

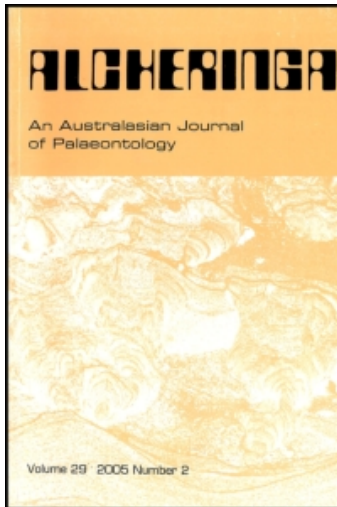
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### Alcheringa: An Australasian Journal of Palaeontology

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t770322720>

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Online Publication Date: 01 December 2008

**To cite this Article** Vergel, M.(2008)'Palynology of late Palaeozoic sediments (Tupe Formation) at La Herradura Creek, San Juan province, Argentina',Alcheringa: An Australasian Journal of Palaeontology,32:4,339 — 352

**To link to this Article:** DOI: 10.1080/03115510802417075

**URL:** <http://dx.doi.org/10.1080/03115510802417075>

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# Palynology of late Palaeozoic sediments (Tupe Formation) at La Herradura Creek, San Juan province, Argentina

M. VERGEL

VERGEL, M., December, 2008. Palynology of late Palaeozoic sediments (Tupe Formation) at La Herradura Creek, San Juan province, Argentina. *Alcheringa* 32, 339–352. ISSN 0311-5518.

Palynomorph assemblages recovered from the Tupe Formation at La Herradura Creek, San Juan province, Argentina, are analysed. The middle section of the sequence includes a marine fossiliferous interval belonging to the *Tivertonia jachalensis*–*Streptorhynchus inaequiornatus* (T–S) Faunal Biozone, recently ascribed an Early Permian age. The section below the marine fossiliferous unit yielded palynofloras typical of previously described ‘*Tupense*’ assemblages. The palynoflora recovered from beds above the marine horizon is diverse, relatively well preserved and includes species never recorded from the Tupe Formation. This latter palynoassemblage includes species diagnostic of Early Permian palynofloras such as *Convurrencosporites confluens* (Archangelsky & Gamero) Playford & Dino, *Pseudoreticulatispora pseudoreticulata* (Balme & Hennelly) Bharadwaj & Srivastava, *Horriditriteles ramosus* (Balme & Hennelly) Bharadwaj & Salujha, *Anapiculatisporites tereteangulatus* (Balme & Hennelly) Playford & Dino, *Laevigatosporites colliensis* (Balme & Hennelly) Venkatachala & Kar, *Marsupipollenites triradiatus* Balme & Hennelly, *Protohaploxypinus sewardii* (Virkki) Hart and *Pakhapites fusus* (Bose & Kar) Menéndez. Correlations with assemblages from western Argentina and other Gondwanan regions suggest an Early Permian age (not older than Asselian–Sakmarian) for the upper part of the sequence, supporting the age attributed to the T–S Biozone.

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Key words: Palynology, Early Permian, Tupe Formation, Paganzo Basin, Argentina.

LA HERRADURA CREEK is located on the western flank of Perico Hill, about 10 km northwest of Huaco city, San Juan province, Argentina. Palaeogeographically, the area belongs to the Precordillera Central or western sector of the Paganzo Basin, an area in which thick sequences of Carboniferous and Permian strata of the Paganzo Group were deposited. The Paganzo Group incorporates glacial, alluvial, lacustrine, fluvial and marine-littoral deposits assigned to the Guandacol, Tupe and Patquía formations.

The middle section of the Tupe Formation at La Herradura Creek has

been regarded as the stratotype of the *Tivertonia jachalensis*–*Streptorhynchus inaequiornatus* (T–S) Faunal Biozone (Sabattini *et al.* 1991). This interval has been identified at several localities in western Argentina and characterizes a marine incursion from the Palaeo-Pacific into the western Paganzo Basin (Sabattini *et al.* 1991, López Gamundi *et al.* 1994). It was previously regarded as being of Late Carboniferous age (Sabattini *et al.* 1991, González 1997) but, based on brachiopod correlations, has been assigned recently to the Early Permian (Cisterna *et al.* 2002, 2006). This study aims to analyse palynological assemblages recovered from samples of the section studied by Cisterna *et al.* (2002) in order to verify the age of the T–S Biozone.

## Stratigraphy and age of the Tupe Formation

The Tupe Formation in the Precordillera area is a siliciclastic succession dominated by sandstones with alternating mudstones, calcareous claystones and coals. It conformably overlies the Upper Carboniferous Guandacol Formation and its top is transitional to the Lower Permian Patquía Formation.

Limarino *et al.* (1986) divided the Tupe Formation into two informal members in the Huaco area. The lower 'Areniscas, Sabulitas and Mantos de Carbón member' includes a lower interval with abundant fossil plants belonging to the *Nothorhacopteris argentinica*–*Botrychiopsis weissiana*–*Ginkgophyllum diazii* (NBG) Floral Biozone, which typifies the Upper Carboniferous of northwestern Argentina (Limarino *et al.* 1986, Archangelsky 1996). The upper interval of the lower member hosts a marine fauna belonging to the T–S Biozone. It is succeeded by the 'Abigarrado member', which essentially consists of reddish sandstones and mudstones.

