PALYNOSTRATIGRAPHY OF SOME PALEOZOIC ROCK UNITS OF BOLIVIA: ADDITIONAL RESULTS

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Resumen

Palinoestratigrafía de algunas formaciones paleozoicas de Bolivia: resultados adicionales

Este trabajo sintetiza resultados palinoestratigráficos obtenidos del análisis de 175 muestras procedentes de 16 secciones estratigráficas de superficie y afloramientos aislados de diferentes regiones de Bolívia, y envuelve 19 formaciones con edades que varían del Ordovícico al Terciario. De estas, solamente las 11 siguientes (del intervalo Silúrico - Carbonífero) presentaron resultados que fueron conclusivos en diferentes grados: formaciones Uncía, Kirusillas, Tarabuco, Santa Rosa, Icla, Los Monos, Tequeje, Tomachi, Toregua (y partes indiferenciadas del Grupo Retama), Kaka y Copacabana (incluyendo informalmente el "miembro Chorrito"). Dataciones y atribuciones bioestratigráficas son propuestas para las mismas, a la luz de las zonaciones coetáneas usadas en Euroamérica y regiones de Gondwana Occidental, además de los resultados bioestratigráficos obtenidos anteriormente por el autor en Bolivia. Son efectuadas comparaciones con datos de la literatura geológica de ese país y sugeridos cambios en la identificación y relaciones estratigráficas de algunas unidades litológicas regionales.

INTRODUCTION

The present contribution is a continuation of our previous studies on the Paleozoic palynostratigraphy of Bolivia (Melo 2000; Miranda *et al.* 2003). It gives the results of new biostratigraphic investigations, based on 175 outcrop samples from 16 stratigraphic sections and localities in the Bolivian Altiplano, Cordillera Oriental, and Subandean / Interandean regions of that country. The sections are listed next in alphabetical order: Alarache, Arani, Campanario, Carrasco Flank NE, Cochabamba, La Cumbre, Pelado Anticline, Sella, Tequeje, Tomachi Syncline Flank NE, Tomachi Syncline Flank SW (Teoponte), Yucumo Arroyo Seis / Río Caripó, Yucumo Bella Vista Flank SW, Yucumo Camino Tomachi (Retama–Río Kaka), Yucumo Río Carnabalito, and Yucumo Río San Miguel (see Miranda 2005 for detailed lithological and sequence stratigraphy descriptions of most of these sections). Their geographic distribution (Fig. 1) in relation to the Bolivian geological provinces is as follows: Alarache and Campanario Sections in the Southern Subandean Ranges; Sella Section in the Southern Interandean[1] Ranges; Arani Section and Cochabamba outcrop localities in the Cordillera Oriental; La Cumbre Section in the Bolivian

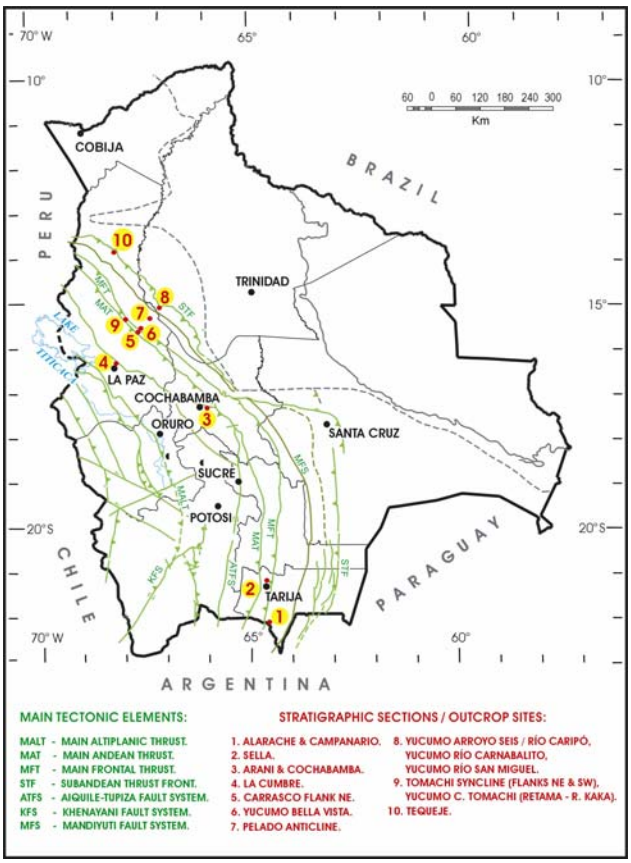

Figure 1. Location map of the stratigraphic sections and outcrop sites investigated in this study.

[1] According to some modern Bolivian authors (*e.g.*, Suárez-Soruco 2000, p. 8-9), the Interandean regions and the Huarina Folded Belt are parts of the Cordillera Oriental Ranges.

Altiplano, and the remaining 10 sections in the Northern Subandean / Interandean Ranges. In terms of the regional lithostratigraphy, this work focuses on 19 formations, collectively spanning in age from Ordovician to Tertiary, yet only those in the Silurian – Carboniferous interval turned out palynologically productive. The formations are (in ascending stratigraphic order): Anzaldo, Sella, Enadere, San Benito, Cancañiri, Uncía and Kirusillas; Tarabuco; Tequeje, Santa Rosa and Icla (basal part); Huamampampa, Los Monos and Tomachi; Toregua and Kaka (both within the Retama Group); Copacabana (including the "Chorrito" informal member); Bopi, and Bala. Samples were processed at BPA palynological laboratory according to PETROBRAS standard techniques described by Quadros & Melo (1987), and one slide has been mounted and examined for each sample.

Biostratigraphic determinations in this paper rely chiefly on published data concerning Paleozoic miospores and marine palynomorphs (chitinozoans and the organic-walled microphytoplankton), many of them with well-controlled stratigraphic distribution in Brazilian basins. Most of the biostratigraphic information used herein derives from a number of previous and ongoing Western Gondwanan studies (*e.g.*: Lange 1967; Lanzoni & Magloire 1969; Cramer *et al.* 1974; Lobo-Boneta *et al.* 1976; Suárez-Soruco & Lobo-Boneta 1983; Suárez-Soruco 1984; McGregor 1984; Volkheimer *et al.* 1986; Barreda 1986; Boumendjel 1987; Pérez-Leyton 1991; Racheboeuf *et al.* 1993; Blieck *et al.* 1996; Le Hérissé *et al.* 1996; Limachi *et al.* 1996; Vavrdová *et al.* 1996; Oliveira 1997; Loboziak *et al.* 1997, 1998, 1999; Melo *et al.* 1999; Grahn 2002, 2003; Grahn & Gutiérrez 2001; Grahn & Melo 2002, 2003, 2004 and in press; Grahn *et al.* 2000, 2002, 2003 and in press; Le Hérissé 2001, 2005; Loboziak & Melo 2000, 2002; Azcuy & Di Pasquo 2000; Di Pasquo *et al.* 2001; Melo & Loboziak 2000, 2001, 2003; Playford & Dino 2000a-b; Rubinstein 2001; Wood *et al.* 2002; Rubinstein *et al.* 2005). Selected works on the Silurian – Carboniferous palynostratigraphy of Euramerica and other regions were also considered (*e.g.*: Neves *et al.* 1972, 1973; Clayton *et al.* 1977; Paris 1981; Paris *et al.* 1981, 2000; Wicander & Wood 1981; Richardson & McGregor 1986; Streel *et al.* 1987; Schweineberg 1987; Steemans 1989; Riley 1993; Molyneux *et al.* 1996; Le Hérissé *et al.* 2000). Other sources include PETROBRAS' previous palynological studies of outcrop and subsurface sections in Southern Subandean / Interandean areas of Bolivia (Melo 2000, Miranda *et al.* 2003).

PRESENTATION AND DISCUSSION OF RESULTS

Fortunately, most of the samples analyzed herein (134 out of 175, or *ca.* 77 %) proved palynologically productive to varied degrees, although particular stratigraphic sections display remarkably low rates of palyniferous samples, *e.g.*, from 42% in Sella Section (Southern Interandean region) down to 0% in the Arani and La Cumbre Sections (Cordillera Oriental and Bolivian Altiplano, respectively). Fig. 2 shows the sample distribution *per* section and rock unit in this study, totalling 175 samples. Note that Northern Subandean / Interandean sections concentrate the major sampling (128, or 73 %), but only a very minor proportion of barren samples (17, or *ca.* 9.7 %). The most densely sampled formations are: Tomachi (46 samples, 26 %), Kirusillas (30 samples, 17 %), Tequeje (26 samples, 15 %) and Tarabuco (14 samples, 8 %). Other 16 or 19 rock units account for the remaining 34 % of the total sampling.

Of the older Paleozoic (pre-Kirusillas) rock units, only the Late Silurian Uncía Formation could be tentatively dated. All others proved barren or otherwise non-diagnostic biochronostratigraphically, *viz.*: the Sella, Anzaldo, San Benito and Cancañiri Formations in Southern Subandean / Interandean sections, Cordillera Oriental and Bolivian Altiplano, and the Enadere Formation in the Northern Subandean region. The same holds true for the two post-Carbonifeous rock units sampled in Northern Subandean Bolivia (Bopi and Bala Formations). Lastly, a considerable amount of productive samples from the Late Silurian – Late Carboniferous interval also have yielded insufficient palynological results.

In respect of the sections investigated (Fig. 2), the most densely sampled ones are in Northern Subandean / Interandean areas, *viz.*: Carrasco Syncline Flank NE (with 24 samples, or 14 % of the total), Yucumo Arroyo Seis / Río Caripó (23 samples, or 13 %), Tomachi Syncline Flank NE (22 samples, or *ca.* 12.6 %), Yucumo Bella Vista (20 samples, or 11 %), and Tequeje (17 samples, or *ca.* 9.7 %). Altogether these five sections correspond to more than 57 % of the total sampling investigated.

