The upper Paleocene-lower Eocene San Francisco de Paula section: Biostratigraphic synthesis

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ABSTRACT: The San Francisco de Paula section is one of the few that permit direct correlations between siliceous and calcareous microfossil zonal schemes near the Paleocene/Eocene boundary. We discuss these correlations, delineate unconformities in the section and discuss the location of the Paleocene/Eocene boundary.

INTRODUCTION

The well known San Francisco de Paula section (Brönnimann and Rigassi 1963), located in the vicinity of La Habana, Cuba, extends from upper Paleocene through lower Eocene. Expected to be continuous across the Paleocene/Eocene boundary and thus seen as a potential GSSP section, it was sampled in detail (in the relevant interval) for integrated magnetobiochemostratigraphic analysis.

Magnetostratigraphic analysis has yielded no results due to overprint, and diagenetic alteration has jeopardized the use of isotopic stratigraphy. However, the section is unusual in permitting direct correlation between calcareous and siliceous microfossil-based zonations. Sanfilippo and Hull (1999, this volume) have partly discussed the correlations between the three planktonic microfossil groups. We summarize here these correlations and add correlation to the benthic foraminiferal framework of Berggren and Miller (1989).

BIOZONAL SUBDIVISIONS

We recognize that the delineation of biostratigraphic subdivisions in the San Francisco de Paula section is ambiguous in some intervals. This is due to a combination of factors such as poor preservation which prevents confident identification of taxa (radiolarians), barren intervals which hampers the precise delineation of biozonal boundaries (radiolarians and calcareous nannofossils), and reworking which may introduce doubt on the location of biozonal boundaries (planktonic foraminifera). Yet, this section is among the few that allow direct correlation between radiolarians, planktonic and benthic foraminifera and calcareous nannofossils. In addition, the correlation between the four groups clearly support the delineation of unconformities in the succession as demonstrated by Aubry (1999, this volume) and Fernández-Rodríguez et al. (1999, this volume).

Radiolarians

Age determination is constrained by a few diagenetically resistant markers, and by the use of the evolutionary development of morphotypes of a given lineage (Sanfilippo and Hull 1999, this volume). Three zones have been identified (zonal scheme of Sanfilippo and Nigrini 1998a). The interval from the base of the section in sample SFP37 to sample SFP30A (in the interval between 43.44m and 20.0 m below the marker bed SFE0) belongs to the *Bekoma campechensis* Zone. The interval between sample SFP15 to SFP 11 (from 1.5 to 1.1m below the marker bed) is assigned to the *Bekoma bidartensis* Zone. The interval between sample SFP10 and SFE16 (from 1.1m below the marker bed) to SFE 16 at the top of the section has been assigned to the *Buryella clinata* Zone.

Planktonic foraminifera

Planktonic foraminifera are abundant at most levels in the San Francisco de Paula section and their preservation varies from poor to good. This has resulted in confident recognition of Zones P4, P5, P6 and P7 (Fernández-Rodríguez et al. 1999, this volume; zonation in Berggren et al. 1995). However, in the interval between samples SFE3 and SFE 12, preservation is poor and strong reworking has hampered delineation of the P6/P7 zonal boundary.

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The interval between the base of the section up to sample SFP 29 is assigned to the upper part of Zone P4. The absence of *Acarinina subsphaerica* and the sporadic distribution of *A. soldadoensis* has prevented recognition of Subzones P4b and P4c defined in Berggren et al. (1995). The interval between sample SFP 28 and SFP 22 is confidently assigned to Zone P5. The interval between sample SFP 21 and SFE 2 is assigned to Subzone P6b, characterized by the co-occurrence of *Morozovella formosa formosa* and *Pseudohasterigerina wilcoxensis.* This assignment is tentative due to the reworking of *Morozovella velascoensis* (whose highest occurrence [HO} defines the top of Zone P5: there is a sharp drop in the abundance of this species between samples SFP 22 and 21) and poor preservation (which may have resulted in the dissolution of *Morozovella aragonensis* whose lowest occurrence [LO] defines the base of Zone P7). The interval between samples SFE 12 and SFE 16 is confidently assigned to Zone P7.

