

## 27. PLANKTONIC FORAMINIFERAL EVENTS AND STABLE ISOTOPE RECORDS IN THE UPPER MIOCENE, SITE 654<sup>1</sup>

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### ABSTRACT

The late Miocene sediments of the Tyrrhenian ODP Site 654 encompass a deepening sequence which begins with glauconite shallow water sands followed by a rapid transition to deep water sediments and culminates with dolomitic mudstones associated with Messinian evaporites. The sequence compares well with the so-called "Sahelian cycle" and with post-orogenic cycles recognized in peninsular Italy and Sicily. The studied interval, consisting of 55 m thick nannofossil oozes, belongs to the *Globorotalia suterae* subzone and lower part of the *Globorotalia conomiozea* Zone, indicating late Tortonian and early Messinian age, respectively. Biomagnetostratigraphic correlation assigns the Tortonian/Messinian boundary an age of 6.44–6.45 Ma. In addition, six main events have been recognized, based on the range of keeled globorotaliids and coiling direction changes of keeled and unkeeled globorotaliids, which have been correlated to the geomagnetic time-scale. Comparison with North Atlantic sites and land sections of the Guadalquivir basin and northern Morocco provides good correlations with the events documented in these areas. In particular, Event IV, which predates the FO of *Globorotalia conomiozea*, may be used to recognize the Tortonian/Messinian boundary in extra-Mediterranean areas where *G. conomiozea* is missing. Variations in the distribution of different species of *Globigerinoides* are related to changes in the surficial marine environment. Although no clear trends can be recognized on the oxygen and carbon isotope records of *Globigerinoides obliquus*, the parallelism between the occurrence of low salinity species (*G. sacculifer*) and peaks of low  $\delta^{18}\text{O}$  values, as well as that of normal salinity species (*G. obliquus*) and peaks of high  $\delta^{18}\text{O}$  values, suggests strong local changes of environmental conditions. The high amplitude of the fluctuations of  $\delta^{18}\text{O}$  values suggests important variations in the salinity of the Tyrrhenian Sea, related to a rapidly changing water budget. The major feature of the carbon isotope record is a large decrease between 7.0 and 6.95 Ma, which therefore predates the 6.2 Ma global "carbon shift."

### INTRODUCTION

The upper Miocene sequence drilled at Site 654 (40°34.76'N, 10°41.80'E, 2217 m water depth) could be considered as a "text-book" example of a transgressive sequence. Shallow water sediments represented by marine glauconitic sands are followed by nannofossil oozes of deep water environment, as indicated also by benthic foraminiferal assemblages (Shipboard Scientific Party, 1987). The sequence is capped by dolomitic mudstones indicating reduced circulations and severe exchanges with the open ocean. The major aims of this study are: (1) to describe and discuss the grain-size distribution and to correlate it with biostratigraphic results; (2) to recognize the major paleontologic events and to compare them with those documented in Miocene land marine sections from the Mediterranean and Atlantic provinces; (3) to compare the latter events with the oxygen isotope stratigraphy; and (4) to compare the oxygen and carbon isotopic records at Site 654 with similar records of the open ocean well tied to the paleomagnetic time-scale, and to investigate the Mediterranean record of the global "carbon shift" of the late Miocene.

### METHODS

The planktonic foraminifers of 114 samples have been analyzed semiquantitatively, and their distribution is plotted in the range chart of Figure 1. Eighty samples of 20 cm<sup>3</sup> were dried for 6 hr at 60°C, weighted, and then washed through sieves of 500, 200, 125, and 50  $\mu\text{m}$  mesh. The residues were dried and weighted. The values, reported per 100 g of original sample and displayed in Table 1 and Figure 2, have been used for the grain-size distribution except for samples at each 50–52 cm interval and the core catchers. Unfortunately, poor recovery, core deformation due to rotary drilling, strong burrowing, and irregular sampling severely hampered efforts to obtain highly precise results.

Oxygen and carbon isotope analyses have been performed on *Globigerinoides quadrilobatus* and *Globigerinoides obliquus* from 36 different levels. The analytic procedure has been described in Vergnaud Grazzini et al. (this volume). Paired analyses of both species suggest that *G. quadrilobatus*  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  values are higher by about 0.20‰ and 0.23‰, respectively, than those of *G. obliquus*. It was therefore possible to build a more complete record using data from *G. obliquus* and  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  values of *G. quadrilobatus* adjusted by –0.20‰ and –0.23‰, respectively. It is not yet possible to state precisely whether the different isotopic composition of both species depend on different seasonal depth habitat or other specific effects.

### LITHOLOGY AND GRAIN-SIZE DISTRIBUTION

Five major units, numbered 2 to 6, have been recognized within the Miocene sequence (Borsetti et al., this volume).

1. Unit 2, 69.9 m thick (312.16–242.7 mbsf) is characterized by interbedded gypsum and carbonate layers.

2. Unit 3, 36.3 m thick (348.9–312.6 mbsf) is characterized by dolomitic dark shales, suggesting an anoxic environment. Convolute laminations and microfaults have been observed. The first intervals of thin laminated dolomitic mudstone appear at the top of 654A-40R. In this unit (Section 1) planktonic foraminifers become very rare or are absent.