In most of the palyniferous samples the organic matter (o.m.) is poorly preserved (degraded and/or carbonized). Palynomacerals usually show colors ranging from dark brown to opaque black, except in sections like Pelado Anticline and Yucumo Arroyo Seis / Río Caripó, and the Upper Carboniferous interval of the Yucumo Bella Vista Section, where pale colors and low thermal maturation of the o.m. are often observed. Concerning the composition of the organic residues, unstructured o.m. and marine palynomorphs are most common in samples from the Silurian – Early Devonian interval, whereas land-derived plant debris

Sections > / Rock units V	Southern Subandean/Interandean			Cordillera Oriental		Altiplano	Northern Subandean/Interandean										Subtotals *per* rock unit V
	Alarache	Campanario	Sella	Arani	Cochabamba	La Cumbre	Carrasco NE	Yucumo Bella Vista	Tomachi NE	Tomachi SW (Teoponte)	Pelado Anticline	Yuc. Camino Tomachi (Retama – Río Kaka)	Yuc. Arroyo 6 / Río Caripó	Yuc. Río San Miguel	Yuc. Río Carnabalito	Tequeje	
Bala Fm.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**01** *(01)*	**01** *(01)*
Bopi Fm.	–	–	–	–	–	–	–	**01** *(01)*	–	–	–	–	–	–	–	–	**01** *(01)*
Copacabana Fm. (undifferentiated)	–	–	–	–	–	–	–	**03** *(01)*	–	–	–	–	–	–	–	–	**03** *(01)*
"Chorrito" mb. (Cobacabana Fm.)	–	–	–	–	–	–	–	–	–	–	**04** *(01)*	–	–	–	–	–	**04** *(01)*
Kaka Fm.[1] (upper Retama Gp.)	–	–	–	–	–	–	–	**03** *(00)*[1]	–	–	–	–	–	–	–	–	**03** *(00)*
Retama Gp.[2] (undifferentiated)	–	–	–	–	–	–	–	–	**01** *(00)*	–	–	**04** *(01)*[2]	–	–	–	–	**05** *(01)*
Toregua Fm.[3] (lower Retama Gp.)	–	–	–	–	–	–	–	**07** *(00)*[3]	–	–	–	–	–	–	–	–	**07** *(00)*
Undesign. rock unit	–	–	–	–	–	–	–	–	–	–	–	**01** *(00)*	–	–	–	–	**01** *(00)*
Tomachi Fm.[4]	–	–	–	–	–	–	–	**06** *(00)*	**21** *(01)*[4]	–	–	**01** *(00)*[4]	**11** *(00)*[4]	–	**03** *(00)*	**04** *(01)*[4]	**46** *(02)*
Los Monos Fm.	**02** *(00)*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**02** *(00)*
Huamampampa Fm.	**03** *(00)*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**03** *(00)*
Icla Fm. (basal)	**01** *(00)*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**01** *(00)*
Tequeje Fm.	–	–	–	–	–	–	**03** *(01)*	–	–	–	–	–	**12** *(00)*	**02** *(00)*	–	**09** *(00)*	**26** *(01)*
Santa Rosa Fm.	**02** *(01)*	–	–	–	–	–	**05** *(00)*	–	–	–	–	–	–	–	–	–	**07** *(01)*
Tarabuco Fm.[5]	**03** *(01)*	–	**04** *(02)*	–	–	–	**04** *(02)*	–	–	**02** *(00)*	–	–	–	**01** *(00)*[5]	–	–	**14** *(05)*
Kirusillas Fm.	**01** *(00)*	**05** *(00)*	**07** *(04)*	–	–	**01** *(01)*	**12** *(04)*	–	–	**02** *(00)*	–	–	–	**02** *(00)*	–	–	**30** *(09)*
Uncía Fm.	–	–	–	–	**02** *(01)*	–	–	–	–	–	–	–	–	–	–	–	**02** *(01)*
Cancañiri Fm.	–	**01** *(01)*	–	–	–	**01** *(01)*	–	–	–	–	–	–	–	–	–	–	**02** *(02)*
Undesign. rock unit	–	–	–	–	–	**01** *(01)*	–	–	–	–	–	–	–	–	–	–	**01** *(01)*
San Benito Fm.	–	–	–	**01** *(01)*	**02** *(02)*	–	–	–	–	–	–	–	–	–	–	–	**03** *(03)*
Anzaldo Fm.	–	–	–	**06** *(06)*	–	–	–	–	–	–	–	–	–	–	–	–	**06** *(06)*
Enadere Fm.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**03** *(03)*	**03** *(03)*
Sella Fm.	–	**03** *(01)*	**01** *(01)*	–	–	–	–	–	–	–	–	–	–	–	–	–	**04** *(02)*
Subtotals *per* > section	**12** *(02)*	**09** *(02)*	**12** *(07)*	**07** *(07)*	**04** *(03)*	**03** *(03)*	**24** *(07)*	**20** *(02)*	**22** *(01)*	**04** *(00)*	**04** *(01)*	**06** *(01)*	**23** *(00)*	**05** *(00)*	**03** *(00)*	**17** *(05)*	**Total 175** *(41)*

Figure 2. Sample distribution *per* section and rock unit. Sections are grossly arranged from south (left) to north (right). Bracketed figures *in italics* correspond to the amount of *barren samples*. However, some palynologically productive samples also lack biostratigraphic resolution. Indices to rock units as follows: Kaka Fm.[1] – includes one sample misattributed to the Copacabana Fm. in the Yucumo Bella Vista Section; Retama Gp.[2] – includes 2 samples doubtfully assigned to this unit in the Yucumo Camino Tomachi (Retama – Río Kaka) Section; Toregua Fm.[3] – includes 2 samples doubtfully assigned to this unit and another misattributed to the Kaka Formation (all in the Yucumo Bella Vista Section); Tomachi Fm.[4] – includes 2 samples misattributed to the Retama Gp. in the Tomachi Syncline Flank NE Section, and 10 samples misattributed to the Tequeje Fm. in the Yucumo Arroyo Seis / Río Caripó Section (5), Yucumo Camino Tomachi (Retama – Río Kaka) Section (1), and Tequeje Section (4); Tarabuco Fm.[5] – includes one sample doubtfully assigned to this rock unit in the Yucumo Río San Miguel Section.

(mainly miospores and woody/herbaceous phytoclasts) often represents a major organic component of the post-Silurian samples. Nevertheless, indicators of marine paleoenvironment are not uncommon in Middle and Late Devonian samples. In this study they have provided particularly useful biostratigraphic information for Ludlow – Pridoli, Early Devonian, and Givetian – Frasnian strata.

Characteristic shear gashes as described by Arai (2000, 2001) and Arai & Melo (2003), potentially indicative of tectonic disturbances and stratal deformation (*e.g.*, folding and faulting), affect variable proportions of the palynomacerals in samples from at least three Northern Subandean sections: Yucumo Arroyo Seis – Río Caripó, Yucumo Bella Vista, and Yucumo Río San Miguel. The shear imprint consists of a very characteristic, subparallel and *en-échelon* tearing pattern. Individual fractures are commonly eye-shaped, sigmoidal or variably undulated, and may cut across any preexisting structures of the microfossils. These destructive features are often observed in palynomacerals from some highly tectonized Middle and Late Devonian sections of Southern Subandean Bolivia (notably the Sábalo wells), but are not so frequent in the materials investigated herein.

The palynological results obtained from the various rock units in the sixteen sections investigated (Figs. 3-4) are largely in agreement with our previous biostratigraphic conclusions, obtained from partly coincident lithostratigraphic intervals and outcrop regions elsewhere in southern Bolivia (Melo 2000; Melo *in* Miranda *et al.* 2003). Biochronostratigraphic and paleoenvironmental results issued from each individual section are abridged in Figs. 5-18. In summary, the new datings herein point out to the following age spans and/or biozonal attributions *per* rock unit in the geological sections or outcrop areas investigated (units focused in ascending stratigraphic order):

Sella, Anzaldo, Enadere, San Benito and Cancañiri Formations

As stated above, due to the overall barrenness or extremely poor palynological content of the samples analyzed, no biochronostratigraphic information could be obtained from these five units. For this reason, the Ordovician – Early Silurian age range proposed for the same in the Bolivian geological literature (Suárez-Soruco & Díaz-Martínez 1996; Suárez-Soruco 2000; plus references cited therein) could not be confirmed in the present study.

Uncía and Kirusillas Formations

Parts of these two shaly units, investigated herein, are assigned a Ludlow – early Pridoli age span (Late Silurian), mainly on the basis of chitinozoan evidence (Assemblages A?-B *sensu* Grahn & Melo 2003, originally described from the lower Manacapuru and possibly upper Pitinga Formations of the Brazilian Amazon Basin). The Uncía Formation of the Altiplano and Cordillera Oriental regions is currently regarded in the Bolivian literature as a partly sandier equivalent of the Kirusillas Formation of the Subandean / Interandean regions (Suárez-Soruco & Díaz-Martínez 1996, text-figs. 7 and 10; Suárez-Soruco 2000, text-figs. 1.7 and 3.3; Grahn 2002, p. 317). Our dating of the Uncía Formation, based on a single but reliable early Pridoli age determination (sample COCH-01 from the Cochabamba outcrop area, Figs. 3 and 8), does confirm such interpretation. On the other hand, it implies a slightly younger extension of the unit's total age span than suggested by megafossils (Wenlock-Ludlow, after Suárez-Soruco & Díaz-Martínez 1996, p. 194). Likewise, the Ludlow (largely late Ludlow) – early Pridoli age range of the Kirusillas Formation has been once again confirmed by our studies, with varied degrees of accuracy, based on samples from the Alarache, Campanario, Sella, Carrasco Flank NE, Tomachi Flank SW (Teoponte), and Yucumo Río San Miguel Sections (Figs. 3-7, 10, 13, 18). The present results are in good agreement with the most recent palynological datings and correlations of that same rock unit (Cramer *et al.* 1974, reinterpreted and updated by Melo 2000; Grahn 2002; Grahn & Gutiérrez 2001), even though an essentially Ludlow age is suggested by Bolivian palynologists (Lobo-Boneta *et al.* 1976; Limachi *et al.* 1996).