The La Herradura Creek section exposes a succession of about 76 m of the Tupe Formation. This unit rests conformably on the Guandacol Formation and is in transitional contact with the succeeding Patquía Formation. Cisterna *et al.* (2002, fig. 2) analysed the marine fauna of the T–S Biozone and illustrated the positions of palynological samples used in this study.

Earlier palaeobotanical evidence (Archangelsky 1996) suggested that the Tupe Formation was of late Westphalian–Stephanian age. Palynological evidence also indicated a Westphalian age (Césari & Gutiérrez 2000). A fossil fauna belonging to the T–S Biozone from the middle part of the Tupe Formation was also assigned a Late Carboniferous age by Sabattini *et al.* (1991), and a Stephanian age was supported by González (1997) and Taboada (1997).

However, the precise age for the T–S Biozone has been disputed by subsequent authors. In particular, Cisterna & Sabattini (1998) proposed a general Early Permian age and, more recently, Cisterna *et al.* (2002, 2005, 2006) argued for a more precise (Asselian) age for this Biozone. Recent megafloal studies at La Delfina Mine, North of Cuesta de Huaco in the San Juan Precordillera have suggested that deposition of the Tupe Formation spanned the Late Carboniferous to Early Permian (Coturel & Gutiérrez 2005).

## Palynology

### *Materials and methods*

Samples for palynological analysis were taken throughout the studied section (see fig. 2 of Cisterna *et al.* 2002). They were prepared using standard palynological techniques. Three productive samples P(1a), P(1b) and P(9a) were obtained from the mudstones, but the calcareous and carbonaceous horizons associated with marine invertebrate fossils were barren of plant microfossils. Spore and pollen preservation is poor, especially in samples P(1a) and P(1b), due to thermal alteration. The palynofloras were studied using standard transmitted light microscopy.

*Repository.* The palynological slides are housed in the Colección Paleobotánica, Preparados Microscópicos of the Instituto Miguel Lillo, Universidad Nacional de Tucumán, Argentina, labelled LIL PB-PM N° 411 for sample P(1a), LIL PB-PM N° 412 for sample P(1b) and LIL PB-PM N° 413 for sample P(9a). England Finder coordinates are provided for figured specimens.

### *Previous palynological studies*

Numerous palynological studies have been undertaken on upper Palaeozoic sequences

of central-western Argentina. The palynostratigraphy of various basins was summarized by Archangelsky (1987, 1996) and Césari & Gutiérrez (2000). The latter authors developed an integrated Early Carboniferous–Permian biostratigraphic scheme for central-western Argentina incorporating four palynozones: the *Cordylosporites–Verrucosisporites* (CV) Assemblage Biozone (Early Carboniferous), the *Raistrickia densa–Convolutispora muriornata* (DM) Assemblage Biozone (Late Carboniferous), the *Fusacolpites fusus–Vittatina subsaccata* (FS) Assemblage Biozone (Early Permian: Asselian to Sakmarian) and the *Lueckisporites–Weylandites* (LW) Assemblage Biozone (Permian, no older than late Artinskian–Kungurian).

The DM Biozone was sub-divided into three interval sub-biozones: Sub-biozone A (spanning the Guandacol Formation and equivalent units), Sub-biozone B (Tupe Formation and equivalents; it contains abundant macrofloral remains of the NBG Biozone) and Sub-biozone C (upper part of the Tupe and Cerro Agua Negra formations and the middle intervals of the Santa Máxima and El Imperial formations of the Calingasta–Uspallata and San Rafael basins; all of these represent marine-littoral deposits).

The FS Biozone was recognized in the Bajo de Véliz and Tasa Cuna formations (Paganzo Basin) and equivalents such as the upper sections of the Santa Máxima and El Imperial formations and in the Río del Peñón Formation. The FS Biozone characterizes strata bearing the first macrofloral remains of glossopterids; geochronological data suggest it is of Asselian–Artinskian age (Thompson & Mitchell 1972). Recently, Césari (2007) collated palynological and radiometric data from several western Gondwanan areas to support an Asselian–Artinskian age for the FS Biozone.

Palynological studies of the Tupe Formation have been principally carried out in Sierra de Maz of La Rioja province (Césari 1984, 1986, 1987, Césari & Limarino 1987) and from the Huaco area of San Juan province (Limarino *et al.* 1986, Ottone 1991, Ottone & Azcuy 1991). Most of the studied palynofloras are from coal beds corresponding to the ‘Areniscas, Sabulitas y Mantos de Carbón Member’ (Limarino *et al.* 1986) and are characterized by diverse spore–pollen assemblages (Tables 1, 2).

#### *Palynological results*

A preliminary palynological study of the Tupe Formation at La Herradura Creek was presented by Vergel & Fasolo (1999) who recognized two assemblages that they assigned to the Late Carboniferous. The lower assemblage, from the basal parts of the section, yielded palynomorph species previously cited for the Tupe Formation and equivalent units. The assemblage from the upper part of the section (above the marine beds) was interpreted as younger in age and included taxa later listed by Cisterna *et al.* (2002). This study aims to re-examine these assemblages and, with new palynological data, ascertain the precise age of these beds.

All of the palynomorph species recorded in the present study are well known and adequately circumscribed in previous palynological literature, hence, the taxa are simply listed (Tables 1, 2) and the most stratigraphically representative species are illustrated (Figs 1A–R, 2A–R).