<sup>1</sup> Kastens, K. A., Mascle, J., et al., 1990. *Proc. ODP, Sci. Results*, 107: College Station, TX (Ocean Drilling Program).

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Figure 1. Range chart of the planktonic foraminiferal species at Hole 654A. Note: most of the globorotaliids that have been distinguished might only be phenotypes, but their occurrence may have a paleoenvironmental significance. "Scituliiform" *Globorotalia* (columns 5 and 6) encompass transitional morphotypes. Frequency of the species in the fraction larger than 125  $\mu\text{m}$ :

- A = Abundant—1 out of 2 or 3 individuals is of the species  
 C = Common—1 out of 4–7 individuals is of the species  
 F = Few—1 out of 8–30 individuals is of the species  
 R = Rare—less than 1 individual out of 30 is of the species

Note: *Globigerina quinqueloba* Natland is the dominant species in the fraction smaller than 125  $\mu\text{m}$ ; compared to that of other larger species, its abundances are always significantly higher.

Column:

- 1: sinistral *Neogloboquadrina acostaensis* (Blow)
- 2: dextral
- 3: sinistral *Neogloboquadrina humerosa* Takayanagi and Saito *N. praehumosa* Natori
- 4: dextral
- 5: sinistral *Globorotalia* "scituliiform"
- 6: dextral
- 7: sinistral *Globorotalia ventriosa* Ogniben
- 8: dextral
- 9: sinistral *Globorotalia suterae* Catalano and Sprovieri
- 10: dextral
- 11: sinistral *Globorotalia exserta* Romeo
- 12: dextral
- 13: sinistral *Globorotalia nicolae* Catalano and Sprovieri
- 14: dextral
- 15: sinistral *Globorotalia cibaoensis* Bermudez
- 16: dextral
- 17: sinistral *Globorotalia juanai* Bermudez and Bolli *G. praemargaritae* Catalano and Sprovieri *G. martinezi* Perconig *G. andalusiana* Perconig
- 18: dextral
- 19: sinistral *Globorotalia scitula* (Brady)
- 20: dextral
- 21: sinistral *Globorotalia saheliana* Catalano and Sprovieri
- 22: dextral
- 23: sinistral *Globorotalia sphericomiozea* Walters *G. saphoe* Bizon and Bizon
- 24: dextral
- 25: sinistral *Globorotalia conomiozea* Kennett (Mediterranean form)
- 26: dextral
- 27: sinistral *Globorotalia subconomiozea* Bandy
- 28: dextral
- 29: sinistral *Globorotalia mediterranean* Catalano and Sprovieri
- 30: dextral
- 31: sinistral *Globorotalia conoidea* Walters
- 32: dextral
- 33: sinistral *Globorotalia conoidea* Walters
- 34: dextral
- 35: sinistral *Globorotalia plesiotumida* Blow and Banner *G. merotumida* Blow and Banner
- 36: dextral
- 37: sinistral *Globorotalia limbata* (Fornasini)
- 38: dextral
- 39: dextral *Globorotalia menardii* form 5 Tjalsma
- 40: sinistral *Globorotalia menardii* form 4 Tjalsma
- 41: *Globigerina bulloides* d'Orbigny
- 46: *Globigerina decoraperta* Takayanagi and Saito
- 47: *Globigerina nepenthes* Todd *G. druyi* Akers
- 48: *Orbulina universa* d'Orbigny
- 49: *Dentoglobigerina altispira* (Cushman and Jarvis)
- 50: *Globigerinoides obliquus* Bolli
- 51: *Globigerinoides extremus* Bolli
- 52: *Globigerinoides quadrilobatus* (d'Orbigny)
- 53: *Globigerinoides trilobus* (Reuss)
- 54: *Globigerinoides bulloides* Crescenti
- 55: *Globigerinoides ruber* (d'Orbigny)
- 56: *Globigerinoides sacculifer* (Brady)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
40R-1, 36-38																			
40R-1, 50	R																		
40R-1, 86-89																			
40R-2, 36-39																			
40R-2, 50			R																
40R-2, 86-89																			
40R-3, 36-39																			
40R-3, 50			R																
40R-3, 86-89																			
40R-4, 36-39	R	R																	
40R-4, 50			R																
40R-4, 86-89	R	R																	
40R-5, 36-39			R																
40R-5, 50			R			R													
40R-CC			R																
41R-1, 36-39	F																		
41R-1, 50	R																		
41R-1, 93-95			C																
41R-2, 36-38																			
41R-2, 50			C																
41R-2, 93-95		F		R	R					R									
41R-3, 36-38																			
41R-3, 50			C						F	R									
41R-3, 93-95																			
41R-4, 36-38																		R	
41R-4, 50			C		F				cf		C		C						
41R-4, 92-95																		F	
41R-CC		R																	
42R-1, 36-38	R			R															
42R-1, 50			C		C				R										
42R-1, 82-84			F																
42R-1, 90-92			R			R				R									
42R-2, 36-38			F							C				F					
42R-2, 50			C		C				F										
42R-2, 80-82			F							R									
42R-2, 90-92						R				C									
42R-3, 36-38			C				R			C					R				
42R-3, 50			C							C									
42R-3, 82-84			F							C									
42R-3, 90-92			F							C				F					
42R-4, 36-38			F			F	F								F		F		
42R-4, 50			C		F				C									C	
42R-4, 82-84			R		C	R		R										R	
42R-4, 90-92			F		C			F											
42R-5, 36-38			F															R	
42R-5, 50			C		F				C									C	
42R-5, 82-84	R				C		C												R
42R-5, 90-92			C			C		C	R										