Tarabuco Formation (*s.l.*)

The currently accepted total age span of the sandy / shaly Tarabuco Formation (*s.l.*) is latest Ludlow? / early Pridoli through Lochkovian, *i.e.*, from Late Silurian to earliest Devonian (Limachi *et al.* 1996; Grahn & Gutiérrez 2001; Grahn 2002). Unfortunately this study has provided no biostratigraphic results for the lower intervals of the formation exposed in the Alarache and Sella Sections of southern Bolivia. Higher parts of the same rock unit in the Alarache Section, as well as equivalent strata in the Carrasco Flank NE Section, *i.e.*, the shalier "Río Carrasco Formation" of Bolivian authors (Martínez *et al.* 1971 *apud* Suárez-Soruco & Díaz-Martínez 1996, p. 134), have yielded palynomorphs consistent with (or at least not older than)

Lithostratigraphy		Southern Subandean / Interandean			Cordillera Oriental	
Name	Intervals	*Alarache*	*Campanario*	*Sella*	*Arani*	*Cochabamba*
Los Monos Fm.	lower	early Givetian (eqv. *A. eisenacki / S. biconstricta*)	—	—	—	—
Huamampampa Fm.	undiff.	Devonian undiff. (biozone indet.)	—	—	—	—
	lower	Devonian undiff. (biozone indet.)	—	—	—	—
Icla	basal	pre-late Ems.? (biozone indet.)	—	—	—	—
Santa Rosa Fm.	top / upper	late? Lochkovian (*Emsiensis*)	—	—	—	—
	low./ basal	No results	—	—	—	—
Tarabuco	top / upper	E. Devon.?/L. Sil.? (biozone indet.)	—	late Lochkovian (*U. loboi*)	—	—
	undiff.	early Pridoli ? (bioz.undesig.)	—	—	—	—
	low. /basal	No results	—	No results	—	—
Kirusillas [1] & Uncía [2] Fms. ([1]– at Alarache, Campanario and Sella) ([2]– at Cochabamba only)	top / upper	l. Ludow/e. Pridoli (bioz. undesig.) [1]	—	No results [1]	—	—
	undiff.	—	late Ludlow + (bioz. undesig.) [1]	No results [1]	—	early Pridoli (biozone undesig.) [2]
	lower / basal	—	late Ludlow + (? Chitinoz. Assbl. A) [1]	Ludlow + (bioz. undesig.) [1]	—	—
Barren/Undated Formations: Cancañiri	basal	—	No results	—	—	—
San Benito	various	—	—	—	No results	No results
Anzaldo [3] & Sella [4]	various	—	No results [4]	No results [4]	No results [3]	—

Figure 3. Palynozonation and dating of Paleozoic outcrop sections of the Cordillera Oriental and Southern Subandean / Interandean areas of Bolivia.

the late Ludlow – early Pridoli age span, but without any definite biozonal attribution (Figs. 5, 7). On the other hand, rocks doubtfully identified as "Tarabuco Formation" in the Yucumo Río San Miguel Section (Northern Subandean Bolivia) are within the early Lochkovian *Eisenackitina bohemica* Partial Range Zone (Fig. 18), whereas "true" Tarabuco Formation strata exposed far to the south, in the Sella Section, belong to the late Lochkovian (Early Devonian) *Urochitina loboi* Total Range Zone (Fig. 10). Therefore, those rocks are coeval with Santa Rosa Formation outcrops of the Carrasco Flank NE Section in Northern Interandean Bolivia, where the same biozones are recognized (Figs. 3-4). Another later Lochkovian dating was issued from supposedly "mid-Tarabuco" strata in the Tomachi Flank SW (Teoponte) Section of Northern Interandean Bolivia (Fig. 13), coeval with the *Emsiensis* Morphon Assemblage Zone of the Solimões Basin. These age determinations point out to the marked diachronism of some Paleozoic rock units in the various Bolivian regions (cf. Suárez-Soruco & Díaz-Martínez 1996, p. 220, text-fig. 9). By analogy with our previous biostratigraphic results from the Sella Section (Melo 2000), and considering also a similar situation documented by Limachi *et al.* (1996) in the Sobo-Sobo Section of Southern Interandean Bolivia, it is suggested that Tarabuco Formation samples yielding late Lochkovian chitinozoans and miospores must be from a considerably high stratigraphic position within the formation, presumably lateral to sandier Santa

Rock units	Intervals	La Cumbre	Carrasco NE	Yucumo Bella Vista	Tomachi NE	Tomachi SW (Teoponte)	Pelado Anticline	Yuc. Camino Tomachi	Yuc. Arr. 6 / R. Caripó	Yuc. Río San Miguel	Yuc. Río Carnabalito	Tequeje
Bala	undiff.	—	—	—	—	—	—	—	—	—	—	No results
Bopi	undiff.	—	—	No results	—	—	—	—	—	—	—	—
Copacabana	basal	—	—	Westphalian C + (*S. incrassatus*)	—	—	—	—	—	—	—	—
Copacabana ("Chorrito")	undiff.	—	—	—	—	—	Late Carboniferous (biozone indet.)	—	—	—	—	—
	Kaka Fm. equiv.	—	—	—	—	—	late Viséan (Mag)	—	—	—	—	—
Retama (Kaka)	various	—	—	late Viséan (Mag)	—	—	—	—	—	—	—	—
Retama	undiff.	—	—	—	Early Carb.(?) (bioz. undesig.)	—	—	(?)L. Devon. / l. Vis. (bioz. indet. & Mag?)	—	—	—	—
Retama (Toregua)	various	—	—	late Frasnian + ("V"=BMu, *A. mourai*)	—	—	—	—	—	—	—	—
undesig. unit	indet.	—	—	—	—	—	—	early? Frasnian (*A. mourai*)	—	—	—	—
Tomachi	top / upper	—	—	early Frasnian + (*U. sahar*/*U. defl.*)	early Frasnian (various biozones)	—	—	early? Frasnian (*A. mourai*)	late? Frasnian (?"IV" basal)	—	early Frasnian (*U. sahar*/*U. defl.*)	—
	undiff.	—	—	—	?l. Ems. / Givet. (?FD/AP – TA)	—	—	—	early Givetian + (LLi–Trg = Lem–TA)	—	early Givetian + (up to TA = Trg)	M. Dev. (e.Givet.) (AD+ = Per+)
Tequeje	undiff.	—	Lochkovian undiff. (biozone undesig.)	—	—	—	—	—	e. – l. Lochkov. (*E. bohem.*- *Ems.*)	Lochkovian (?) (biozone indet.)	—	Prag. – early Ems. (Su, *R. magnifica*)
	low./basal	—	Lochkovian undiff. (biozone undesig.)	—	—	—	—	—	—	—	—	e.- l. Lochkovian (up to *Emsiensis*)
Santa Rosa	top / upper	—	late Lochkovian (*U. loboi*)	—	—	—	—	—	—	—	—	—
	lower / basal	—	early Lochkovian (*E. bohemica*)	—	—	—	—	—	—	—	—	—
Tarabuco	various	—	late Ludlow + (biozone undesig.)	—	—	late? Lochkovian (*Emsiensis*)	—	—	—	early Lochkovian (*E. bohemica*)	—	—
Kirusillas	top / upper	—	late Ludlow? + (biozone undesig.)	—	—	l. Ludow? / e. Pridoli (bioz. undesig.)	—	—	—	—	—	—
	undiff.	No results	late Ludlow? + (biozone undesig.)	—	—	—	—	—	—	l. Ludow? / e. Pridoli (Chitin. Assbl. A?-B)	—	—
Cancañiri	undiff.	No results	—	—	—	—	—	—	—	—	—	—
undesig. unit	indet.	No results	—	—	—	—	—	—	—	—	—	—
Enadere	various	—	—	—	—	—	—	—	—	—	—	No results

Figure 4. Palynozonation and dating of Paleozoic outcrop sections of the Bolivian Altiplano (La Cumbre) and Northern Subandean / Interandean areas.

Rosa Formation sections elsewhere. A somewhat diverse interpretation is illustrated, *e.g.*, in the columnar outcrop analysis of the Sella Section provided by PETROBRAS/INTER-EP, according to which the Santa Rosa/Tarabuco boundary is *ca.* 550 m above sample SE-01 (containing *U. loboi*). Most probably, the Lochkovian shales of the Sella, Tomachi Flank SW and possibly also Yucumo Río San Miguel Sections can be correlated with the so-called *cuello pelítico* or Chululuyoj Member[2] of the Tarabuco Formation (Suárez-Soruco & Díaz-Martínez 1996, p. 42) in more central parts of the Subandean region and Cordillera Oriental.

Santa Rosa Formation

This unit has been investigated for this study in only two outcrop sections, Alarache and Carrasco Flank NE, situated respectively in the Southern Subandean and Northern Interandean regions. No chitinozoans have been recorded in the former, probably reflecting the predominance of very proximal marine or even non-marine sedimentary settings in the Alarache area. Here (Fig. 5), only the upper part of the Santa Rosa Formation could be dated by miospores indicative of the later Lochkovian *Emsiensis* Morphon Assemblage Zone (also identified in the Tarabuco Formation). By contrast, chitinozoans occur both in the lower and uppermost parts of the same formation in the Carrasco Flank NE Section (Fig. 7). These are attributed to the early Lochkovian *Eisenackitina bohemica* Partial Range Zone and the *Urochitina loboi* Total Range Zone of late Lochkovian age, respectively. They confirm that this distinctive sandy unit is largely restricted to the Lochkovian, as nowadays accepted by several workers (Racheboeuf *et al.* 1993; Blieck *et al.* 1996; Limachi *et al.* 1996; Melo, 2000). Nevertheless, coeval intervals in some southern Bolivian sections (*e.g.*, Sella) also comprise shalier lithofacies locally attributed to the Tarabuco Formation (see discussion in the preceding item). Grahn (2002) does not exclude a possible extension of the uppermost Santa Rosa strata into the earliest Pragian, but the Emsian extension formerly proposed by others (McGregor 1984; Isaacson & Sablock 1988) is no longer acceptable in the light of more recent palynological evidence.

Icla and Tequeje Formations

Only very poor biostratigraphic results have been obtained from the Icla Formation, in contrast to the new, more conclusive datings of the Tequeje Formation in the present study. Scanty miospore evidence provided by a single basal Icla sample from the Alarache Section (ALA-10) is barely suggestive of Early Devonian, possibly pre-late Emsian age for the same, in view of the exclusive occurrence of small, morphologically simple trilete spores in the local palynoflora (Fig. 5). Indeed, the bulk of the lower Icla Formation is currently assigned a Pragian – early Emsian age span by several authors (Racheboeuf *et al.* 1993; Blieck *et al.* 1996; Melo 2000; Grahn 2002). As concerns the Tequeje Formation of northern Bolivia, chitinozoan-based earliest Devonian datings issued from the Carrasco Flank NE Section are confirmed on the basis of more reliable miospore and chitinozoan evidence, particularly from the Yucumo Arroyo Seis / Río Caripó and Tequeje Sections (Figs. 7, 11, 14). According to Limachi *et al.* (1996, p. 185), the identification of the Tequeje Formation in the Carrasco outcrop section is doubtful because of the unusual sandier lithology prevailing in that area, which is atypical for this pelitic unit, and more reminiscent of the Icla or Huamampampa Formations to the south. However, the Lochkovian[3] dating obtained in this study excludes any possible correlation of the sampled strata with the latter two units, and is rather in agreement with the Lochkovian – Pragian age span determined for the Tequeje Formation in the adjacent Madre de Dios Basin of northern Bolivia (Vavrdová *et al.* 1996). Our present results, issued from three additional Northern Subandean / Interandean sections, further confirm the early Lochkovian to possibly early Emsian total age span of that rock unit (*Eisenackitina bohemica* through *Ramochitina magnifica* chitinozoan Zones, and *Emsiensis* through Su spore Zones; Fig. 4). Where fully developed in northern Bolivian areas, the Tequeje Formation is correlated by some authors with the entire Santa Rosa – Los Monos stratigraphic succession of Southern Subandean localities (Suárez-Soruco & Díaz-Martínez 1996, text-fig. 7). In the present study, however, we adopt the more restricted Early Devonian age span recorded by Vavrdová *et al.* (1996), so that

[2] The Chululuyoj unit is treated as an independent formation by Racheboeuf *et al.* (1993) and Blieck *et al.* (1996), who restricted the Tarabuco Formation to the Late Silurian interval only.