Benthic foraminifera

Benthic foraminifera are unevenly distributed, poorly preserved and diluted by planktonic foraminifera and clastic particles in the San Francisco de Paula section. In general assemblages are highly diversified and many taxa are represented by a few specimens only. They are characteristic of middle to outer bathyal deposition, but comprise few exotic taxa indicative of downslope transport. Zones BB1 and BB2 were identified in the lower and upper part of the section, respectively (Fluegeman 1999, this volume; zonal zcheme of Berggren and Miller 1989).

While the marker species *Angulogavelinella avnimelechi* is rare in the section, *Anomalinoides rubinginosus* was found at only one level and *Neoflabellites jarvisi* was not encountered. The common occurrence of *Stensioina beccariiformis* and *Osangularia velascoensis* was thus used to characterize Zone BB1. Zone BB2 is an interval zone between the HO of *Angulogavelinella avnimelechi* and *Neoflabellites jarvisi* at the base and the LO of *Cibicidoides subspiratus* at the top. Because of the absence or rarity of the marker species whose HOs define the base of the zone, the BB1/BB2 zonal boundary has been delineated between samples SFP 24 and SFP 23, based on the HOs of *Stensionia beccariiformis* and *Osangularia velascoensis* in sample SFP 24. Zone BB2 extends to the top of the section.

Calcareous nannofossils

Except for sample SFP34, all levels sampled in the lower part (below sample SFP 34) of the San Francisco de Paula section were barren of calcareous nannofossils (Aubry 1999, this volume). Calcareous nannofossils occur at almost all levels above sample SFP 23. Preservation is generally poor, particularly in the upper part of the section (above sample SFP 12). With the exception of the upper interval where discoasters are strongly overgrown so that only few specimens can be confidently identified, marker species are common and well preserved, permitting a definitive zonal assignment. Zone NP6 was identified in sample SFP 34. The interval between samples SFP 23 and SFP 13 belongs to Zone NP10, with Subzones NP10a and NP10d extending, respectively, between samples SFP23 and SFP 22 (Subzone NP10a) and SFP21 and SFP 13 (Subzone NP10d). The upper part of the section from sample SFP 12 up to sample SFE 16 belongs to Zone NP12.

BIOSTRATIGRAPHIC CORRELATIONS

Due to both the presence of barren intervals and unconformities, the San Francisco de Paula section is not the "ideal" section that would permit detailed correlation between microfossil groups. Nevertheless, it supports correlations established eslewhere and part of it constitutes the first known record of lower Eocene siliceous sediments in the NP10-P6 zonal interval.

Calcareous microfossils

The correlations observed between calcareous microfossil zonal schemes in the San Francisco de Paula section (text-figure 1) are essentially those observed elsewhere (see Berggren et al. 1995). The HO of *Morozovella velascoensis* (P5/P6 zonal boundary) is located in Zone NP10. The LO of *M. aragonensis* (P6/P7 zonal boundary) lies in Zone NP12. Zone NP 6 correlates with Zone P4. In addition, Zone BB1 correlates with Zone P4 and P5 (partim) whereas Zone BB2 correlates with Zone NP10 to NP12.

Radiolarians

Few deep sea sites have provided the opportunity to correlate zonal schemes based on siliceous microfossils with those based on calcareous microfossils (Sanfilippo and Nigini 1998b). In addition, these authors (1998b, Figure 13.1) have identified an "interval of non-radiolarian bearing sediments" corresponding to the upper part of the *Bekoma bidartensis* Zone, and correlating with calcareous nannofossil Zones NP10, NP11 and NP12 (lower part). The San Francisco de Paula section partly fills this gap. In this section, radiolarian bearing sediments of the *B. bidartensis* Zone correlative with Subzone NP10d were recovered. In addition, the *B. bidartensis/B. clinata* zonal boundary clearly occurs in Zone NP12.