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
40R-1, 36-38																			
40R-1, 50										R									
40R-1, 86-89																			
40R-2, 36-39																			
40R-2, 50						R				R		R		C		F			
40R-2, 86-89										R		R		R					
40R-3, 36-39										R		R		R					
40R-3, 50						cf				R		R		C		F			
40R-3, 86-89										F									
40R-4, 36-39												R		R					
40R-4, 50																			
40R-4, 86-89						R										R	F		R
40R-5, 36-39	C				C					C									
40R-5, 50										R						R	F		
40R-CC					R	R										R			
41R-1, 36-39																			
41R-1, 50		R	R	R								C	C	C					
41R-1, 93-95																			
41R-2, 36-38	F																		
41R-2, 50			R		R					R		C		R				C	
41R-2, 93-95																			
41R-3, 36-38	F	R			F					F		F							
41R-3, 50	R				R					R				C				C	
41R-3, 93-95												R							
41R-4, 36-38	R				R														
41R-4, 50					cf											F	F	F	
41R-4, 93-95	F											F							
41R-CC								R		R									
42R-1, 36-38	R																		
42R-1, 50						cf													R
42R-1, 82-84	F				R														
42R-1, 90-92	C	R	C																
42R-2, 36-38	R					R						C							
42R-2, 50						cf				R							F	F	
42R-2, 80-82	C											C							
42R-2, 90-92	R											F	R						
42R-3, 36-38			R									C							
42R-3, 50						cf				C		C		C		R		C	
42R-3, 82-84																			
42R-3, 90-92																			
42R-4, 36-38																			
42R-4, 50																			
42R-4, 82-84																			
42R-4, 90-92																			
42R-5, 36-38																			
42R-5, 50																			
42R-5, 82-84																			
42R-5, 90-92																			





	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
45R-1, 50			C		C				C										
45R-1, 61-63	R						C												
45R-1, 90-92	F						C												
45R-2, 32-34							R												
45R-2, 50			R		C		C		cf							cf			
45R-2, 61-63							F												
45R-2, 90-92							F												
45R-3, 32-34	R						C												
45R-3, 50			R		C		R		cf							cf			
45R-3, 61-63	R						C												
45R-3, 90-92							C												
45R-4, 32-34	C						C											F	
45R-4, 50			C		R	C													
45R-4, 61-63							C												
45R-4, 90-92	F						C											F	
45R-5, 32-34	F				R	R													
45R-5, 50			R		R														
45R-5, 61-63	R		R		F	R	F	R											
45R-5, 90-92					R														
45R-6, 32-34					R														
45R-6, 50			R		C														
45R-6, 61-63	R																		
45R-6, 90-92	R						R	R											

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
45R-1, 50												cf					R		C
45R-1, 61-63																			
45R-1, 90-92																	R		
45R-2, 32-34																			
45R-2, 50																			
45R-2, 61-63																			
45R-2, 90-92																			
45R-3, 32-34																			
45R-3, 50	R																		
45R-3, 61-63																			
45R-3, 90-92																			
45R-4, 32-34																			
45R-4, 50	R																		
45R-4, 61-63																			
45R-4, 90-92																			
45R-5, 32-34																			
45R-5, 50	C																		
45R-5, 61-63																			
45R-5, 90-92																			
45R-6, 32-34																			
45R-6, 50	R																		
45R-6, 61-63	R																		
45R-6, 90-92																			

	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
45R-1, 50			C		R		R	C		F		C	C	R	R			
45R-1, 61-63		C	R			F	R		R		F	F						
45R-1, 90-92		R	R			F	R		R		F	C						
45R-2, 32-34			R				R		R		F	C						
45R-2, 50			R				R		F	F	F	F		R				
45R-2, 61-63			C				F				C	C						
45R-2, 90-92			F				R		F	F	F	C						
45R-3, 32-34			F				R		F	F	C	C						
45R-3, 50			F	R			R		C		F	F						
45R-3, 61-63			F	R	R		R		C		F	F			F			
45R-3, 90-92			C	R					C		R	C	R		R		F	
45R-4, 32-34			F						F	C	F	A					C	
45R-4, 50			C		R	R	C		C		F	F	R	R	R		R	
45R-4, 61-63			F	R		F			C		F	F	R					
45R-4, 90-92									F	C	F	C					F	
45R-5, 32-34			C				R		F		C	R	R					
45R-5, 50			F	R		R		R	F		C	R	R	R	R			
45R-5, 61-63			R				F		R		C	R	R					
45R-5, 90-92									R		R	R				R	R	
45R-6, 32-34											R						R	
45R-6, 50			C		R	R	C		C		C	C	R	R	R		C	
45R-6, 61-63									R		R						R	
45R-6, 90-92			R	R			R		R		R						R	

Figure 1 (continued).