[3] Actually, only an undifferentiated Lochkovian dating is supported by few chitinozoans from the Tequeje Formation samples of the Carrasco Flank NE Section (*Angochitina filosa*, *Cingulochitina ervensis*, *C. serrata*). However, a more restricted late Lochkovian age can be inferred for the same, since they are stratigraphically above uppermost Santa Rosa Formation strata yielding the diagnostic index species *Urochitina loboi* (in sample SC 2-C PL-14 – see Fig. 7).

Middle to Late Devonian strata previously attributed to the Tequeje Formation in at least the Yucumo Arroyo Seis / Río Caripó, Yucumo Camino Tomachi (Retama – Río Kaka) and Tequeje Sections (Figs. 11, 14, 16) are assigned in this paper to the overlying Tomachi Formation. The Tequeje Formation is here envisaged as the northern Bolivian equivalent of the Santa Rosa and lower Icla units of Southern Subandean areas. Additional field works are needed in order to elucidate the nature of the major biostratigraphic hiatus which intervenes between the Early Devonian and Middle to Late Devonian sequences of northern Bolivia, and apparently accounts for the regional absence of much of the Emsian and possibly basal Eifelian.

Outcrop Section: ALARACHE

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
ALA-17 (Los Monos)	Indeterminate (limited palynological data)	Middle Devonian (inferred early Givetian) [2]	Shallow marine (strong i.t.o.m.)
ALA-16 (Los Monos)	*A. eisenacki / S. biconstricta* Zone equivalent [3]	Middle Devonian (early Givetian)	As above (strong i.t.o.m.)
ALA-14 [4] (Huamampampa)	Indeterminate (no age-significant fossils)	Indeterminate	Indeterminate (rare land plant spores present)
ALA-13 [4] (Huamampampa)	As above (no diagnostic fossils)	Devonian (undifferentiated)	Marine (considerable i.t.o.m.)
ALA-12 [4] (low. Huamampampa)	As above (no diagnostic fossils)	As above	Non-marine (?) (marine palynomorphs absent)
ALA-10 [4] (basal Icla)	As above (very limited spore evidence)	Early Devonian (? pre-late Emsian)	Marine (no i.t.o.m. recorded)
ALA-08 (upper Santa Rosa)	*Emsiensis* Morphon Assemblage Zone [5]	Early Devonian (late early /late Lochkovian)	Non-marine (?) (marine palynomorphs absent)
ALA-07 [6] (basal Santa Rosa)	Indeterminate (barren of palynomorphs)	Indeterminate	Non-marine (?) (only land plant clasts recorded)
ALA-05 (top Tarabuco)	As above (no diagnostic fossils)	Early Devonian or older (pre-late Lochkovian?)	Shallow marine (moderate i.t.o.m.)
ALA-04 (Tarabuco)	Biozone undesignated (no zonal or index fossils)	Late Silurian (early Pridoli?)	Marine (no i.t.o.m. recorded)
ALA-02 [6] (lower Tarabuco)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (sample almost devoid of o.m.)
ALA-01 (upper Kirusillas)	Biozone undesignated (no zonal or index fossils)	Late Silurian (late Ludlow / early Pridoli)	Shallow marine (some i.t.o.m.)

Notes:
[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[2] – Age inference based on the dating of the stratigraphically lower sample ALA-16.
[3] – Chitinozoan concurrent range zone of early Givetian age, defined by Grahn *et al.* (2002) in the Paraná Basin (Brazil and eastern Paraguai). Correlation proposed on the basis of accessory species only.
[4] – Samples with poor palynological content (no conclusive age and/or paleoenvironmental determinations).
[5] – Spore zone defined by Rubinstein *et al.* (2005) in the Brazilian Solimões Basin.
[6] – Samples barren of palynomorphs (no biochronostratigraphic determinations possible).

Figure 5. Biochronostratigraphic and paleoenvironmental summary of Alarache Section.

Outcrop Section: CAMPANARIO

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
CAM-07 (Kirusillas)	Indeterminate (no diagnostic fossils)	Silurian (inferred Late Silurian?) [2]	Marine (no i.t.o.m. recorded)
CAM-06 (Kirusillas)	Biozone undesignated (no zonal or index fossils)	Late Silurian (no older than late Ludlow)	As above (no i.t.o.m. recorded, several chits.)
CAM-12 (lower Kirusillas)	As above (akin to Chitinoz. Assembl. A) [3]	As above (no older than late Ludow)	As above (no i.t.o.m. recorded, abund. chits.)
CAM-11 (basal Kirusillas)	Indeterminate (no age-significant fossils)	Indeterminate	As above (only rare marine fossils present)
CAM-10 (basal Kirusillas)	As above (no diagnostic fossils)	Silurian (undifferentiated)	As above (no i.t.o.m. recorded)
CAM-04 [4] (basal Cancañiri)	As above (barren of palynomorphs)	Indeterminate	Indeterminate (no o.m. content)
CAM-03 [5] (top Sella)	As above (no age-significant fossils)	As above	Marine (?) (possible chitinoz. remains present)
CAM-08 [4] (Sella)	As above (barren of palynomorphs)	As above	Indeterminate (no o.m. content)
CAM-01 [5] (Sella)	As above (no age-significant fossils)	As above	Marine (?) (possible chitinoz. remains present)

Notes:
[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[2] – Age inference based on the dating of the stratigraphically lower samples CAM-06 and CAM-12.
[3] – Informal chitinozoan assemblage of late Ludlow age, described by Grahn & Melo (2003) from the lower Manacapuru Formation of the Amazon Basin, northern Brazil. Besides, the chitinozoan fauna of sample CAM-12 is strongly reminiscent of a Late Silurian assemblage reported by us from an Uncía Formation sample of the Cochabamba outcrop area, in the Cordillera Oriental region.
[4] – Samples barren of palynomorphs, and apparently devoid of any o.m. content.
[5] – Samples with poor palynological content (no conclusive age and/or paleoenvironmental determinations).

Figure 6. Biochronostratigraphic and paleoenvironmental summary of Campanario Section.

Outcrop Section: CARRASCO FLANK NE

Sample code [1] & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [2]
SC PL-17 (Tequeje)	Biozone undesignated (limited palynological data)	Early Devonian (Lochkovian undiff.)	Shallow marine (moderate i.t.o.m.)
SC PL-16 [3] (Tequeje)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (almost no organic residue)
SC PL-14R (basal Tequeje)	Biozone undesignated (limited palynological data)	Early Devonian (Lochkovian undiff.)	Shallow marine (considerable i.t.o.m.)
SC 2-C PL-14 (top Santa Rosa)	*Urochitina loboi* Total Range Zone [4]	Early Devonian (late early /late Lochkovian)	As above (strong i.t.o.m.)
SC PL-13 (upper Santa Rosa)	Biozone undesignated (no zonal or index fossils)	Early Devonian (Lochkovian undiff.)	Marine (no i.t.o.m. recorded)
SC PL-12R & PL-11 (low./basal Santa Rosa)	*Eisenackitina bohemica* Partial Range Zone [5]	Early Devonian (early Lochkovian)	As above (no i.t.o.m. recorded, abund. chits.)
SC PL-11R (basal Santa Rosa)	Indeterminate (no age-significant fossils)	Indeterminate	As above (no i.t.o.m. recorded)
SC PL-9 (Tarabuco)	Biozone undesignated (limited palynological data)	Late Silurian (no older than late Ludlow)	As above (no i.t.o.m. recorded)
8-SC 2-C PL-8 (Tarabuco)	Indeterminate (no age-significant fossils)	Indeterminate	As above (no i.t.o.m. recorded)
SC PL-7 [3] & PL-7R [3] (low./basal Tarabuco)	As above (barren of palynomorphs)	As above	Indeterminate (almost no o.m. content)
SC PL-6 (upper Kirusillas)	Biozone undesignated (limited palynological data)	Late Silurian (late Ludlow? or younger)	Marine (no i.t.o.m. recorded)
SC PL-5 [3] (upper Kirusillas)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (no o.m. content)
SC PL-5R, 4, 44R [3], M.4R (Kirusillas)	As above (no age-significant fossils)	As above	Marine (?) (confirmed for M.4R only)
3-SC 2-C PL-3 (Kirusillas)	Biozone undesignated (limited palynological data)	Late Silurian (late Ludlow? or younger)	As above (no i.t.o.m. recorded)
SC PL-M.3R & PL-2 (Kirusillas)	As above (limited palynological data)	Silurian (Late Silurian? for PL-2)	As above (no i.t.o.m. recorded)
SC PL-M.2R (Kirusillas)	Indeterminate (no age-significant fossils)	Indeterminate	As above (no i.t.o.m./ very rare acritarchs only)
SC PL-1 [3] & PL-M.1R [3] (Kirusillas)	As above (barren of palynomorphs)	As above	Indeterminate (almost no o.m. content)

Notes:
[1] – In order to accomodate the large number of samples in this table, those stratigraphically adjacent that share similar biochronostratigraphic and paleoenvironmental attributions are treated collectively on a same line.
[2] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[3] – Samples barren of palynomorphs (no biochronostratigraphic determinations possible).
[4] – Chitinozoan range zone of later Lochkovian age, defined by Volkheimer *et al.* (1986) in NW Argentina, and also recognized (under diverse regional designations) in Bolivian and northern Brazilian basins.
[5] – Global chitinozoan zone of early Lochkovian age, defined by Paris *et al.* (2000).

Figure 7. Biochronostratigraphic and paleoenvironmental summary of Carrasco Flank NE Section. Here, our "Tarabuco" assignments correspond to the "Río Carrasco Formation" of Bolivian authors.

