontology, 58(4), 377–388.

Choffat, P. (1894). Notice stratigraphique sur les gisements de végétaux fossiles dans le Mésozoïque du Portugal (pp. 229–282). Memórias Serviços Geológicos de Portugal.

Choffat, P. (1903). L’Infralias et le Sinémurien du Portugal. Comunicaciones Serviço Geológico de Portugal, 5, 49–114.

Choffat, P. (1919). L’Infralias et le Sinémurien du Portugal. Revue de la Paléontologie du Portugal, 270, 1770–1772.

Cousminer, H. L., & Manspeizer, W. (1976). Triassic pollen date of a borehole in the Djebel Melita 1 borehole (Gulf of Gabes, South-eastern Tunisia). Micropaleontology, 58(4), 377–388.

Choffat, P. (1894). Notice stratigraphique sur les gisements de végétaux fossiles dans le Mésozoïque du Portugal (pp. 229–282). Memórias Serviços Geológicos de Portugal.

Choffat, P. (1903). L’Infralias et le Sinémurien du Portugal. Comunicaciones Serviços Geológicos De Portugal, 5, 49–114.

Cirilli, S. (2010). Upper Triassic–lowermost Jurassic palynology and palynostratigraphy: A review. Geological Society, London, Special Publications, 334(1), 285–314. https://doi.org/10.1144/SP334.12

Cirilli, S., & Esabit, Y. (1991). First discovery of Samaropollenites and the Onslow Microflora in the Upper Triassic of Israel, and its phytogeographic implications. Palaeogeography, Palaeoclimatology, Palaeoecology, 85, 207–212. https://doi.org/10.1016/0031-0182(91)90160-S

Cirilli, S., & Montanari, L. (1994). The Carnian evaporites succession of Bistríc River (southern Albany). Palaeopelagos, 4, 107–118.

Cirilli, S., & Roghi, G., et al. (1999). Palynomorphs. In C. Loriga (Ed.), Comunicações Serviços Geológicos de Portugal, 199, 229–282. Memórias Serviços Geológicos de Portugal.

Cousminer, H. L., & Manspeizer, W. (1976). Triassic pollen date of a borehole in the Djebel Melita 1 borehole (Gulf of Gabes, South-eastern Tunisia). Micropaleontology, 58(4), 377–388.

Choffat, P. (1894). Notice stratigraphique sur les gisements de végétaux fossiles dans le Mésozoïque du Portugal (pp. 229–282). Memórias Serviços Geológicos de Portugal.

Choffat, P. (1903). L’Infralias et le Sinémurien du Portugal. Comunicaciones Serviços Geológicos De Portugal, 5, 49–114.

Cirilli, S. (2010). Upper Triassic–lowermost Jurassic palynology and palynostratigraphy: A review. Geological Society, London, Special Publications, 334(1), 285–314. https://doi.org/10.1144/SP334.12

Cirilli, S., & Esabit, Y. (1991). First discovery of Samaropollenites and the Onslow Microflora in the Upper Triassic of Israel, and its phytogeographic implications. Palaeogeography, Palaeoclimatology, Palaeoecology, 85, 207–212. https://doi.org/10.1016/0031-0182(91)90160-S

Cirilli, S., & Montanari, L. (1994). The Carnian evaporites succession of Bistríc River (southern Albany). Palaeopelagos, 4, 107–118.

Cirilli, S., & Roghi, G., et al. (1999). Palynomorphs. In C. Loriga (Ed.), Comunicações Serviços Geológicos de Portugal, 199, 229–282. Memórias Serviços Geológicos de Portugal.

Cousminer, H. L., & Manspeizer, W. (1976). Triassic pollen date of a borehole in the Djebel Melita 1 borehole (Gulf of Gabes, South-eastern Tunisia). Micropaleontology, 58(4), 377–388.

Choffat, P. (1894). Notice stratigraphique sur les gisements de végétaux fossiles dans le Mésozoïque du Portugal (pp. 229–282). Memórias Serviços Geológicos de Portugal.

Choffat, P. (1903). L’Infralias et le Sinémurien du Portugal. Comunicaciones Serviços Geológicos De Portugal, 5, 49–114.

Cirilli, S. (2010). Upper Triassic–lowermost Jurassic palynology and palynostratigraphy: A review. Geological Society, London, Special Publications, 334(1), 285–314. https://doi.org/10.1144/SP334.12

Cirilli, S., & Esabit, Y. (1991). First discovery of Samaropollenites and the Onslow Microflora in the Upper Triassic of Israel, and its phytogeographic implications. Palaeogeography, Palaeoclimatology, Palaeoecology, 85, 207–212. https://doi.org/10.1016/0031-0182(91)90160-S

Cirilli, S., & Montanari, L. (1994). The Carnian evaporites succession of Bistríc River (southern Albany). Palaeopelagos, 4, 107–118.

Cirilli, S., & Roghi, G., et al. (1999). Palynomorphs. In C. Loriga (Ed.), Comunicações Serviços Geológicos de Portugal, 199, 229–282. Memórias Serviços Geológicos de Portugal.