Specimens from samples P(1a) and P(1b), recovered from the lower and middle part of the studied section, are poorly preserved and yielded impoverished assemblages, hence no quantitative analysis was attempted. Palynomorphs from sample P(9a), close to the top of the Tupe Formation, are moderately well preserved and very diverse. Trilete spores (45%) and

Spores from the Tupe Formation	A	B	C	D	E	Spores from the Tupe Formation	A	B	C	D	E
<i>Punctatisporites fungosus</i>	X					<i>Convolutispora globosa</i>		X			
<i>Punctatisporites glaber</i>	X	X				<i>Convolutispora ordoñezii</i>		X			
<i>Punctatisporites gretensis</i>	X	X	X	X		<i>Foveosporites horttonensis</i>	X	X	X	X	
<i>Leiotriletes directus*</i>	X					<i>Foveosporites pellucidus</i>	X	X			
<i>Calamospora smileyana</i>	X	X				<i>Rugospora cortaderensis</i>	X	X			
<i>Calamospora hartungiana</i>	X	X				<i>Reticulatisporites passaspectus</i>		X			X
<i>Calamospora plicata*</i>						<i>Raistrickia densa</i>	X		X		
<i>Retusotriletes anfractus</i>		X				<i>Raistrickia rotunda</i>	X	X			
<i>Retusotriletes golatensis*</i>					X	cf. <i>Waltispora pollita</i>	X				
<i>Retusotriletes diversiformis*</i>					X	<i>Verrucosporites andersonii*</i>					X
<i>Cyclogranisporites microgranulatus</i>	X					<i>Spelaeotriletes arenaceus*</i>					X
<i>Cyclogranisporites microgranus</i>	X		X			<i>Spelaeotriletes ybertii</i>	X		X	X	
<i>Apiculatasporites caperatus</i>		X		X		<i>Vallatisporites arcuatus</i>		X	X	X	
<i>Anapiculatisporites variornatus</i>		X				<i>Vallatisporites ciliaris</i>	X	X	X	X	
<i>Granulatisporites austroamericanus*</i>					X	<i>Spinozonotriletes</i> sp. cf. <i>S. hirsutus</i>		X			X
<i>Granulatisporites</i> sp. cf. <i>G. microgranifer</i>	X					<i>Cristatisporites chacoparanaensis</i>		X			X
<i>Apiculinetusispora variornata</i>	X					<i>Cristatisporites crassilabratius</i>	X				X
<i>Anapiculatisporites variornatus</i>		X				<i>Cristatisporites inconstans</i>	X	X	X	X	
<i>Anapiculatisporites tereteangulatus*</i>					X	<i>Cristatisporites lestai</i>	X	X	X	X	
<i>Converrucosporites confluens*</i>						<i>Cristatisporites menendezii</i>	X	X	X	X	
<i>Converrucosporites</i> sp.*					X	<i>Cristatisporites rolleri</i>		X			X
<i>Pseudoreticulatispora pseudoreticulata*</i>					X	<i>Cristatisporites spinosus</i>	X	X	X	X	X
<i>Brevitriletes cornutus*</i>					X	<i>Lundbladisporea braziltensis</i>	X	X	X	X	
<i>Apiculatisporis variornatus*</i>					X	<i>Lundbladisporea irregularis</i>	X	X	X	X	
<i>Horriditriletes ramosus*</i>					X	<i>Lundbladisporea riobonitensis</i>		X	X	X	
<i>Horriditriletes uruguayensis*</i>					X	<i>Laevigatosporites collitensis*</i>		X	X	X	X
<i>Convolutispora muriornata</i>	X	X				<i>Laevigatosporites vulgaris</i>		X			