3. Unit 4, 55.0 m thick (403.9–348.9 mbsf) starts with a fining upward sequence which culminates at 391.6 mbsf (654A-44R-4, 32–34 cm) with sediments finer than 125  $\mu\text{m}$ . Sediments finer than 200  $\mu\text{m}$  occur at 402.7 mbsf (654A-45R-5, 32–34 cm) but from 401 mbsf (654A-45R-4, 90–92 cm) up to 396.6 mbsf (654A-44R-5, 80–82 cm), the sediments get coarser. Sediments finer than 200  $\mu\text{m}$  occur again at 393.1 mbsf (654A-44R-5, 32–34 cm). This sequence, with sediments passing from shallow water sands to deep water nannofossil oozes, characterizes a prograding transgression. Sediments finer than 200  $\mu\text{m}$  occur again at 390.1 mbsf (654A-44R-3, 32–34 cm). From 390.1 to 386.8 mbsf, the sediments are getting coarser; at 384 mbsf their grain-size ranges from 125 to 50  $\mu\text{m}$  (Fig. 2). The strong bioturbation throughout both intervals points to a sediment redistribution

Table 1. Weights of original dried samples and sieved residues.

Hole 654A sample	Weight of original sample (g)	Weight of each sieved residue per 100 g of original sample (g)			
		500 μm	200 μm	125 μm	50 μm
40R-1, 36-39	22.90	0.712	0.148	0.066	0.279
40R-1, 86-89	30.52	0.170	0.138	0.052	0.318
40R-2, 36-39	24.29	0.000	0.144	0.161	0.852
40R-2, 86-89	23.38	0.000	0.304	0.197	0.868
40R-3, 36-39	21.61	0.000	0.444	0.426	1.185
40R-3, 86-89	19.36	0.000	0.336	0.165	0.971
40R-4, 36-39	21.12	0.000	0.270	0.360	1.359
40R-4, 86-89	23.19	0.000	0.276	0.397	1.419
40R-5, 36-39	22.13	0.000	0.601	0.407	1.753
41R-1, 36-39	21.18	0.000	0.227	0.293	2.682
41R-1, 93-95	20.04	0.000	0.349	0.215	1.487
41R-2, 36-39	18.01	0.000	0.328	0.439	1.949
41R-2, 93-95	17.34	0.000	0.138	0.063	0.496
41R-3, 36-38	11.06	0.000	0.353	0.922	1.374
41R-3, 93-95	18.54	0.000	0.318	0.210	0.588
41R-4, 36-38	17.83	0.000	0.780	0.426	1.644
41R-4, 93-95	21.96	0.000	0.328	0.246	1.307
42R-1, 90-92	13.60	0.000	0.794	0.507	2.574
42R-2, 36-38	10.35	0.000	0.957	0.792	4.165
42R-2, 80-82	21.22	0.000	0.448	0.401	1.423
42R-2, 90-92	19.07	0.000	0.608	0.435	1.893
42R-3, 36-38	17.60	0.000	0.744	0.443	2.523
42R-3, 82-84	15.65	0.000	0.556	0.294	1.885
42R-3, 90-92	16.27	0.000	0.676	0.436	2.243
42R-4, 36-38	18.34	0.000	0.562	0.916	3.271
42R-4, 82-84	16.39	0.000	0.262	0.250	1.477
42R-4, 90-92	18.01	0.000	0.283	0.183	1.277
42R-5, 36-38	17.81	0.000	0.376	0.410	1.842
42R-5, 90-92	12.28	0.000	0.285	0.293	1.783
42R-6, 36-38	13.38	0.000	0.239	0.351	2.130
43R-1, 34-36	22.01	0.000	0.568	0.509	2.044
43R-1, 60-62	17.27	0.052	0.492	0.307	2.641
43R-1, 92-94	17.01	0.000	0.476	0.335	1.817
43R-2, 34-36	16.21	0.000	0.432	0.469	2.116
43R-2, 60-62	16.62	0.000	0.644	0.427	1.649
43R-2, 92-94	16.13	0.000	0.577	1.073	3.180
43R-3, 34-36	15.65	0.000	0.307	0.435	1.994
43R-3, 60-62	19.25	0.000	0.390	0.395	2.041
43R-3, 92-94	16.98	0.000	0.436	0.406	1.643
43R-4, 34-36	16.53	0.000	0.387	0.653	2.788
43R-4, 60-62	11.42	0.000	0.359	0.525	3.379
43R-4, 92-94	17.18	0.000	0.501	0.215	3.050
43R-5, 34-36	19.65	0.000	0.544	0.529	2.381
43R-5, 60-62	14.05	0.000	0.693	1.338	2.976
43R-5, 92-94	19.42	0.000	0.731	2.507	18.093
44R-1, 32-34	15.435	0.000	1.289	0.777	7.535
44R-1, 80-82	18.07	0.000	0.515	1.079	3.857
44R-1, 92-94	16.96	0.000	0.501	1.167	4.245
44R-1, 80-82	18.07	0.000	0.515	1.079	3.857
44R-1, 92-94	16.96	0.000	0.501	1.167	4.245
44R-2, 32-34	16.60	0.000	0.867	1.548	5.667
44R-2, 80-82	19.05	0.000	0.572	0.604	3.805
44R-2, 92-94	16.16	0.000	0.408	0.495	2.994
44R-3, 32-34	18.14	0.000	0.226	0.391	1.858
44R-3, 80-82	17.51	0.000	0.183	0.354	2.649
44R-3, 92-94	18.61	0.000	0.167	0.258	21.321
44R-4, 32-34	16.46	0.000	0.000	0.000	0.936
44R-4, 80-82	18.43	0.000	0.000	0.109	0.825
44R-4, 92-94	16.16	0.000	0.087	0.099	0.972
44R-5, 32-34	17.46	0.000	0.000	0.115	0.870
44R-5, 80-82	19.56	0.000	0.000	0.077	1.109
44R-5, 92-94	16.70	0.000	0.060	0.078	1.623
44R-6, 32-34	18.39	0.000	0.043	0.098	1.104
44R-6, 80-82	19.97	0.000	0.316	0.270	2.724
44R-6, 92-94	17.08	0.000	0.381	0.387	3.162
45R-1, 32-34	16.94	0.000	0.236	0.337	1.871
45R-1, 61-63	16.84	0.000	0.433	0.724	4.090
45R-1, 90-94	16.07	0.000	0.224	0.436	4.057
45R-2, 32-34	15.31	0.000	0.346	0.633	3.775
45R-2, 61-63	14.82	0.000	0.490	0.823	4.648
45R-2, 90-92	19.58	0.000	0.541	0.837	4.580
45R-3, 32-34	18.26	0.000	0.471	0.471	4.041
45R-3, 61-63	16.74	0.000	0.323	0.603	4.497
45R-3, 90-92	16.87	0.000	0.688	1.037	5.715
45R-4, 32-34	16.11	0.000	0.925	1.098	5.026
45R-4, 61-63	15.52	0.084	1.056	1.997	4.953
45R-4, 90-92	14.81	0.277	1.465	1.884	9.661
45R-5, 32-34	18.43	0.000	0.966	0.760	9.864
45R-5, 61-63	19.76	0.167	1.447	1.305	4.539
45R-5, 90-92	14.53	0.303	1.597	6.423	5.803
45R-6, 32-34	20.49	1.767	14.104	11.859	28.136
45R-6, 61-63	21.70	2.843	11.335	13.970	31.106
45R-6, 90-92	21.34	1.579	8.866	12.667	18.740