STRATIGRAPHIC INTERPRETATION OF THE SECTION

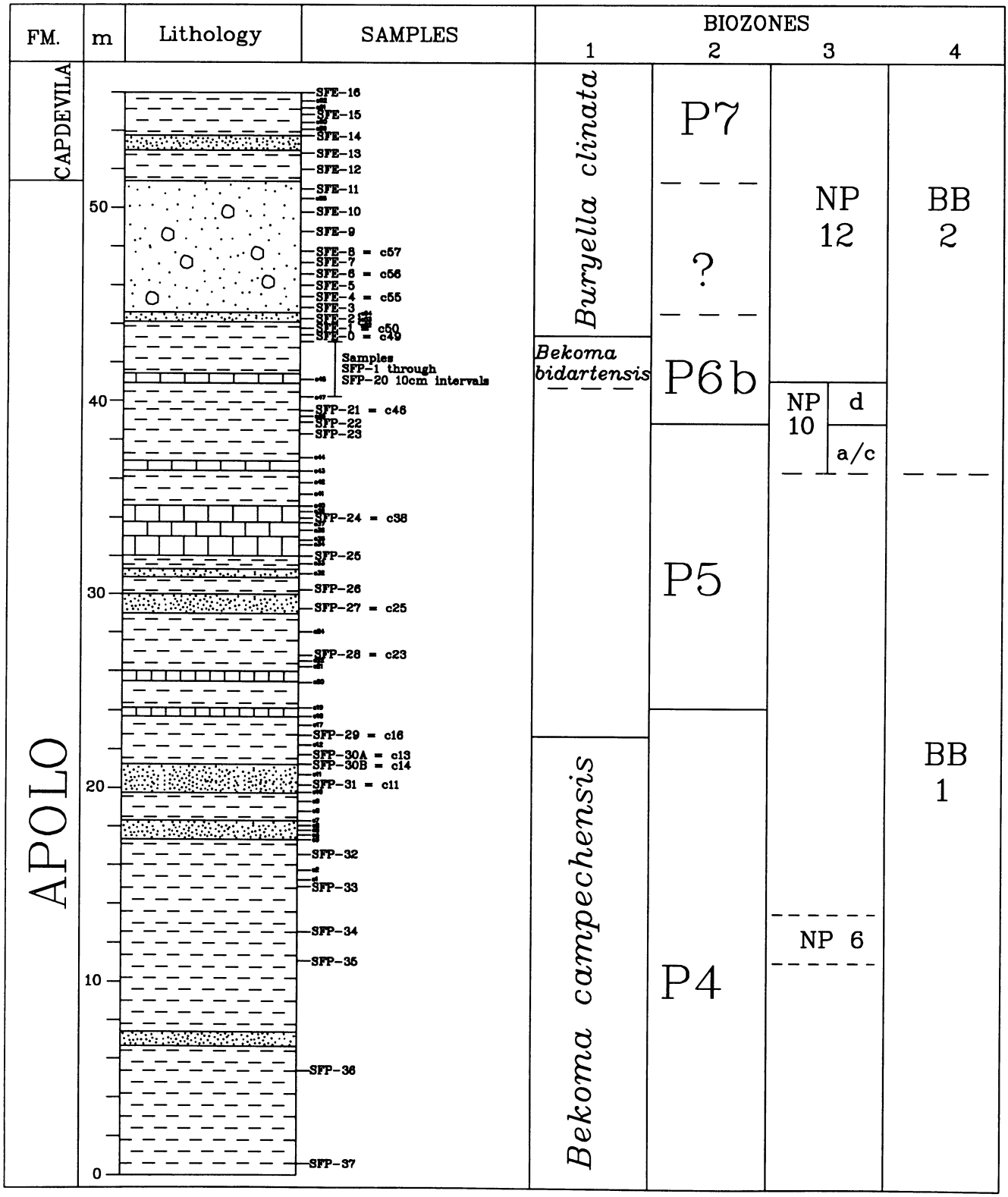
Unconformities

The four microfossil zonal schemes (calcareous nannofossils, planktonic and benthic foraminifera and radiolarians) permit a comprehensive stratigraphic interpretation of the section because the intervals that are barren of different fossil groups do not overlap, or overlap only partially. Of particular interest is the coincidence of biozonal boundaries at some levels, indicative of unconformities. These are discussed by Aubry (1999, this volume) and Fluegeman et al. (1999, this volume).

Three unconformities are clearly delineated:

- Between samples SFP 24 and 23 (between - 3.0m and -2.5m), as indicated by the location at the same level of the BB1/BB2 and the base of Zone NP10. The benthic foraminiferal zonal boundary is defined by the HOs of *Angulogavelinella avnimelechi* and *Neoflabellites jarvisi.* In the scarcity/absence of these taxa, it was taken at the simultaneous HOs of *Stensionia beccariiformis* and *Osangularia velascoensis* in sample SFP 24. It is well established that the HO of *Stensionia beccariiformis* occurs in Zones P5 and NP9 (see discussion in Berggren and Aubry 1998). The stratigraphic gap includes Subzone NP9b (represented in the San Augustine section), and part of Zone NP10a. Based on calcareous nannofossil stratigraphy alone, it is not possible to determine whether the interval between samples SFP23 and 22 belongs to Subzone NP10a or c. Correlation with Zone P5 supports assignment to Subzone NP10a. The hiatus is >0.5 my-long.