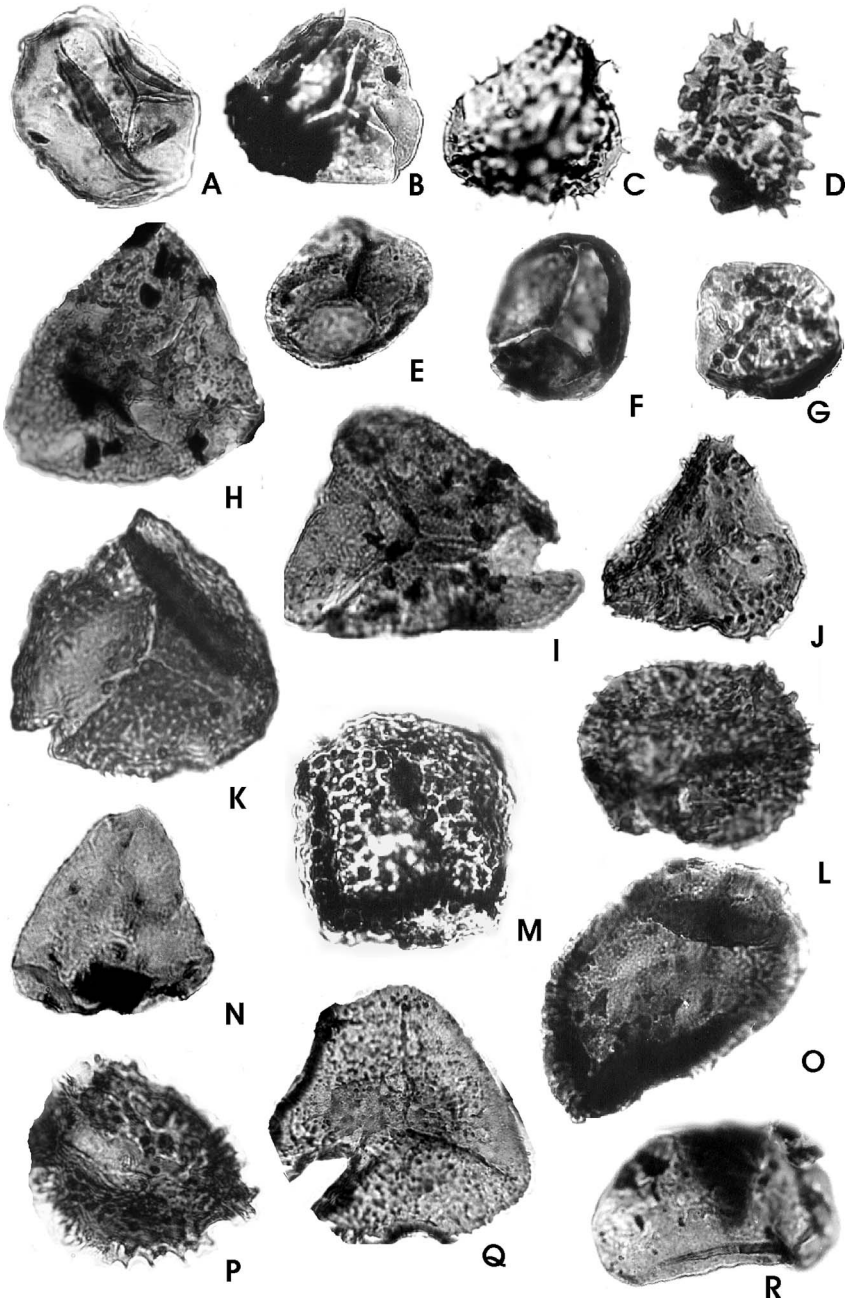
Table 1. Distribution of spore species identified in the studied samples and from the other "Tupense" sequences; A, From Sierra de Maz (Césari 1984, 1986, Césari & Limarino 1987); B, from Huaco area (Limarino *et al.* 1986, Ottone 1991, Ottone & Azcuy 1991); C, from La Herradura sample P(1a); D, from La Herradura sample P(1b); E, from La Herradura sample P(9a). The asterisk indicates the first record of the taxon from the Tupe Formation.

Pollen and other miospores from the Tupe Formation	A	B	C	D	E	Pollen and other miospores from the Tupe Formation	A	B	C	D	E
<i>Cannanoropollis densus</i>	X	X			X	<i>Pteruchipollenites gracilis</i>	X				X
<i>Cannanoropollis janakii</i>		X			X	<i>Scheuringipollenites ovatus*</i>	X				X
<i>Cannanoropollis korbaensis*</i>		X			X	<i>Colpisaccites granulatus</i>		X			X
<i>Plicatipollenites densus</i>		X				<i>Pakhapites fusus</i>		X			X
<i>Plicatipollenite gondwanensis</i>	X	X	X			<i>Marsupipollenites triradiatus</i>		X			X
<i>Plicatipollenite malabarensis</i>	X	X			X	<i>Siriatobieites</i> sp.		X			X
<i>Plicatipollenite trigonalis</i>		X				<i>Protohaploxypinus amplius</i>	?				X
<i>Caheniasaccites</i> spp.	X	X			X	<i>Protohaploxypinus seawardii*</i>					X
<i>Potonieisporites brasiliensis</i>		X			X	<i>Cycadopites cymbatus*</i>					X
<i>Potonieisporites congoensis*</i>		X			X	<i>Praecolpaites</i> sp.*					X
<i>Potonieisporites frenguelli</i>	X					<i>Equisetosporites argentinensis</i>	X				
<i>Potonieisporites magnus</i>	X	X				<i>Gnetaceapollenites</i> sp.		X			X
<i>Potonieisporites neglectus</i>	X	X				<i>Vittatina costabilis*</i>					X
<i>Potonieisporites novicus</i>		X			X	<i>Vittatina saccata*</i>					X
<i>Potonieisporites triangulatus</i>		X	X			<i>Vittatina subsaccata*</i>					X
<i>Circumplicatipollis plicatus</i>		X				<i>Portallites gondwanensis</i>	X	X	X		X
<i>Circumplicatipollis stigmatum</i>		X				<i>Brazilea scissa</i>		X			X
<i>Crucisaccites latisulcatus</i>		X			X	<i>Navifusa variabilis*</i>					X
<i>Crucisaccites monoletus</i>	X	X			X	<i>Tetraporina punctata</i>		X			X
<i>Crucisaccites</i> sp.	X					<i>Tetraporina sibirica</i>		X			X
<i>Divarisaccus stringoplicatus</i>		X				<i>Circulisporites</i> sp.*					X
<i>Limitisporites hexagonalis</i>	X				X	<i>Gorgonisphaeridium</i> sp.*					X

Table 2. Distribution of pollen species and other miospores identified in the studied samples and from the other "Tupense" sequences: A, from Sierra de Maz (Césari 1984, 1986, Césari & Limarino 1987); B, from Huaco area (Limarino *et al.* 1986, Ottone 1991, Ottone & Azcuy 1991); C, from La Herradura sample P(1a); D, from La Herradura sample P(1b); E, from La Herradura sample P(9a). The asterisk indicates the first record of the taxon from the Tupe Formation.

monosaccate pollen grains (35%) are the most abundant taxa; bisaccate, plicate pollen grains and monoete spores are less

common (10%); and striate pollen (5%) are rare. A few specimens of algae (2%) and acritarchs (1%) were also identified.