Outcrop Area: COCHABAMBA

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
COCH-01 [Road] [2] (Uncia)	Biozone undesignated (equiv. Chitinozoan Assemblage B) [3]	Late Silurian (early Pridoli)	Marine (some i.t.o.m.)
COCH-02 [Quarry] [2] (Uncia)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (almost no o.m. content)
COCH-07 [Dam] [4] (San Benito)	As above (barren of palynomorphs)	As above	As above (almost no o.m. content)
COCH-05 [Dam] [4] (San Benito)	As above (barren of palynomorphs)	As above	As above (almost no o.m. content)

Notes:
[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[2] – Discrete samples from two distinct outcrop localities (sample COCH-01 is from the Road Outcrop, and COCH-02 from the Quarry Outcrop). Only the former is palynologically productive.
[3] – Informal chitinozoan assemblage of early Pridoli age, described by Grahn & Melo (2003) from the lower Manacapuru Formation of the Amazon Basin, northern Brazil. Besides, the chitinozoan fauna of sample COCH-01 is strongly reminiscent of a Late Silurian assemblage reported by us from a Kirusillas Formation sample of the Campanario Section, in southern Bolivia (CAM-12).
[4] – Samples barren of palynomorphs (no biochronostratigraphic determinations possible), collected from a same geological section (Dam Outcrop). Sample COCH-07 is stratigraphically higher than COCH-05.

Figure 8. Biochronostratigraphic and paleoenvironmental summary of three Cochabamba outcrop sites.

Outcrop Section: PELADO ANTICLINE

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
M-6R [2] ("Chorrito" mb. of Copacabana Fm.)	Mag Zone of northern Brazil [3], and TC-NM zones of W. Europe [4]	Early Carboniferous (late Viséan)	Non-marine (abundant spores and phytoclasts, no marine palynomorphs)
M-5R [2] ("Chorrito" mb. of Copacabana Fm.)	Biozone undesignated (no zonal or index fossils)	Late Carboniferous (undifferentiated)	Shallow marine (very strong i.t.o.m.)
M-3R ("Chorrito" mb. of Copacabana Fm.)	Indeterminate (no age-diagnostic fossils) [5]	Indeterminate	Marine (no i.t.o.m. / flooding surface?)
M-2R [6] ("Chorrito" mb. of Copacabana Fm.)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (sample devoid of o.m.)

Notes:

[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".

[2] – As shown in the table above, current field controls are in disagreement with the biochronostratigraphic results obtained. According to those controls, sample M-6R would be stratigraphically higher than M-5R, but the opposite situation is indicated by their very distinct palynological content (indisputably of Early Carboniferous and Late Carboniferous age, respectively). Miscurated samples or other artifacts could be some of the possible causes of this problem.

[3] – Miospore interval zone of late Viséan age, defined by Melo & Loboziak (2003) in northern Brazilian basins.

[4] – Miospore zones of late Viséan age erected in Western Europe (Neves *et al.* 1972, 1973; Clayton *et al.* 1977, Riley 1993).

[5] – The organic residue of this sample is dominated by tasmanaceans, and seemingly lacks terrestrial elements.

[6] – Sample barren of palynomorphs (no biochronostratigraphic determination possible).

Figure 9. Biochronostratigraphic and paleoenvironmental summary of Pelado Anticline Section.

Outcrop Section: SELLA

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
SE-01 (top? Tarabuco) [2]	*Urochitina loboi* Total Range Zone [3]	Early Devonian (late early /late Lochkovian)	Shallow marine (strong i.t.o.m.)
SE-02 (top? Tarabuco) [2]	Biozone undesignated (no zonal or index fossils)	Early Devonian (?) (Lochkovian? undiff.)	As above (some i.t.o.m.)
SE-04 [4] (lower Tarabuco)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (almost no o.m. content)
SE-05 [4] (lower Tarabuco)	As above (barren of palynomorphs)	As above	As above (almost no o.m. content)
SE-07 [4] (top Kirusillas)	As above (barren of palynomorphs)	As above	As above (very little o.m. content)
SE-08 [4] (upper Kirusillas)	As above (barren of palynomorphs)	As above	As above (very little o.m. content)
SE-09 [4] (Kirusillas)	As above (barren of palynomorphs)	As above	As above (almost no o.m. content)
SE-10 (basal Kirusillas)	Indeterminate (no diagnostic fossils)	Silurian (inferred Late Silurian) [5]	Marine (no i.t.o.m. recorded)
SE-14 (basal Kirusillas)	Biozone undesignated (no zonal or index fossils)	Late Silurian (no older than Ludlow?)	As above (some i.t.o.m.)
SE-13 (basal Kirusillas)	As above (no zonal or index fossils)	As above (no older than Ludlow)	As above (some i.t.o.m.)
SE-11 [4] (basal Kirusillas)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (almost no o.m. content)
SE-18 [4] (Sella)	As above (barren of palynomorphs)	As above	As above (almost no o.m. content)

Notes:

[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".

[2] – Palynological evidence from sample SE-01 suggests a quite high stratigraphic position for the same (as well as for sample SE-02, only *ca.* 10 m below the former), *i.e.*, in the uppermost Tarabuco Formation, close to the base of the overlying Santa Rosa Formation. By contrast, a diverse interpretation is shown in the columnar outcrop analysis of the Sella Section provided by PETROBRAS/INTER-EP.

[3] – Chitinozoan range zone of later Lochkovian age, defined by Volkheimer *et al.* (1986) in NW Argentina, and also recognized (under diverse regional designations) in Bolivian and northern Brazilian basins.

[4] – Samples barren of palynomorphs (no biochronostratigraphic determinations possible).

[5] – Age inference based on the dating of the stratigraphically lower samples SE-14 and SE-13.

Figure 10. Biochronostratigraphic and paleoenvironmental summary of Sella Section (see also Melo 2000).

Huamampampa Formation

The 3 samples analyzed for this study in the Alarache Section, Southern Subandean Bolivia, could not be dated because of their insufficient palynological content and the very poor preservation of the o.m. The maximum age span known for this formation is late Emsian or early Eifelian through possibly earliest Givetian, in areas where it develops partly lateral to the upper Icla sub-unit (Melo 2000; Grahn 2002).

Outcrop Section: TEQUEJE

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
S-4-TE PL-44 (Bala)	Indeterminate (insuffic. palynol. data) [2]	Indeterminate (no age-diagnostic forms)	Non-marine (?) (no marine palynomorphs present)
S-4-TE PL-25 (Tequeje, *sic*) [Tomachi?] [3]	As above (barren of palynomorphs)	As above	Indeterminate (almost no organic residue)
S-4-TE PL-24 (Tequeje, *sic*) [Tomachi?] [3]	Biozone undesignated (no strictly zonal fossils) [4]	Middle Devonian (no older than early Givet.)	Shallow marine (massive i.t.o.m.)
S-4-TE PL-23 (Tequeje, *sic*) [Tomachi?] [3]	As above (no strictly zonal fossils) [4]	Middle Devonian (early Givetian)	As above (massive i.t.o.m.)
S-4-TE PL-22 (Tequeje, *sic*) [Tomachi?] [3]	AD Oppel Zone + (W. Eur.) [5] (= Per Intv. Zone + in Brazil)	Middle Devonian (late Eifel. or early Givet.)	As above (considerable i.t.o.m.)
S-4-TE PL-21 (Tequeje)	Su Interval Zone (W. Eur.) [5] (= upper Ems Intv. Zone of Brazil)	Early Devonian (latest Prag. – early Ems.)	Marine (moderate i.t.o.m.)
S-4-TE PL-20 (Tequeje)	Biozone undesignated (no strictly zonal fossils) [4]	Early Devonian (no older than Pragian)	As above (moderate i.t.o.m.)
S-4-TE PL-19 (Tequeje)	Biozone indeterminate (poor palynological content)	Early Devonian (undifferentiated)	As above (moderate i.t.o.m.)
S-4-TE PL-18 (Tequeje)	*Ramochitina magnifica* Range Zone [6] / ?Su Intv.Z. [5]	Early Devonian Prag.+ (?latest Prag. – e. Ems.)	As above (moderate i.t.o.m.)
S-4-TE PL-17 (Tequeje)	As above [6]	As above (no older than Pragian)	Marine (no i.t.o.m. recorded)
S-4-TE PL-16 (Tequeje)	Biozone undesignated (no strictly zonal fossils) [4]	Early Devonian (no younger than Lochkovian)	As above (no i.t.o.m. recorded)
S-4-TE PL-12 (lower Tequeje)	*Emsiensis* Morphon Assemblage Zone [7]	Early Devonian (late early /late Lochkovian)	As above (moderate i.t.o.m.)
RÍO TEQUEJE PL-12R (lower Tequeje)	As above [7]	As above	As above (moderate i.t.o.m.)
S-4-TE PL-11 (basal Tequeje)	Biozone undesignated (no strictly zonal fossils) [4]	(?) Earliest Devonian (? pre-late Lochkovian)	Marine (no i.t.o.m. recorded)
RÍO TEQUEJE PL-3R (top Enadere)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (only unstructured o.m.)
S-4-TE PL-3 & PL-1 (Enadere)	As above (barren of palynomorphs)	As above	As above (scarce / almost no organic residue)

Notes:
[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[2] – Only land plant clasts and rare, doubtful sporomorphs (unclassifiable, opaque rounded forms) are present.
[3] – The Middle Devonian dating of these four samples (assigned to the Early Devonian Tequeje Fm. by PETROBRAS/INTER-EP field geologists) rather supports their attribution to the younger Tomachi Fm.
[4] – Age determinations based on non-zonal (but age-diagnostic) miospore and marine palynomorph taxa.
[5] – Spore zones defined in Western Europe (Su and AD Zones after Streel *et al.* 1987; Steemans 1989) and Brazil (Ems and Per Zones after Melo & Loboziak 2001, 2003).
[6] – Chitinozoan zone of Pragian age, widely recognized in South America (Lange 1967; Volkheimer et al. 1986; Grahn *et al.* 2000).
[7] – Spore zone defined by Rubinstein *et al.* (2005) in the Brazilian Solimões Basin.

Figure 11. Biochronostratigraphic and paleoenvironmental summary of Tequeje Section.

Los Monos Formation

This rock unit is also exposed in the Alarache Section (Fig. 5). Of the two samples analyzed, only one (ALA-16) has yielded sufficient biochronostratigraphic information, permitting its correlation with the *Alpenachitina eisenacki – Spinachitina biconstricta* Concurrent Range Zone, of early Givetian age (Grahn *et al.* 2002), on the basis of accessory chitinozoan taxa. The other sample, ALA-17, contains an abundant palynoflora, but the spores are so destroyed that only a generalized Middle Devonian dating can be proposed. Elsewhere in southern Bolivia and northwestern Argentina, the Los Monos Formation and its Argentinian equivalent, the Tonono Formation of the Tarija Basin, are now known to range from the latest Eifelian or early Givetian through the early Frasnian (Barreda 1986; Pérez-Leyton 1991; Ottone 1996; Melo 2000 and unpublished data; Grahn 2002).