- Between samples SFP 22 and 21 (between - 3.0 m and - 2.5 m), as indicated by the absence of Subzone NP10b and NP10c and the location at the same level of the P5/P6b zonal boundary and the base of Zone NP10d. The hiatus is >0.5 my-long.



TEXT-FIGURE 1
Correlation between siliceous and calcareous microfossil biozones in the San Francisco de Paula section. Location of biozonal boundaries given in Table 1. Biozonal frameworks are as follows: (1): radiolarian zones: Sanfilippo et al., 1985, Nishimura, 1987; (2) planktonic foraminifera: P-zones: Berggren et al., 1995; (3) calcareous nannofossils: NP-zones: Martini, 1971, Aubry, 1996; (4) deep benthic foraminifera: BB-zones: Berggren and Miller, 1989.

- Between samples SFP 11 and SFP 10 (between -1.1m and 1.0m). The hiatus includes the uppermost part of Subzone NP10d, Zone NP11 and (at least) the lowermost part of Zone NP12. The hiatus is >0.8 my-long.

The Paleocene/Eocene boundary

The San Francisco de Paula section was sampled because the published literature suggested a continuous record across the Paleocene/Eocene boundary. Until defined by a Global Stratotype Section and Point (GSSP) the Paleocene/Eocene boundary is taken as corresponding to the base of the Ypresian Stage in Northwestern Europe, shown to be essentially correlative with the First Appearance Datum (FAD) of the calcareous nannofossil species *Tribrachiatus digitalis* (Aubry et al. 1996; Aubry 1996).

Due to an unconformity (see above), *T. digitalis,* the marker species for the Total Range Subzone NP10b, does not occur in the San Francisco de Paula section. Thus, the Paleocene/Eocene boundary in the section corresponds to an unconformable contact between samples SFP 22 and 21 and is located about 2.75m below the marker bed at 0m in the section.