## Age and biostratigraphic correlation

### *Correlation within central western Argentina*

Sample P(1a) from the lower part of the sequence at La Herradura Creek yielded taxa similar to those recorded from other 'Tupense' assemblages, or Upper Carboniferous sequences (e.g. the lower part of the Santa Máxima and El Imperial formations, Estratos de Mascasín). Consequently, this part of the sequence is correlated with the DM Biozone (Césari & Gutiérrez 2000) and is assigned a Late Carboniferous age.

Sample P(1b) from the middle part of the sequence, just below the marine beds, yielded a taxonomically impoverished and poorly preserved assemblage. Hence, its precise age is difficult to determine.

The more diverse assemblage from sample P(9a), although containing several of the palynomorph species documented from the underlying assemblages, also yields taxa not previously recorded from the Tupe Formation (indicated with an asterisk in Tables 1, 2). The assemblage includes species diagnostic of Early Permian palynofloras

such as: *Converrucosisporites confluens* (Archangelsky & Gamero) Playford & Dino, 2002, *Pseudoreticulatispora pseudoreticulata* (Balme & Hennesly) Bharadwaj & Srivastava, 1969, *Horriditriteles ramosus* (Balme & Hennesly) Bharadwaj & Salujha, 1964, *Anapiculatisporites tereteangulatus* (Balme & Hennesly) Playford & Dino, 2002, *Laevigatosporites colliensis* (Balme & Hennesly) Venkatachala & Kar, 1968, *Marsupipollenites triradiatus* Balme & Hennesly, 1956, *Protohaploxypinus sewardii* (Virkki) Hart, 1964 and *Pakhapites fusus* (Bose & Kar) Menéndez, 1971.

*Converrucosisporites confluens* is an Early Permian (Asselian–early Sakmarian) index species that has been widely recorded across Gondwana (e.g. Backhouse 1991, Césari & Gutiérrez 2000 and references therein; Stephenson & Filatoff 2000, Playford & Dino 2002).

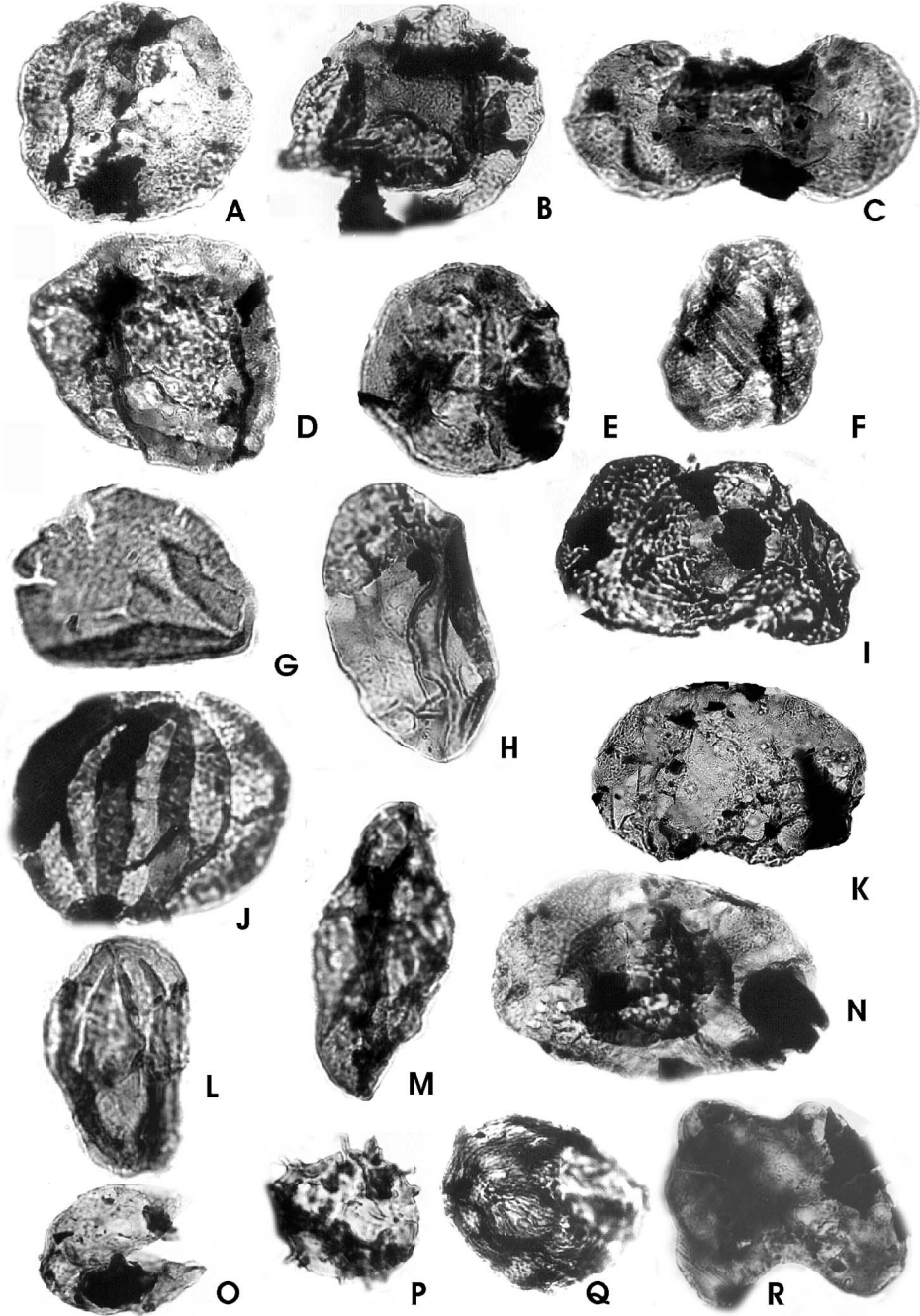
Other taxa of broad biostratigraphic significance include *Horriditriteles ramosus* and *Anapiculatisporites tereteangulatus*. They were originally described from Australian Permian sequences and were later recorded from Early Permian strata elsewhere in Gondwana (e.g. Anderson 1977, Vergel 1993, Lindström 1995, Stephenson