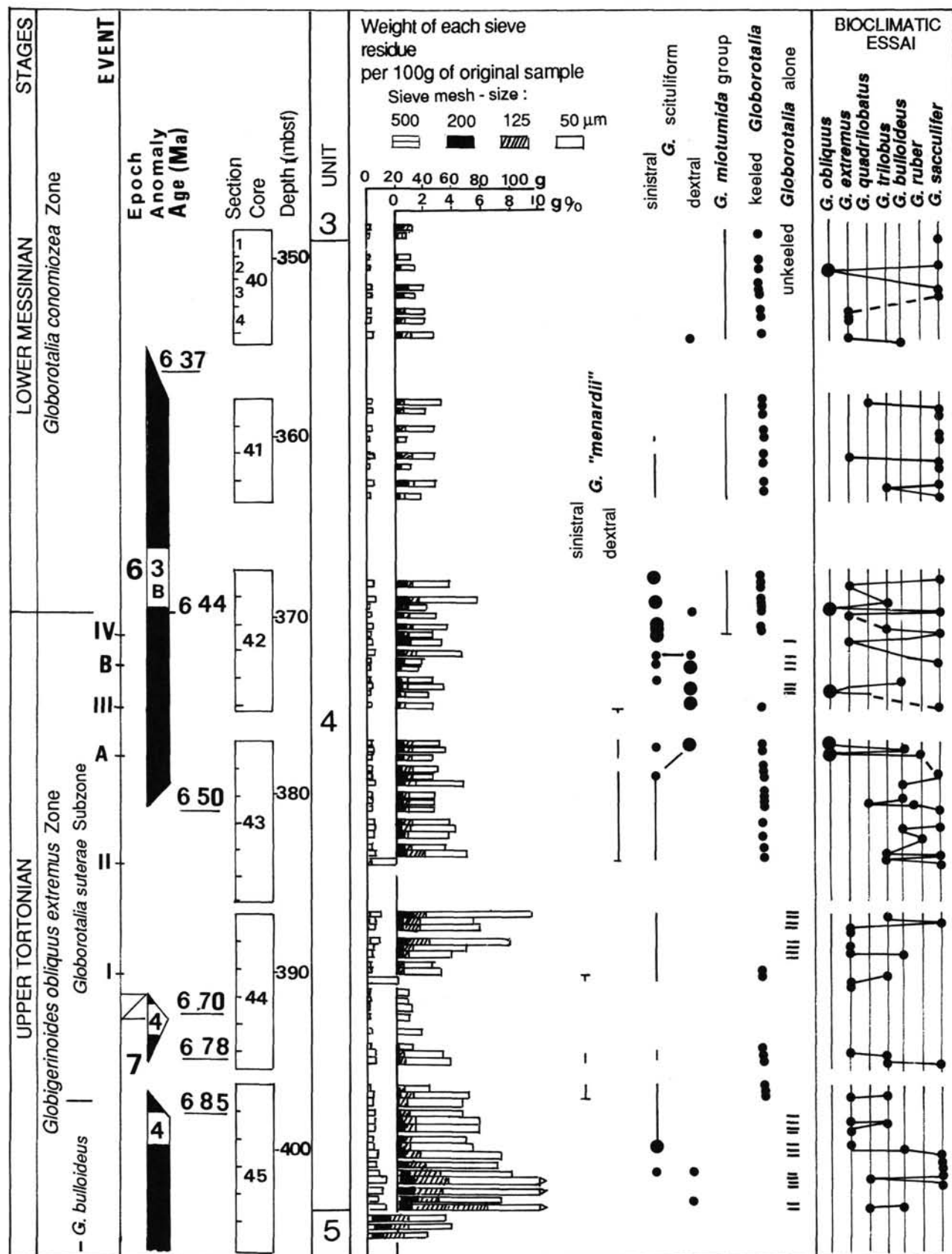


Figure 2. Stratigraphic subdivisions at Site 654 (on the left). Grain-size percentages per 100 g of sediment. Major planktonic events. The bioclimatic "curve" is based on the presence of species of *Globigerinoides* on the right). The points indicate the "warmest" species occurring in each sample, the species ranking from the coolest (on the left) to the warmest (on the right).

through a local or a contour current rather than to a turbiditic origin. Because of their larger size (usually over 125  $\mu\text{m}$ ), keeled globorotaliids are absent. The rest of Unit 4 shows only a slight upward grain-size decrease. This unit yields the most diversified and better preserved foraminiferal assemblages in which the benthic assemblage is characterized by epibathyal forms.

4. Unit 5, 11.8 m thick, (415.7–403.9 mbsf) consists of fine glauconitic sand with bioturbation. It contains large benthic foraminifers (*Operculina* and some Ostreid-rich levels, both suggesting a deposition in a near-shore deltaic environment. This unit passes to the nannofossil ooze of Unit 4 toward the top. The boundary between Units 5 and 4 identified in 654A-45R-5, 145 cm (Borsetti et al., this volume), is clearly characterized by an abrupt decrease of the sand fraction (Fig. 2).

5. Unit 6, 8.1 m thick (473.8–415.7 mbsf) consists of a conglomerate underlain and is overlain by red beds which do not contain any age-diagnostic fauna and may be related to a continental environment.

### PLANKTONIC FORAMINIFERAL EVENTS

Planktonic foraminifers are abundant in Units 4 and 5 but provide a detailed stratigraphy in Unit 4 only. The entire interval belongs to the *G. obliquus extremus* and *G. conomiozea* Zones (Iaccarino and Salvatorini, 1982; Iaccarino, 1985). The late Tortonian *G. obliquus extremus* Zone