Tomachi Formation

According to our current usage (explained in a preceding item), the formation's stratigraphic range in northern Bolivian areas can be extended down to Middle and Late Devonian strata formerly assigned to the Tequeje Formation[4]. Moreover, the unit's highest part includes early Frasnian rocks apparently misattributed to the overlying Retama Group in the Tomachi Flank NE Section. Results issued from the

[4] We consider that the Middle Devonian miospore/microphytoplankton assemblage described by Ottone & Rossello (1996) from the Angosto del Beu locality of Northern Subandean Bolivia derives most probably from the lower Tomachi Formation, rather than the Tequeje Formation as believed by those authors. Our palynological results lend definitely no support to the restricted Frasnian age assigned by some authors to the Tomachi Formation (*e.g.*, Suárez-Soruco & Díaz-Martinez 1996, p. 180). Palynological and marine megafossil evidence mentioned by Suárez-Soruco (2000, p. 80) seems to confirm the Middle Devonian age of the basal Tomachi Formation in its own type locality. An early Givetian age is also likely for the unit's base in the Tequeje Section (this paper).

present study, based on a large number of productive samples from 5 outcrop sections in northern Bolivia (Figs. 4, 12, 14-17), point out to a late early Eifelian (Middle Devonian) through early (or early late?) Frasnian minimum age span for the Tomachi Formation. This encompasses at least the Per – BPi zonal range of the Brazilian miospore biozonation (AD – BJ/BM in Western Europe), besides reaching the Frasnian *Angochitina mourai* Partial Range Zone (and very doubtfully the basal part of Phase Zone "IV") at

Outcrop Section: TOMACHI FLANK NE

Sample code [1] & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [2]
S-1-TO PL-30 (Retama Gp., undifferent.)	Biozone undesignated (no strictly zonal fossils)	(?) Early Carboniferous (? Tournaisian)	Uncertain (all marine palynomorphs reworked?) [3]
S-1-TO PL-24 (Retama, sic) [Tomachi?] [4]	*Angochitina mourai* Partial Range Zone [5,6]	Late Devonian (early Frasnian)	Shallow marine [6] (strong i.t.o.m.)
S-1-TO PL-23 (Retama, sic) [Tomachi?] [4]	As above [5,6] (also: BJ-BM & BPi spore zones) [7]	As above	Shallow marine [6] (strong i.t.o.m.)
S-1-TO PL-22 (Tomachi)	*U. saharicum* / *U. deflandrei* [8] (also: *F. pilosa* range zone) [8]	As above	Transgressive marine (considerable i.t.o.m.)
S-1-TO PL-21 (Tomachi)	As above [8] (also: *H. glabra* range zone) [8]	As above	As above (strong i.t.o.m.)
S-1-TO PL-20 (Tomachi)	Biozone undesignated (no strictly zonal fossils)	Middle /Late Devonian [9] (late Givet. – earliest Frasn.)	As above (strong i.t.o.m.)
S-1-TO PL-18 (Tomachi)	As above (no strictly zonal fossils)	Middle Devonian [9] (no younger than late early Givet.)	Shallow marine (strong i.t.o.m.)
S-1-TO PL-17 & PL-15 (Tomachi)	(?)no older than TA Zone [7] (also: no older than Trg Zone) [7]	Middle Devonian (late early or younger Givet.?)	As above (massive i.t.o.m.)
S-1-TO PL-14 (Tomachi)	Biozone undesignated (poor palynological evidence)	Middle Devonian (undifferentiated)	As above (strong i.t.o.m.)
S-1-TO PL-13, 12, 11, 10 (Tomachi)	Indeterminate (palynomorphs rare, absent or non-diag.)	Indeterminate	Shallow marine (variable i.t.o.m., except PL-11)
S-1-TO PL-9, 8, 6, 5 (Tomachi)	Biozone undesignated (no strictly zonal fossils)	Middle Devonian [9] (early Givetian, doubt. PL-5)	As above (variable i.t.o.m.)
S-1-TO PL-4 (Tomachi)	Indeterminate (very poor miospore evidence)	late Early? / Middle Devon. (late Emsian? or younger)	Marine (moderate i.t.o.m.)
S-1-TO PL-3 (Tomachi)	As above (poor palynological evidence)	(?) Middle Devonian (undifferentiated)	Shallow marine (strong i.t.o.m.)
S-4-TE PL-2 (Tomachi)	As above (doubtful chitinoz. evidence)	As above very doubtfully early Givet.	As above (strong i.t.o.m.)
S-4-TE PL-1 (Tomachi)	(?)no older than FD/AP trans. [7] (very poor miospore evidence)	late Early? / Middle Devon. (late Emsian? or younger)	Indeterminate (insufficient o.m. content)

Notes:
[1] – In order to accomodate the large number of samples in this table, those stratigraphically adjacent that share similar biochronostratigraphic and paleoenvironmental attributions are treated collectively on a same line.
[2] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[3] – This sample contains mixed (autochthonous *versus* possibly reworked) palynomorph assemblages.
[4] – The Frasnian dating obtained for these samples (assigned to the Famennian – Early Carboniferous Retama Gp. by PETROBRAS/ ANI field geologists) rather supports their attribution to the older Tomachi Fm.
[5] – Late Devonian chitinozoan zone defined by Grahn *et al.* (2003) in the Brazilian Solimões Basin.
[6] – Determinations based on the assumption that palynomacerals in these samples are not reworked.
[7] – Spore zones defined in Western Europe (FD, AP, TA, BJ and BM Zones after Streel *et al.* 1987) and Brazil (Trg and BPi Zones after Melo & Loboziak 2003).
[8] – Informal marine palynomorph range zones of regional applicability, used by Melo (unpublished data) in the Camiri and Sábalo areas of Southern Subandean Bolivia.
[9] – Age determinations based mainly on accessory marine palynomorph taxa (acritarchs and chitinozoans).

Figure 12. Biochronostratigraphic and paleoenvironmental summary of Tomachi Flank NE Section.

Outcrop Section: TOMACHI FLANK SW (TEOPONTE)

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
S-1-TEO P-1 (Tarabuco)	*Emsiensis* Morphon Assemblage Zone [2]	Early Devonian (late early /late Lochkovian)	Marine (scarce i.t.o.m.)
S-1-TEO PL-7 (Tarabuco)	Indeterminate (no strictly zonal species)	Late Sil. / Early Dev. [3] (Pridoli /Lochkovian age span)	As above (no i.t.o.m. recorded)
TEO PL-2 (Kirusillas)	As above (no strictly zonal fossils)	As above [3]	As above (no i.t.o.m. recorded)
TEO PL-1 (Kirusillas)	Biozone undesignated (limited chitinoz. evidence) [4]	Late Silurian (late Ludlow? / early Pridoli)	As above (no i.t.o.m. recorded)

Notes:
[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[2] – Spore zone defined by Rubinstein *et al.* (2005) in the Brazilian Solimões Basin.
[3] – Age determinations based on non-zonal (but age-diagnostic) marine palynomorph taxa present in these samples, and age constraints issued from the stratigraphically lower sample PL-1.
[4] – Dating based on the presence of chitinozoans *Pterochitina perivelata* and *Angochitina* cf. *filosa*.

Figure 13. Biochronostratigraphic and paleoenvironmental summary of Tomachi Flank SW (Teoponte) Section.

Outcrop Section: YUCUMO ARROYO SEIS / RÍO CARIPÓ

Sample code [1] & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [2]
S-3-CA PL-29 (top Tomachi)	(?) "IV" basal (poor zonal evidence) [3]	Late Devonian [4] (early late? Frasnian)	Shallow marine [4] (strong i.t.o.m.)
S-3-CA PL-25 (Tomachi)	TA Zone of W. Europe [5] & Trg Zone of northern Brazil [6]	Middle Devonian (late early Givetian)	As above (massive i.t.o.m.)
S-3-CA PL-24 (Tomachi)	LLi Interval Zone [6]	As above (no older than early Givet.)	As above (massive i.t.o.m.)
S-3-CA PL-21 (Tomachi)	Lem Zone of W. Europe [5] & LLi Zone of northern Brazil [6]	As above (no older than early Givet.)	As above (massive i.t.o.m.)
S-3-CA PL-20, 19, 17 (Tomachi, except PL-17 [8])	Biozone undesignated (no strictly zonal fossils) [7]	As above (no older than early Givet.)	As above (massive i.t.o.m.)
S-3-CA PL-15, 13 [9], 12 [9] (Tequeje, *sic*) [Tomachi?] [8]	LLi Interval Zone [6]	As above (no older than early Givet.)	As above (massive i.t.o.m.)
S-3-CA P-10 [9,10] (Tequeje)	no older than upper Ems Interval Zone [6]	Early Devonian [10] (Pragian – early Emsian)	As above (moderate i.t.o.m.)
S-3-CA PL-P-9 [10] (Tequeje, *sic*) [Tomachi?] [8]	(?)AD Zone + [5] (= ?Per Zone + [6]) (poor miospore evidence)	late Early/?Mid. Devon. (late Emsian or younger) [10]	As above (considerable i.t.o.m.)
S-3-CA PL-8, 7 [9], 6 [9] (Tequeje)	*Emsiensis* Morphon Assemblage Zone [11]	Early Devonian (late early /late Lochkovian)	As above (strong to moderate i.t.o.m.)
S-3-CA PL-3 [9] (Tequeje)	*Eisenackitina bohemica* [12] & Chitinozoan Assembl. C [13]	As above (early Lochkovian)	As above (moderate i.t.o.m.)
YUCUMO PL-2R [9] (Tequeje)	Biozone undesignated (no strictly zonal fossils) [7]	As above (probably early Lochkovian)	Marine (minor i.t.o.m.)
Varied prefixes: PL-5R [9], PL-1, PL-5 [9], PL-3R [9] (Tequeje)	(?) *Eisenackitina bohemica* [12] & (?) Chitinozoan Assembl. C [13]	As above (probably early Lochkovian)	As above [distal for PL-5R] (minor to no i.t.o.m.)
S-3-CA PL-4 (Tequeje)	Indeterminate (too limited palynol. evidence)	As above (inferred early Lochkovian)	Distal marine (no i.t.o.m. recorded)
YUCUMO ARROYO-6 PL-4R (Tequeje)	Biozone undesignated (no strictly zonal fossils) [7]	As above (early Lochkovian)	As above (no i.t.o.m. recorded)

Notes:

[1] – In order to accomodate the large number of samples in this table, those stratigraphically adjacent that share similar biochronostratigraphic and paleoenvironmental attributions are treated collectively on a same line.
[2] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[3] – Limited miospore evidence for late early Frasnian (basal Phase Zone "IV"). Most other palynomorphs in this sample (particularly marine ones) are likewise consistent with early Frasnian datings.
[4] – Age and paleoenvironmental determinations only valid if most palynomorphs are not reworked.
[5, 6] – Spore zones defined in Western Europe (Streel *et al.* 1987 [5]) and Brazil (Melo & Loboziak 2003 [6]).
[7] – Age determinations based on non-zonal (but age-diagnostic) marine palynomorph taxa.
[8] – The definitely post-early Emsian dating of these samples (assigned to the Early Devonian Tequeje Fm. by PETROBRAS/INTER-EP field geologists) rather supports their attribution to the younger Tomachi Fm.
[9] – Sheared palynomacerals in the organic residue of these samples suggest stratal deformation and/or faulting.
[10] - Miscontrolled/miscurated samples or tectonic inversions are possible causes for this anomalous succession.
[11] - Spore zone defined by Rubinstein *et al.* (2005) in the Brazilian Solimões Basin.
[12] - Partial Range Zone of the global Devonian chitinozoan biozonation defined by Paris *et al.* (2000).
[13] - Informal chitinozoan assemblage described by Grahn & Melo (2003) from the Brazilian Amazon Basin.