Fig. 1. Palynomorphs from the Tupe Formation at La Herradura Creek. **A**, *Calamospora plicata* (Luber & Waltz) Hart, 1965; P(9a), LilPb-PM 413 (B), EF: Q36-2, × 500. **B**, *Leiotriteles directus* Balme & Hennesly, 1956; P(9a), LilPB-PM 413 (E), EF: B44–B45, × 700. **C**, *Anapiculatisporites tereteangulatus* (Balme & Hennesly) Playford & Dino, 2002; P(9a), LilPB-PM 413 (C), EF: W28, × 700. **D**, *Horriditriteles ramosus* (Balme & Hennesly) Bharadwaj & Salujha, 1964; P(9a), LilPB-PM 413 (G), EF: W36, × 700. **E**, *Retusotriteles golatensis* Staplin, 1960; P(9a), LilPb-PM 413 (H), EF: V51, × 700. **F**, *Retusotriteles diversiformis* (Balme & Hennesly) Balme & Playford, 1967; P(9a), LilPB-PM 413 (H), EF: C25, × 700. **G**, *Brevitriteles cornutus* (Balme & Hennesly) Backhouse, 1991; P(9a), LilPB-PM 413 (J), EF: N33 O33, × 700. **H**, *Converrucosisporites* sp.; P(9a), LilPB-PM 413 (L), EF: L48-2, × 600. **I**, *Granulatisporites austroamericanus* Archangelsky & Gamero, 1979; P(9a), LilPB-PM 413 (J), EF: J37, × 700. **J**, *Horriditriteles uruguayensis* (Marques-Toigo) Archangelsky & Gamero, 1979; P(9a), LilPB-PM 413 (M), EF: P41-4, × 700. **K**, *Pseudoreticulatispora pseudoreticulata* (Balme & Hennesly) Bharadwaj & Srivastava, 1969; P(9a), LilPB-PM 413 (D), EF: H34, × 600. **L**, *Apiculatisporis variornatus* di Pascuo, Azcuy & Souza, 2003; P(9a), LilPB-PM 413 (A), EF: S51-1, × 500. **M**, *Verrucosisporites andersonii* (Anderson) Backhouse, 1988; P(9a), LilPB-PM 413 (F), EF: W50, × 600. **N**, *Converrucosisporites confluens* (Archangelsky & Gamero) Playford & Dino, 2002; P(9a), LilPB-PM 413 (A), EF: E29-4, × 700. **O**, *Lundbladisporea braziliensis* (Marques-Toigo & Pons) Marques-Toigo & Picarelli, 1985; P(9a), LilPB-PM 413 (B), EF: N36-3, × 500. **P**, *Cristatisporites inconstans* Archangelsky & Gamero, 1979; P(1a), LilPB-PM 411 (A), EF: Y43, × 700. **Q**, *Spelaotriteles arenaceous* Neves & Owens, 1966; P(9a), LilPB-PM 413 (C), EF: L24-4, × 500. **R**, *Laevigatosporites colliensis* (Balme & Hennesly) Venkatachala & Kar, 1968; P(9a), LilPB-PM 413 (H), EF: J29, × 600.



2004 and references therein). The presence of *Laevigatosporites colliensis*, *Marsupipollenites triradiatus*, *Protohaplaxypinus sewardii*

and *Pakhapites fusus* also indicates an age not older than Asselian based on their known Gondwanan ranges (Backhouse



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1991, Farabee *et al.* 1991, Lindström 1995, Raine *et al.* 2006).

Forms such as *Pseudoreticulatispora pseudoreticulata* and *Praecolpatites* sp. are generally attributed to palynofloras not older than early Sakmarian but they are rare components of the P(9a) assemblage (two specimens). In Australian palynostratigraphic schemes, the first appearance of *P. pseudoreticulata* defines the base of Stage 3 (Kemp *et al.* 1977) or the *Pseudoreticulatispora pseudoreticulata* Zone (Backhouse 1991) considered to be of Artinskian age. The appearance of this taxon in the South African Karoo Basin palynofloral assemblages also indicates an age not older than Tastubian (Anderson 1977).

Palynoassemblages with signatures younger than the typical 'Tupense' floras were previously recorded from several sections in central-western Argentina. From the base of the Patquía Formation at Cuesta de Huaco (San Juan province), Limarino & Césari (1987) recorded a palynoassemblage that, based on radiometric evidence, reflects an Asselian to Sakmarian age. Several taxa are shared with sample P(9a) of this study; hence, the assemblages are probably coeval.

Ottone (1989) assigned palynofloras from the middle and upper part of the

Santa Maxima Formation (Calingasta–Uspallata Basin) to the Early Permian. He proposed a correlation between the middle levels of that formation and the marine deposits of the middle Tupe Formation. These assemblages are also similar in composition and probably coeval.