Cousminer, H. L., & Manspeizer, W. (1976). Triassic pollen date of a borehole in the Djebel Melita 1 borehole (Gulf of Gabes, South-eastern Tunisia). Micropaleontology, 58(4), 377–388.

Choffat, P. (1894). Notice stratigraphique sur les gisements de végétaux fossiles dans le Mésozoïque du Portugal (pp. 229–282). Memórias Serviços Geológicos de Portugal.
Palain, C. (1976). Une série détritique terrigène les” Grès de Silves”: Trias et Lias inférieur du Portugal. *Memória Dos Serviços Geológicos De Portugal*, 25, 377.

Palain, C. (1979). Connaissances stratigraphiques sur la base du mésozoïque portugais. *Ciências Da Terra*, 5, 11–28.

Paterson, N. W., & Mangerud, G. (2020). A revised palynozonation for the Middle-Upper Triassic (Anisian–Rhaetian) Series of the Norwegian Arctic. *Geological Magazine*, 157(10), 1568–1592. https://doi.org/10.1017/S0016756819000906

Pérez-López, A., Cambeses, A., Pérez-Valera, F., & Götz, A. E. (2021). Rhaetian tectono-magmatic evolution of the Central Atlantic Magmatic Province volcanism in the Betic Cordillera, South Iberia. *Lithos*, 396, 106230. https://doi.org/10.1016/j.lithos.2021.106230

Riding, J. B., & Warry, S. (Eds.). (2008). *Palynological Techniques* (2nd ed., p. 137). American Association of Stratigraphic Palynologists Foundation.

Robbins, E. I. (1982). Fossil Lake Danville. Unpublished PhD Thesis, Pennsylvania State University, pp. 1–400.

Roghi, G. (2004). Palynological investigations in the Carnian of the Cave del Predil area (Julian Alps, NE Italy). *Review of Palaeobotany and Palynology*, 132, 1–35. https://doi.org/10.1016/j.revpalbo.2004.03.001

Scott, R. A. (1982). Aspects of the Palynology of the Chinle Formation (Upper Triassic), Colorado Plateau, Arizona, Utah, and New Mexico. *United States Geological Survey, Open-File Report*, 82(937), 1–19.

Soares, A. F., Kullberg, J. C., Marques, J. F., da Rocha, R. B., & Callaper, P. M. (2012). Tectono-sedimentary model for the evolution of the Silves Group (Triassic, Lusitanian basin, Portugal). *Bulletin De La Société Géologique De France*, 183(3), 203–216. https://doi.org/10.2113/gssgbull.183.3.203

Torrinha, P., Rocha, R., Rey, J., Cachão, M., Moura, D., Roque, C., Martins, L., Valadares, V., Cabral, J., Azevedo, M. R., Barbiero, L., Clavijo, E., Dias, R. P., Matias, H., Madeira, J., Silva, C. M., Munhá, J., Rebelo, L., Ribeiro, C., … Bensalah, M. K. (2013). A Bacia do Algarve: Estratigrafia, paleogeografia e tectônica. *Geologia De Portugal, Geologia Meso-Cenozóica De Portugal, II*, 29–166.

Van Der Eem, J. G. L. A. (1983). Aspects of middle and late triassic palynology. 6. Palynological investigations in the Ladinian and lower Carnian of the Western Dolomites Italy. *Review of Palaeobotany and Palynology*, 39(3–4), 189–300. https://doi.org/10.1016/0034-6667(83)90016-7

Verati, C., Rapaille, C., Féraud, G., Marzoli, A., Bertrand, H., & Youbi, N. (2007). 40Ar/39Ar ages and duration of the Central Atlantic Magmatic Province volcanism in Morocco and Portugal and its relation to the Triassic-Jurassic boundary. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 244(1–4), 308–325. https://doi.org/10.1016/j.palaeo.2006.06.033

Vigran, J. O., Mangerud, G., Mørk, A., Worsley, D., & Hocbli, P. A. (2014). Palynology and geology of the Triassic succession of Svalbard and the Barents Sea (Vol 14). *Norges Geologiske Undersøkelser*. https://doi.org/10.5167/ruhz-99116

Vilas-Boas, M., Paterson, N. W., Pereira, Z., Fernandes, P., & Cirilli, S. (2021a). Constraining the age of the first pulse of continental rifting associated with the breakup of Pangea in Southwest Iberia. *EGU General Assembly Conference Abstracts* (pp. EGU21–1346).

Vilas-Boas, M., Pereira, Z., Cirilli, S., Duarte, L. V., & Fernandes, P. (2021b). New data on the palynology of the Triassic-Jurassic boundary of the Silves Group, Lusitanian Basin, Portugal. *Review of Palaeobotany and Palynology*, 290, 104426. https://doi.org/10.1016/j.revpalbo.2021.104426

Visscher, H., & Krystyn, L. (1978). Aspects of Late Triassic palynology. 4. A palynological assemblage from ammonoid-controlled late Carnian (Tuvalian) sediments of Sicily. *Review of
Wood, G. D., Gabriel, A. M., & Lawson, J. E. (1996). Palynological techniques processing and microscopy. In J. Jansonius & D. C. McGregor (Eds.), *Palynology: Principles and applications* (1st ed., pp. 29–50). American Association Stratigraphic Palynology.