Figure 14. Biochronostratigraphic and paleoenvironmental summary of Yucumo Arroyo Seis / Río Caripó Section.

the formation's top. A possible downward extension of the unit's base into the upper Emsian or lower Eifelian, though unlikely, is faintly suggested by very poor palynological evidence from the Tomachi Flank NE Section (sample S-4-TE PL-1) and Yucumo Arroyo Seis / Río Caripó Section (sample S-3-CA PL-9) (Figs. 12, 14). In the latter, a sharp downward passage into indisputable earliest Devonian strata of the underlying Tequeje Formation suggests an intervening unconformity, sedimentary condensation or tectonic boundary between both units. Lastly, the "undesignated rock unit" of the Yucumo Camino Tomachi (Retama – Río Kaka) Section, herein dated as early(?) Frasnian (sample PL-6, *Angochitina mourai* Zone, Figs. 4, 16), probably corresponds to a stratigraphic position within the upper Tomachi Formation. Palynologically, the Tomachi Formation can be regarded as the northern Bolivian equivalent of the Los Monos and possibly lowest Iquiri Formations of Southern Subandean regions. Therefore, the stratigraphic gap verified between the Tequeje and Tomachi Formations probably represents the northern Bolivian analogue of the lower Icla / upper Icla (or Icla / Huamampampa) hiatus farther to the south (Melo 2000).

Toregua Formation and other (undifferentiated) portions of the Retama Group

In the present study, the Toregua Formation and undifferentiated intervals of the Retama Group have been investigated in three northern Bolivian sections: Yucumo Bella Vista, Tomachi Flank NE and Yucumo Camino Tomachi (Retama – Río Kaka) (Figs. 4, 12, 15, 16). The palynological characterization of this stratigraphic interval is rather dubious, because of the apparently conflicting age determinations (Late Devonian in some samples, Early Carboniferous in others). This could result from various causes, including: **(1)** miscurated sampling and other artifacts; **(2)** the massive reworking of Late Devonian palynomorphs into otherwise barren or poorly palyniferous Early Carboniferous sediments; **(3)** the probable

Outcrop Section: YUCUMO BELLA VISTA

Sample code [1] & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [2]
2-B-V PL-11 (Bopi)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (practically no o.m. content)
2-B-V PL-10 (middle Copacabana)	As above (barren of palynomorphs)	As above	As above (practically no o.m. content)
PL-(8) R (basal Copacabana)	*Striomonosaccites incrassatus* Assemblage Zone [3]	Late Carboniferous (probably Westphalian C)	Apparently non-marine (marine palynomorphs absent)
2-B-V PL-8 (basal Copacabana)	Biozone undesignated (no strictly zonal miospores)	As above (no older than Westphalian) [4]	Shallow marine (massive i.t.o.m.)
PL-(8) RR (Copacabana, sic) [Kaka?] [5]	Mag Interval Zone [6]	Early Carboniferous (late Viséan)	Apparently non-marine (marine palynomorphs reworked)
PL-(6) R & 2-B-V PL-5 (Kaka)	As above (inferred for PL-(6) R)	As above (late Viséan)	As above (marine palynomorphs reworked)
2-B-V PL-4 (Kaka, sic) [Toregua?] [7]	Indeterminate (only badly preserved Late Devon. taxa)	Late Devonian [8] (undifferentiated)	Shallow marine [8] (massive i.t.o.m.)
2-B-V PL-3 (Toregua)	Biozone undesignated (only long-ranging Frasnian taxa)	As above [8] (Frasnian undifferentiated)	As above [8] (massive i.t.o.m.)
PL-(-3) R (Toregua)	Phase Zone "IV" of W. Europe [9] & BMu Zone of northern Brazil [6]	As above [8] (late Frasnian)	As above [8] (massive i.t.o.m.)
2-B-V PL-2 & PL-(2) R (Toregua)	*Angochitina mourai* Partial Range Zone [10]	As above [8] (early late? Frasnian)	As above [8] (massive i.t.o.m.)
PL-(1) R & X B-V PL-1 [11] (Toregua?)	Biozone undesignated (no strictly zonal fossils)	As above (Frasnian undifferentiated)	As above (massive to strong i.t.o.m.)
PL-(-3), S-2-B.V. PL-4, PL-5 (upper Tomachi)	*U. saharicum* / *U. deflandrei* [12] (except S-2-B.V. PL-4)	As above (Frasn. undiff., infer. PL-4)	As above [distal for PL-5] (considerable to massive i.t.o.m.)
PL-(-6) R, S-2-B.V. PL-7, PL-(-7) R (upper Tomachi)	As above [12] (except S-2-B.V. PL-7)	As above (early Frasnian) [13]	As above (considerable to strong i.t.o.m.)

Notes:

[1] – In order to accomodate the large number of samples in this table, those stratigraphically adjacent that share similar biochronostratigraphic and paleoenvironmental attributions are treated collectively on a same line.
[2] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[3] – Late Carboniferous miospore zone defined by Playford & Dino (2000b) in the Brazilian Amazon Basin.
[4] – Age inference based on the presence of taeniate saccate pollen grains (see Loboziak *et al.* 1997).
[5] – The late Viséan dating obtained for this sample (assigned to the Late Carboniferous Copacabana Fm. by PETROBRAS/INTER-EP field geologists) rather supports its attribution to the older Kaka Fm.
[6] – Miospore zone defined by Melo & Loboziak (2001, 2003) in the Brazilian Amazon Basin.
[7] – The Late Devonian dating obtained for this sample (assigned to the Early Carboniferous Kaka Fm. by PETROBRAS/INTER-EP field geologists) rather supports its attribution to the older Toregua Fm.
[8] – Age and paleoenvironmental determinations only valid if Devonian marine palynomorphs are not reworked.
[9] – Miospore zone defined by Streel *et al.* (1987) in Western Europe.
[10] – Late Devonian chitinozoan zone defined by Grahn *et al.* (2003) in the Brazilian Solimões Basin.
[11] – Sheared palynomacerals in the organic residue of these samples suggest stratal deformation and/or faulting.
[12] – Informal regional range zone used by Melo (unpubl. data) in the Southern Subandean Camiri and Sábalo areas.
[13] – The early Frasnian dating is supported by the concurrence of typically Frasnian marine microphytoplankton taxa and fairly numerous spores of the *Grandispora* / *Samarisporites* spp. complex.

Figure 15. Biochronostratigraphic and paleoenvironmental summary of Yucumo Bella Vista Section.

miscorrelation of sequences with very distinct ages, lumped together under one same lithostratigraphic designation, or **(4)** tectonic recurrences of Frasnian strata (? Tomachi Formation) within or above the Early Carboniferous sections. A late (early? late) Frasnian age was determined for the Toregua Formation in at least the Yucumo Bella Vista Section (samples PL-(-3) R, 2-B-V PL-2 and PL-(2) R – see Fig. 15), within the *Angochitina mourai* Partial Range Zone and BMu spore Zone (or its Western European equivalent, the basal part of Phase Zone "IV"). In the Tomachi Flank NE Section (sample S-1-TO PL-30, Fig. 12), the undifferentiated Retama Group has yielded some miospores of latest Famennian ("Strunian") to Tournaisian affinity, diluted amidst an overwhelming mass of Late Devonian microphytoplankton and miospores, obviously reworked in spite of their fairly good preservation. Two stratigraphically lower samples in that same section, supposedly belonging to the Retama Group (S-1-TO PL- 23 and PL-24), contain only early Frasnian palynomorphs; hence, they have been tentatively located by us in the underlying Tomachi Formation. Lastly, the Retama Group presents an anomalous palynological succession in the Yucumo Camino Tomachi (Retama – Río Kaka) Section (Fig. 16), where typical Late Devonian palynomorph assemblages (in samples PL-1 and PL-3) overlie an apparently younger interval, *i.e.*, sample PL-5, containing mixed (reworked?) Late Devonian / Early Carboniferous (late Viséan, Mag Zone?) assemblages. Similarly incongruous datings of the Toregua Formation are also found in the Bolivian geological literature, *viz.*: Frasnian through Tournaisian (Beccar-Montaño & Toledo 1990), strictly Early Carboniferous (Suárez-Soruco & Díaz-Martínez 1996), and latest Famennian through either Tournaisian (Vavrdová *et al.* 1996) or Viséan (Suárez-Soruco 2000). The present study failed to identify any *in situ*, typically "Strunian" palynofloras within the Toregua Formation and undifferentitated Retama Group, although some miospores in those units can be as young as Tournaisian or even Viséan.

Outcrop Section: YUCUMO CAMINO TOMACHI (RETAMA – RIO KAKA)

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
PL-1 [2] (Retama Gp., undifferent.) [?]	Indeterminate (typical Late Devon. assembl.)	either Late Devonian or Early Carboniferous [2]	Uncertain: either shallow marine (massive i.t.o.m.) or indet.[3]
PL-3 [2] (Retama Gp., undifferent.) [?]	As above (typical Late Devon. assembl.)	As above [2]	As above [3]
PL-4 (Retama Gp., undifferent.)	Indeterminate (barren of palynomorphs)	Indeterminate	Indeterminate (too poor o.m. content)
PL-5 (Retama Gp., undifferent.)	(?) Mag Interval Zone [4]	(?) Early Carboniferous (? late Viséan)	Possibly non-marine (marine palynomorphs reworked?) [5]
PL-6 (undesignated rock unit)	*Angochitina mourai* Partial Range Zone [6]	Late Devonian (early? Frasnian)	Shallow marine (very strong i.t.o.m.)
PL-7 (Tequeje, *sic*) [Tomachi?] [7]	As above [6]	As above (early? Frasnian)	As above (very strong i.t.o.m.)