Sample P(9a) may also be correlated with the 'upper association' of the El Imperial Formation (García 1995, 1996). García (1996) assigned an Early Permian age to this association, whereas Césari & Gutiérrez (2000) suggested a Stephanian to earliest Permian age.

Gutiérrez & Césari (2000) assigned an Early Permian age to the diverse Bajo de Véliz Formation palynoflora (San Luis province, southeastern Paganzo Basin). Césari & Gutiérrez (2000) referred it to the FS Biozone. Some important species from sample P(9a) at La Herradura Creek are shared with this assemblage; hence the host units may be correlative. The Tasa Cuna Formation (Córdoba province, Paganzo Basin) also yielded assemblages (Césari *et al.* 1999, Balarino & Gutiérrez 2006) equivalent to the palynofloras from Bajo de Véliz and the upper Santa Máxima and El Imperial formations, and is referable to the FS Biozone. Likewise, it shares several taxa with sample P(9a) and may be coeval.



Fig. 2. Palynomorphs from the Tupe Formation at La Herradura Creek. **A**, *Cannanoropollis korbaensis* (Bharadwaj & Tiwari) Foster, 1975; P(9a), LilPb-PM 413 (A), EF: E27-4,  $\times 300$ . **B**, *Potonieisporites congoensis* Bose & Maheshwari, 1968; P(9a), LilPB-PM 413 (H), EF: M42-3,  $\times 400$ . **C**, *Protohaploxypinus sewardii* (Virkki) Hart, 1964; P(9a), LilPB-PM 413 (J), EF: R30,  $\times 700$ . **D**, *Crucisaccites monoletus* Maithy, 1965; P(1a), LilPB-PM 411 (A), EF: K48-4,  $\times 400$ . **E**, *Vittatina costabilis* Wilson, 1962; P(9a), LilPB-PM 413 (E), EF: F42,  $\times 600$ . **F**, *Pakhapites fusus* (Bose & Kar) Menéndez, 1971; P(9a), LilPB-PM 413 (I), EF: Z42,  $\times 700$ . **G**, *Marsupipollenites triradiatus* Balme & Hennelly, 1956; P(9a), LilPB-PM 413 (J), EF: V37,  $\times 500$ . **H**, *Navifusa variabilis* Gutiérrez & Limarino, 2001; P(9a), LilPB-PM 413 (A), EF: V59-3,  $\times 500$ . **I**, *Protohaploxypinus amplus* (Balme & Hennelly) Hart, 1964; P(9a), LilPB-PM 413 (H), EF: H38-3,  $\times 400$ . **J**, *Scheuringipollenites ovatus* (Balme & Hennelly) Foster, 1975; P(9a), LilPB-PM 413 (G), EF: U35-2,  $\times 400$ . **K**, *Pteruchipollenites gracilis* (Segroves) Foster, 1979; P(9a), LilPb-PM 413 (C), EF: J58,  $\times 600$ . **L**, cf. *Praecolpatites sinuosus* (Balme & Hennelly) Bharadwaj & Srivastava, 1969; P(9a), LilPB-PM 413 (J), EF: U30-1,  $\times 500$ . **M**, *Cycadopites cymbatus* (Balme & Hennelly) Segroves, 1970; P(9a), LilPB-PM 413 (A), EF: J32-2,  $\times 600$ . **N**, *Potonieisporites novicus* Bharadwaj emend. Bharadwaj, 1964; P(9a), LilPb-PM 413 (C), EF: C51,  $\times 400$ . **O**, *Brazilea scissa* (Balme & Hennelly) Foster, 1975; P(9a), LilPB-PM 413 (B), EF: B30-4,  $\times 400$ . **P**, *Gorgonisphaeridium* sp.; P(9a), LilPB-PM 413 (A), EF: G60-3,  $\times 1000$ . **Q**, *Circulisporites* sp.; P(9a), LilPB-PM 413 (B), EF: E20-3,  $\times 500$ . **R**, *Tetraporina punctata* (Tiwari & Navale) Kar & Bose, 1976; P(9a), LilPB-PM 413 (G), EF: L28-1,  $\times 500$ .

In conclusion, the palynoflora of the upper part of the Tupe Formation in the La Herradura Creek section best corresponds to Asselian–Sakmarian assemblages from central-western Argentina and is correlated with the FS Biozone.

This upper assemblage from La Herradura Creek represents a palynoflora dominated by long-ranging pteridophyte spores and cordaitalean and conifer pollen that persist from the Late Carboniferous into the Early Permian. The presence of several typical Late Carboniferous taxa such as *Retusotriletes golatensis* Staplin, 1960, *R. diversiformis* (Balme & Hennelly) Balme & Playford, 1967, *Apiculatisporis variornatus* di Pascuo, Azcuy & Souza, 2003, *Reticulatisporites passaspectus* Ottone, 1991, *Spelaeotriletes ybertii* (Marques-Toigo) Playford & Powis, 1979 and *Potonieisporites congoensis* Bose & Maheshwari, 1968 may be the result of reworking. Such taxa are generally less well preserved than typical Early Permian elements in the same assemblage.