An upper Paleocene horizon has become extremely useful for global correlation. In marine sections it is characterized by both the Carbon Isotope Excursion (CIE) and the Benthic Foraminiferal Extinction (BFE) (see Berggren and Aubry 1998 for discussion). We have not been able to generate a reliable isotopic record in the San Francisco de Paula section, but the HO of the *Stensioina beccariiformis* assemblage has been identified between samples SFP 24 and SFP 23. The spacing between sample SFP 24 and SFP 23 is large (2.3 m), which result in the lack of calcareous nannofossil zonal control in this interval. However, complementary samples collected earlier by Gena Fernández-Rodrîguez show that the HO of the *S. beccariiformis* assemblage occurs very close to the level of sample SFP 23 (thus very close to the base of Zone NP10). This indicates that the BFE, and consequently the CIE and the Late Paleocene Thermal Maximum, LPTM, Zachos et al. 1993) are not represented in the San Francisco de Paula section

CONCLUSIONS

Despite the uneven quality of the micropaleontologic record in the San Francisco de Paula, we were able to recognize radiolarian bearing sediments representing an interval not recovered before. Using four microfossil groups, we are able to show the presence of unconformities in the section and to demonstrate that the Paleocene/Eocene boundary corresponds in fact to an unconformable contact.

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TABLE 1
Location of the siliceous and calcareous microfossil biozonal boundaries in the San Francisco de Paula section. Zonal schemes as indicated in caption to Text-figure 1. Average thickness of intervals given in parenthesis. The section was measured from a prominent marker bed labelled as SFP 0, that occurs in the upper part of the section. Samples SFP1 to SFP 37 were taken below the marker bed, samples SFE 1 to 16 above it

<table>
<tr><th>SAMPLES</th><th>LEVELS
(in m)</th><th>RAD-ZONE</th><th>PF-ZONE</th><th>NP-ZONE</th><th>BF-ZONE</th></tr>
<tr><td>SFE 16
to
SFE 12</td><td>+ 12.8 m to
(20.3 m)
+ 7.5 m</td><td rowspan="3">B. clinata
(~13.85 m)</td><td>P7
(~15.80 m)</td><td rowspan="3">NP12
(~13.97 m)</td><td rowspan="8">BB2
(~17.40 m)</td></tr>
<tr><td>SFE 11
to
SFE 3</td><td>+ 6.5 m to
(8.0 m)
+ 1.5 m</td><td>???
(~6.25 m)</td></tr>
<tr><td>SFE 2
to
SFP 10</td><td>+ 1.0 m to
(2.0 m)
- 1.0 m</td><td rowspan="4">P6b
(~4.50 m)</td></tr>
<tr><td>SFP 11
to
SFP 12</td><td>- 1.1 m to
(0.10 m)
- 1.2 m</td><td rowspan="2">B. bidartensis
(~0.50 m)</td></tr>
<tr><td>SFP 13
to
SFP 15</td><td>- 1.25 m to
(0.25 m)
- 1.5 m</td><td rowspan="2">NP10d
(~1.60 m)</td></tr>
<tr><td>SFP 16
to
SFP 21</td><td>- 1.6 m to
(0.9 m)
- 2.5 m</td><td rowspan="3">???
(~17.85 m)</td></tr>
<tr><td>SFP 22
to
SFP 23</td><td>- 3.0 m to
(0.5 m)
- 3.5 m</td><td rowspan="2">P5
(~16.65 m)</td><td>NP10a
(~1.85 m)</td></tr>
<tr><td>SFP 24
to
SFP 29</td><td>- 5.8 m to
(12.8 m)
- 18.6 m</td><td rowspan="3">???
(24.80 m)</td><td rowspan="4">BB1
(~38.84 m)</td></tr>
<tr><td>SFP 30A
to
SFP 33</td><td>- 20.0 m to
(7.30 m)
- 28.30 m</td><td rowspan="3">B. campechensis
(~24.14 m)</td><td rowspan="3">P4
(~24.14 m)</td></tr>
<tr><td>SFP 34</td><td>at - 30.5 m</td><td>NP6
(~2 m)</td></tr>
<tr><td>SFP 35
to
SFP 37</td><td>- 32.35 m to
(11.09 m)
- 43.44 m</td><td>???
(30.00 m)</td></tr>
</table>