ranges from the base of Unit 4 (654A-45R-5, 45 cm) up to 369.9 mbsf (654A-42R-2, 72 cm) with *G. suterae* Subzone clearly recognizable from 396.9 mbsf (654A-45R-1, 50 cm) on the base of the FO of typical specimens of *G. suterae*. The interval below 396.9 mbsf yields only forms transitional to *G. suterae*, making the assignment to the *G. suterae* Subzone not totally proved. The Messinian *G. conomiozea* Zone based on the FO of the zonal marker is detectable from 369.6 mbsf (654A-42R-2, 70–72 cm) (Shipboard Scientific Party, 1987). This zone is inferred to extend up to the laminated dolomitic mudstone, because its upper boundary defined by “the coiling shift from sinistral to dextral” of *Neoglobobulimina acostaensis* (Iaccarino and Salvatorini, 1982; Iaccarino, 1985) has not been detected. Rare dextral specimens of *G. mediterranea* first occur at 654A-43R-1, 50–52 cm, slightly below the Tortonian/Messinian boundary equated to the base of the *G. conomiozea* Zone.

Additional events, based on distribution and coiling changes of globorotaliids have been reported on Figure 2. They are summarized together with other events described elsewhere in this volume, as follows:

Depth (mbsf)	Core-section, interval (cm)	Event	Age (Ma)
348.9	40R-1, 7–5	= Top of unit 4 (Borsetti et al., this volume)	
357.34	40R-CC, 13–15	← Top of chron 6n (3B) (Channell et al., this volume)	6.37
358.31	41R-1, 50–52		
369.63	42R-2, 72	= FO <i>G. conomiozea</i> (Shipboard Scientific Party, 1987)	6.44
371.23	42R-3, 82–84	← Entry of sinistral <i>Globorotalia</i> of the <i>G. miotumida</i> lineage = Event IV	6.45
371.31	42R-3, 90–92		
373.77	42R-5, 36–38	← sinistral unkeeled “scituliiform” <i>Globorotalia</i> dextral = Event B	6.46
374.23	42R-5, 82–84		
374.31	42R-5, 90–92	← LO dextral keeled <i>Globorotalia</i> = Event III	6.47