The incoming of Glossopteridales–Peltaspermales pollen (*Vittatina*, *Protohaploxypinus*, and *Pteruchipollenites*) and the first records for the Tupe Formation of other distinctive spore–pollen taxa (*Converrucoisporites confluens*, *Pseudoreticulatispora pseudoreticulata*, *Horriditriletes ramosus*, *Anapiculatisporites tereteangulatus*, *Laevigatosporites colliensis*, *Protohaploxypinus sewardii* and *Pakhapites fusus*) reflect an important change in the regional floras in the Early Permian. The scarcity of the disaccate and taeniate pollen grains in these Asselian–Sakmarian beds may reflect local dominance of non-glossopterid vegetation or a long temporal lag between the first appearance of glossopterids and their achievement of vegetation dominance.

#### *Correlation with other Gondwanan regions*

According to Souza (2006, and references therein), the precision of Gondwanan

palynological correlation with the international stratigraphical stages is hampered by several factors such as phytogeographical provincialism and the general dearth of radiometric calibration points. However, tentative palynostratigraphic correlation with other Gondwanan regions can be achieved based on the shared occurrences of a few key palynomorph taxa. Correlation between the late Palaeozoic palynostratigraphic schemes of central-western Argentina and several other Gondwanan regions has been summarized by Césari & Gutiérrez (2000). Santos *et al.* (2006) and Souza (2006) presented more detailed palynological correlations and discussions and provided absolute ages for several key sections. Late Palaeozoic assemblages sharing key palynostratigraphic indices with La Herradura Creek assemblage P(9a) can be identified in the Chacoparaná/Paraná Basins of Argentina and Brazil, and in several basins of Australia, Africa and Antarctica.

The P(1a) assemblage from La Herradura Creek can be broadly correlated with the *Potonieisporites*–*Lundbladispota* Zone of the Chacoparanense Basin of Argentina (Vergel 1993). The P(9a) assemblage may correlate more precisely with the lower *Cristatisporites* Sub-zone (Asselian–Sakmarian *sensu* Vergel 1993) in that basin.

Souza & Marques-Toigo (2003) and Souza (2006) established four Biozones in the Paraná Basin, Brazil. There, the *Protohaploxypinus goraiensis* (Pg) Sub-biozone (Early Permian; Souza 2006), which was mainly recognized in the Rio Bonito Formation (Sakmarian, *sensu* Santos *et al.* 2006) and has been correlated with the central-western Argentina FS Biozone, contains the most correlative assemblages to sample P(9a) of this study.

Correlation with the palynostratigraphic zones of the Amazonas Basin, northern Brazil (Playford & Dino, 2000), is imprecise since several species in that basin are not recorded in Argentina. These discrepancies

probably reflect distinct palaeoclimatic differences imposed by palaeolatitude (Playford & Dino 2000).

Within Australia, the main palynostratigraphic zonations of the upper Palaeozoic sequences were established and summarized by Kemp *et al.* (1977), Backhouse (1991, 1993) and Jones & Truswell (1992). The P(1a) assemblage from La Herradura Creek can be tentatively correlated with the *Potonieisporites* Assemblage of Kemp *et al.* (1977) late Westphalian (?Kasimovian), or *Asperispora reticulatispinosus* Assemblage [Jones & Truswell 1992; Westphalian D (?Kasimovian) to early Asselian]. The P(9a) assemblage is best correlated with the *Granulatisporites confluens* Zone (Foster & Waterhouse 1988) or *Pseudoreticulatispora confluens* Zone (Backhouse 1991) assigned to the latest Asselian–Tastubian.

Assemblages from Oman and Saudi Arabia have been studied mainly by Besems & Schuurman (1987), Love (1994) and Stephenson *et al.* (2003). The lower assemblage from La Herradura Creek could be correlated with the OSPZ1 (*sensu* Stephenson *et al.* 2003) assigned to the Late Carboniferous whereas sample (P9a) is partially equivalent to the OSPZ2 (*sensu* Stephenson *et al.* 2003) assigned to the Early Permian (Asselian–Sakmarian).

Palynologic studies from the Upper Palaeozoic of Antarctica were synthesized by Masood *et al.* (1994) and Lindström (1995). The P(9a) assemblage is tentatively correlated with those from Lidkvarvet of the northern Heimefrontfjella, Antarctica, regarded as Stephanian–Asselian in age (Lindström 1995).

## Conclusions

A Late Carboniferous age is proposed for the lower assemblage from the Tupe Formation exposed at La Herradura Creek,

San Juan province, Argentina. This assemblage shares taxa with several other ‘*Tu-pense*’ sections and is correlated with the DM Biozone. The middle (P1b) sample located immediately below the marine sequence is poorly preserved, precluding accurate correlation or age assignment.

The new palynological assemblage recorded from the upper part of the Tupe Formation at La Herradura Creek has striking similarities to palynofloras from the Bajo de Véliz, Tasa Cuna, upper Santa Máxima and El Imperial formations from northwestern Argentina, and is assigned to the FS Biozone (Early Permian) of Césari & Gutiérrez (2000). This assemblage can also be correlated with several Asselian–Sakmarian palynozones within and beyond South America confirming an Early Permian age for the upper Tupe Formation at La Herradura Creek (similar to that of the T–S Faunal Biozone).

## Acknowledgements

The author wishes to thank Dr Sergio Archangelsky and Dr Rafael Herbst for reading and commenting on the manuscript. Dr Gabriela Cisterna and Dr Mauricio Martínez provided stratigraphical and palaeontological data. The manuscript greatly benefitted from careful reviews by Dr C.B. Foster, Dr A.J. Wright and an anonymous reviewer.

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