Notes:

[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".

[2] – These two samples contain only poorly preserved (but typical) Late Devonian palynomorph assemblages. In view of the probable Early Carboniferous dating issued from the stratigraphically lower sample PL-5 (see below), three possible causes can be envisaged to explain this anomaly: **(a)** inaccurate field control or miscurated samples (*i.e.*, sampling artifacts); **(b)** massive reworking of Devonian palynomorphs into otherwise barren Early Carboniferous sediments; or **(c)** tectonic recurrence of Late Devonian strata above the Early Carboniferous section. Additional studies (preferably including field re-sampling) are needed in order to solve this question.

[3] – Paleoenvironmental interpretations vary in accordance with the hypothesis considered (**b** or **c**, above), since all palynomorphs identified in both samples – including the marine ones – are of Devonian age.

[4] – Early Carboniferous spore zone defined in the Brazilian Amazon Basin by Melo & Loboziak (2003). Nevertheless, the biozone identification is doubtful because potential representatives of the zonal species are too darkened and poorly preserved in sample PL-5.

[5] – The vast majority of palynomorphs in this sample – including all the marine ones – are definitely Devonian (mixed Givetian or early Frasnian through "Strunian"). Their disparate preservation and age significance suggest that they are probably all reworked.

[6] – Late Devonian chitinozoan zone defined by Grahn *et al.* (2003) in the Brazilian Solimões Basin.

[7] – The undoubted Late Devonian dating issued from this sample (originally assigned to the Early Devonian Tequeje Fm. by PETROBRAS/INTER-EP field geologists) rather supports its attribution to the Tomachi Fm.

Figure 16. Biochronostratigraphic and paleoenvironmental summary of Yucumo Camino Tomachi (Retama – Río Kaka) Section.

Outcrop Section: YUCUMO RÍO CARNABALITO

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
CAL PL-3 (Tomachi)	*U. saharicum* / *U. deflandrei* complex range zone [2]	Late Devonian (early Frasnian) [3]	Shallow marine (strong i.t.o.m.)
CAL PL-2 (Tomachi)	TA Zone of W. Europe [4] & Trg Zone of northern Brazil [5]	Middle Devonian (late early Givetian)	As above (massive i.t.o.m.)
CAL PL-1 (Tomachi)	Biozone undesignated (limited chitinozoan evidence)	Middle Devonian (probably early Givetian) [6]	As above (massive i.t.o.m.)

Notes:

[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".

[2] – Informal regional range zone used by Melo (unpubl. data) in the Southern Subandean Camiri and Sábalo areas.

[3] – The early Frasnian dating is supported by the concurrence of typically Frasnian marine microphytoplankton taxa and fairly numerous spores of the *Grandispora* / *Samarisporites* spp. complex.

[4, 5] – Partly coeval spore zones defined in Western Europe (Streel *et al.* 1987 [3]) and Brazil (Melo & Loboziak 2003 [4]).

[6] – Age inference based on the concurrence of two chitinozoan species (*Ramochitina boliviensis*, *R. ramosi*) and the abundance of spores of the *Grandispora* / *Samarisporites* spp. complex.

Figure 17. Biochronostratigraphic and paleoenvironmental summary of Yucumo Río Carnabalito Section.

Kaka Formation (upper Retama Group)

New biostratigraphic results derive mainly from the Yucumo Bella Vista Section of Northern Subandean Bolivia (Figs. 4, 15), in particular from two richly palyniferous samples: 2-B-V PL-5 and PL-(8) RR (the latter mistakenly attributed to the overlying Copacabana Formation by PETROBRAS/INTER-EP field geologists). Beside reworked Devonian (Frasnian – "Strunian") miospores and marine palynomorphs, they also contain a typical late Viséan (Early Carboniferous) palynoflora that characterizes the Mag Interval Zone in the Solimões, Amazon and Parnaíba Basins of northern Brazil (Loboziak *et al.* 1998; Melo & Loboziak 2000, 2003). The miospores also permit good correlation with palynological horizons (Azcuy & Ottone 1987) related to the late Viséan *Nothorhacopteris kellaybelenensis* Megaflora (Azcuy & Suárez-Soruco 1993). In Bolivia, the latter occurs not only in the Kaka Formation of the Northern Subandean

Outcrop Section: YUCUMO RÍO SAN MIGUEL

Sample code & Lithostratigraphy	Biostratigraphy (palynozones)	Geological age	Inferred depositional settings [1]
TEO PL-8 (Tequeje)	Indeterminate (insufficient palynological data)	Indeterminate	Marine (rare chitinoz./microphytopl.)
TEO PL-6 (Tequeje)	As above (too poor chitinozoan evidence)	Early Devonian [2] (?no younger than Lochkovian)	As above (no i.t.o.m. recorded)
TEO PL-5 [3] (Tarabuco?)	*Eisenackitina bohemica* [4] & Chitinozoan Assemblage C [5]	As above (early Lochkovian)	As above (no i.t.o.m. recorded)
TEO PL-4 (Kirusillas)	(?) Chitinozoan Assembl. B [5] (limited chitinozoan evidence)	(?) Late Silurian (? no older than early Pridoli)	As above (no i.t.o.m. recorded)
TEO PL-3 (Kirusillas)	Chitinozoan Assemblages B or A [5] (limited chitinoz. evid.)	Late Silurian (late Ludlow or early Pridoli)	As above (negligible i.t.o.m.)

Notes:
[1] – The abbreviation "i.t.o.m." stands for "inflow of terrestrial organic matter".
[2] – Age inference based only on the presence of rare chitinozoans doubtfully compared to *Angochitina filosa*.
[3] – Sheared palynomacerals occur in the organic residue of this sample, suggesting stratal deformation/faulting.
[4] – Partial Range Zone of the global Devonian chitinozoan biozonation defined by Paris *et al.* (2000).
[5] – Informal chitinozoan assemblages described by Grahn & Melo (2003) in the Brazilian Amazon Basin.

Figure 18. Biochronostratigraphic and paleoenvironmental summary of Yucumo Río San Miguel Section.

regions, but also in the Siripaca Formation of the uppermost Ambo Group, in the Titicaca Lake area of the Bolivian-Peruvian Altiplano (Iannuzzi *et al.* 1998; Suárez-Soruco 2000). Radiometric datings of the Mag Zone are potentially obtainable from the Yucumo Bella Vista Section, where volcanic tuffs up to 12 m thick occur between samples 2-B-V PL-5 and PL-(8)RR, both yielding typical Mag palynofloras (Fig. 15).

"Chorrito" informal member of Copacabana Formation

Four samples from the Pelado Anticline Section (Northern Subandean Bolivia, Figs. 4 and 9) were analyzed herein for strata attributed to this rock unit. Of these, only two – samples M-5R and M-6R – have yielded sufficient palynological results. The former contains a typical Late Carboniferous palynoflora, dominated by saccate pollen grains as expected for the Copacabana Formation (see comments below), in addition to marine acritarchs consistent with such age assignment. The latter includes no marine palynomorphs, but a rich, diversified spore assemblage of late Viséan age (Mag Interval Zone), identical to that of the coeval Kaka Formation (see discussion above). There is a yet unsolved problem involving the mutual stratigraphic relationships of those two samples in the Pelado Anticline Section. The lithostratigraphic term "Chorrito" is not recognized in the latest edition of the Bolivian stratigraphic lexicon (Suárez-Soruco & Díaz-Martínez 1996). Nevertheless, our palynological data apparently indicates that at least two distinct rock units (probably the Kaka Formation and Copacabana Formation *s.s.*), with contrasting age and sedimentary settings, are represented in the sampled interval of the Pelado Anticline Section.

Copacabana Formation

In the present study (Figs. 4, 15), the formation's base exposed in the Yucumo Bella Vista Section of Northern Subandean Bolivia is reliably dated as Westphalian (probably Westphalian C, *i.e.*, Moscovian or Atokan, Late Carboniferous), and correlated with the coeval *Striomonosaccites incrassatus* Assemblage Zone of the Brazilian Amazon Basin (Playford & Dino 2000b). Samples 2-B-V PL-8 and particularly PL-(8) R contain a rich, pollen-dominated palynoflora that includes taeniate monosaccates and bisaccates in addition to far more abundant non-taeniates (Fig. 15). These results are consistent with the more comprehensive Permo-Carboniferous, early Bashkirian through Kungurian age span attributed to the Copacabana Formation in the Bolivian geological literature, on the basis of various fossil groups (Merino-Rodo & Blanco-Rojas 1990; Suárez-Soruco & Díaz-Martínez 1996; Suárez-Soruco 2000). Combined palynological / foraminiferal datings of the Copacabana Formation in the Peruvian part of the Madre de Dios Basin (Wood *et al.* 2002) also confirm a Late Carboniferous (Morrowan-Atokan) through Early Permian (Wolfcampian) total age span for that unit, thus in agreement with our partial results from the adjacent Northern Subandean ranges of Bolivia. A major unconformity or tectonic discontinuity probably intervenes between the Copacabana and Kaka Formations in the Yucumo Bella Vista Section, as indicated by the contrasting palynological signatures of two closely spaced samples (2-B-V PL-8 and PL-(8) RR, respectively late Westphalian and late Viséan).

Bopi and Bala Formations

These two rock units, investigated herein on the basis of single samples from the Northern Subandean Yucumo Bella Vista and Tequeje Sections respectively, turned out unproductive palynologically. Therefore, their respective Late Permian – Early Triassic and Tertiary (late Oligocene – early Miocene) age spans, proposed in the Bolivian geological literature (*e.g.*, Suárez-Soruco & Díaz-Martínez 1996, p. 21, p. 15-16 and text-fig. 14), could not be confirmed in the present study.

CONCLUSION

The results of this work confirm once again that international (Euramerican) and Western Gondwanan (mainly derived from Brazilian and Argentinian basins) miospore zonal schemes, together with updated biostratigraphic data issued from marine palynomorphs (both cosmopolitan and Western Gondwanan), can be successfully applied to the dating of Silurian – Carboniferous rocks of Bolivia. On a basin scale they permit a quite detailed subdivision and chronocorrelation of the vertically recurrent or laterally shifting lithofacies attributed to various Bolivian formations. On a more regional scale, the palynomorph data helps to (re)define and trace major Paleozoic stratigraphic sequences and hiatuses across much of that country. Therefore, palynostratigraphy provides a reliable time-framework for the construction of sequence stratigraphy models, devised to support hydrocarbon exploratory efforts and replace the conventional lithostratigraphic approach still so applied to the Paleozoic of Bolivia.

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