Depth (mbsf)	Core-section, interval (cm)	Event	Age (Ma)
375.27	42R-6, 36–38		
377.71	43R-1, 60–62	← dextral unkeeled “scituliiform” <i>Globorotalia</i> sinistral = Event A	6.48
378.03	43R-1, 92–94		
379.78	43R-2, 117–119	← Base of chron 6n (3B) (Channell et al., this volume)	6.50
380.95	43R-3, 83–86		
383.71	43R-5, 60–62	← Entry of dextral keeled <i>Globorotalia</i> = Event II	6.56
384.03	43R-5, 92–94		
	43R-5, 92	= FAD <i>Amaurolithus tricorniculatus</i> fide C. Müller, this volume	
389.23	44R-2, 92–94	← LO of sinistral keeled <i>Globorotalia</i> (in situ or reworked?) = Event I	6.7
390.13	44R-3, 32–34		
391.63	44R-4, 32–34	= Sediment grain size smaller than 125 $\mu\text{m}$	
391.07	44R-3, 126–128	← Top of chron 7n1 (4) (Channell et al., this volume)	6.78
392.71	44R-4, 140–142		
393.73	44R-5, 92–94	← Disappearance or last occurrence (LO)? of sinistral keeled <i>Globorotalia</i> = Event I?	?6.7
394.63	44R-6, 32–34		
392.71	44R-4, 140–142	← Base of chron 7n1 (4) (Channell et al., this volume)	6.78
395.39	44R-6, 108–110		
396.81	45R-1, 40–42	← Top of chron 7n2 (4) (Channell et al., this volume)	6.85
398.41	45R-1, 50–52		
399.90	45R-3, 50	= FO of <i>Globorotalia suterae</i>	
403.9	45R-5, 145	= Base of unit 4 (Borsetti et al., this volume)	

Events which are related to keeled globorotaliids are indicated with roman numbers, events related to unkeeled globorotaliids are indicated with capital letters. All events have been correlated to the geomagnetic time-scale (Berggren et al., 1985) and their interpolated ages have been calculated using those proposed by Channell et al. (this volume).

Event I. This event is defined by the exit of sinistral keeled *Globorotalia* including the *G. plesiotumida*-*G. merotumida* group, *G. menardii* form 4 of Tjalsma (1971) and Zachariasse (1975), and *G. menardii* group 1 of Sierro et al. (1987). This event is not clearly detectable. In fact sinistral keeled globorotaliids occur discontinuously from 393.7 mbsf (654A-45R-5, 90–92) up to 390.13 mbsf (654A-44R-3, 80–82 cm). The absence of sinistral keeled globorotaliids in Core 654A-44R (Sections 4 and 5) is probably due to resedimentation processes which gave origin to sediments too fine (<125  $\mu\text{m}$ ) to yield those foraminifers. Therefore, it is not excluded that reappearance of this group of globorotaliids between 654A-34R-3, 92–94 cm, and 654A-44R-3, 80–82 cm, could be due to reworking.

Event II. This event is characterized by the arrival of dextral keeled *Globorotalia* including *G. cultrata* group, *G. menardii* form 5 of Tjalsma (1971), Zachariasse (1975) and *G. menardii*



group 2 of Sierro et al. (1987). This event occurs at 389.7 mbsf (654A-43R-5, 60–62 cm). This group of globorotaliids, which have flatter profile, slightly more evolute spire and more open umbilicus in comparison with the previous ones, range up to 374.31 mbsf (654A-42R-5, 90–92 cm) where they reduce drastically in number (Event III).

Event A. This event is defined by the change of sinistral to dominant dextral coiling direction of the unkeeled "scituliiform" globorotaliids (including *G. cibaoensis*, *G. janaei*, *G. premargariatae*, *G. ventriosa*, *G. suterae*, *G. exserta*). This event occurs at 377.7 mbsf (654A-43R-1, 60–62 cm) within the range of the dextral keeled globorotaliids.

Event B. This event is characterized by the change of dextral to dominantly sinistral coiled unkeeled "scituliiform" globorotaliids occurring at 373.7 mbsf (654A-42R-3, 36–38 cm). This group remains consistently sinistral up to the top of the sequence. Rare specimens of dextral forms occur at 361.18 mbsf (654A-41R-3, 36–38 cm) and at 354.7 mbsf (654A-40R-5, 50 cm).

Event IV. This event consists of a sudden increase in number of left coiled planoconvex keeled globorotaliids of the *G. miotumida* group of Sierro (1985) or *G. dali* Tjalsma (1971) which replace dextral keeled *Globorotalia*. This event, occurring at 371.2 mbsf (654A-42R-3, 82–84 cm) predates the FO of *G. conomiozea* at 654A-42R-2, 70–72 cm. This sudden increase could either reflect a local Mediterranean bloom of keeled globorotaliids or may result from a sudden inflow of Atlantic waters at intermediate depths.

## COMPARISON WITH OTHER AREAS

The events recognized at Site 654 can be correlated with similar events previously identified within the same time interval, in northern Morocco sections (Feinberg and Lorenz, 1970; Bossio et al., 1976; Wernli, 1977), in Spain (Tjalsma, 1971; Sierro, 1985; and Sierro, in press), in the Atlantic Ocean (Sierro, in press), in the eastern Mediterranean (Crete) (Zachariasse, 1975), and Italy (D'Onofrio et al., 1975; Colalongo et al., 1979).

### Mediterranean-Atlantic Pathways and Adjacent Atlantic Ocean

There are strong correlations in both facies and biostratigraphy between the western margin of the Tyrrhenian Basin, the northwestern margin of the Guadalquivir Basin in southern Spain (Fig. 3), and the South Riffian Basin in northern Morocco. In all three areas, the marine sedimentation begins with shallow water sediments of late Tortonian age associated with or passing to glauconitic sands. During the latest Tortonian (younger than 7.0 Ma), this sequence rapidly grades into deep water hemipelagic nannofossil oozes. This stratigraphic succession has been documented also by Bossio et al. (1976), Wernli (1978), and Cita and Ryan (1978). It also corresponds to the "sahelian cycle" of Ricci Lucchi et al. (1982).

Close to the Tortonian/Messinian boundary, the foraminiferal events seen in the Tyrrhenian Sea are correlatable with those from other areas as follows (from bottom to top) (Fig. 2):

Event I correlates well with the disappearance of *G. menardii* form 4 Tjalsma, 1971 in the Guadalquivir Basin (Event 1 of Sierro, 1985), with the exit of the sinistral keeled *Globorotalia* at DSDP Site 410 from central North Atlantic, and with a drastic reduction of the same forms in northern Morocco.

Event II correlates well with the entry of dextral *G. menardii* form 5 Tjalsma, 1971 in Guadalquivir Basin (Event 2 of Sierro, 1985), with the entry of dextral forms of *G. "menardii"* group of Sierro (1985) in northern Morocco, and at DSDP Sites 410 and 397 (Sierro, in press).

Event A has been reported in the Atlantic (DSDP Sites 410, 397, and 334) and in Morocco (Oued Akrech) (Sierro, in press). It occurs during anomaly 3B, as in the Tyrrhenian Sea.

In the Tyrrhenian Sea, Events III and IV are separated by an interval without dextral keeled globorotaliids. In the Guadalquivir Basin, the south Riff Basin and DSDP Site 410 in the Central North Atlantic, Events III and IV are represented by only one event (Event 3 of Sierro, 1985), and the keeled dextral globorotaliids are followed directly by the "*G. miotumida* group" (sensu Sierro, 1985). This difference may be explained either by actual differences between the three areas, or by a higher biostratigraphic resolution in the Tyrrhenian Sea, where the deposition rate, for this interval, is estimated at about 165 m/Ma (Channell et al., this volume).

A similar succession of events has also been found in the Alboran Sea, at DSDP Site 121 (Montenat and Bizon, 1976).

The coiling change from sinistral to dextral *Neoglobobulina acostaensis* is a worldwide event. It has been recorded in many areas of the Mediterranean Sea below the Messinian evaporites (Zachariasse, 1975; Colalongo et al., 1979; and Spaak, 1983), in the Guadalquivir Basin (Sierro, 1985), in the South Riff Basin (Bossio et al., 1976; El Bied, pers. comm.) and in several DSDP sites from the north Atlantic (Salvadorini and Cita, 1979; Sierro et al., in press), but it was not recorded at Site 654A. Therefore, either a hiatus occurs between Units 4 and 3, or the evolution of the Tyrrhenian Sea toward restricted marine conditions started before the time of this event. Because hiatuses have already been documented in other parts of the Mediterranean area for the same time interval, we would favor this first hypothesis (d'Onofrio et al., 1975; Colalongo, 1979).

### Eastern Mediterranean: Crete

Events I to IV can be correlated with similar events in Crete (Zachariasse, 1975, 1979a). Because the paleomagnetic record of Site 654A is ambiguous (Channell et al., this volume), the synchronicity of the events is uncertain. According to Langereis et al. (1984) the FAD of *G. conomiozea* occurs in the middle part of Chron 5 below anomaly 3A1, at 5.6 Ma. Berggren et al. (1985) and Hsü (1986), reinterpreting Langereis et al.'s magnetostratigraphy, estimate an age of 6.1 Ma, in agreement with the age proposed by Loutit and Kennett (1979) for the evolutionary appearance of *G. conomiozea* in New Zealand. Following the interpretation of Channell et al. (this volume), the estimated interpolated age of Event IV is 6.45 Ma, and that of *G. conomiozea* FO should be 6.44 Ma. The age of the first occurrence of *G. conomiozea* is therefore still a matter of debate.

### Italy: Sicily and Piemonte

The major biostratigraphical events, such as the FO of *Globorotalia suterae* and the FO of *G. conomiozea*, are well correlatable with those identified in the Italian land sections (D'Onofrio et al., 1975; Colalongo et al., 1979), whereas the other aforementioned events were not detected at that time, and correlation with Site 654 is not immediately readable. However, according to Colalongo et al. (1979), *G. miotumida* becomes common in the upper part of the *G. suterae* Subzone, and this datum can be correlated with the Event IV (entry of sinistral coiled globorotaliids of the *G. miotumida* group) which predates the FO of *G. conomiozea*. The remarkable decrease of *G. cultrata* group, noticed by d'Onofrio et al. (1975), can be related to the Event III (last occurrence of dextral keeled globorotaliids).

Conversely, some discrepancies occur between Site 654 and Italian land sections in the stratigraphic position of the first occurrence of some species (*Globorotalia saheliana*, *G. exserta*, and *G. nicolae*).

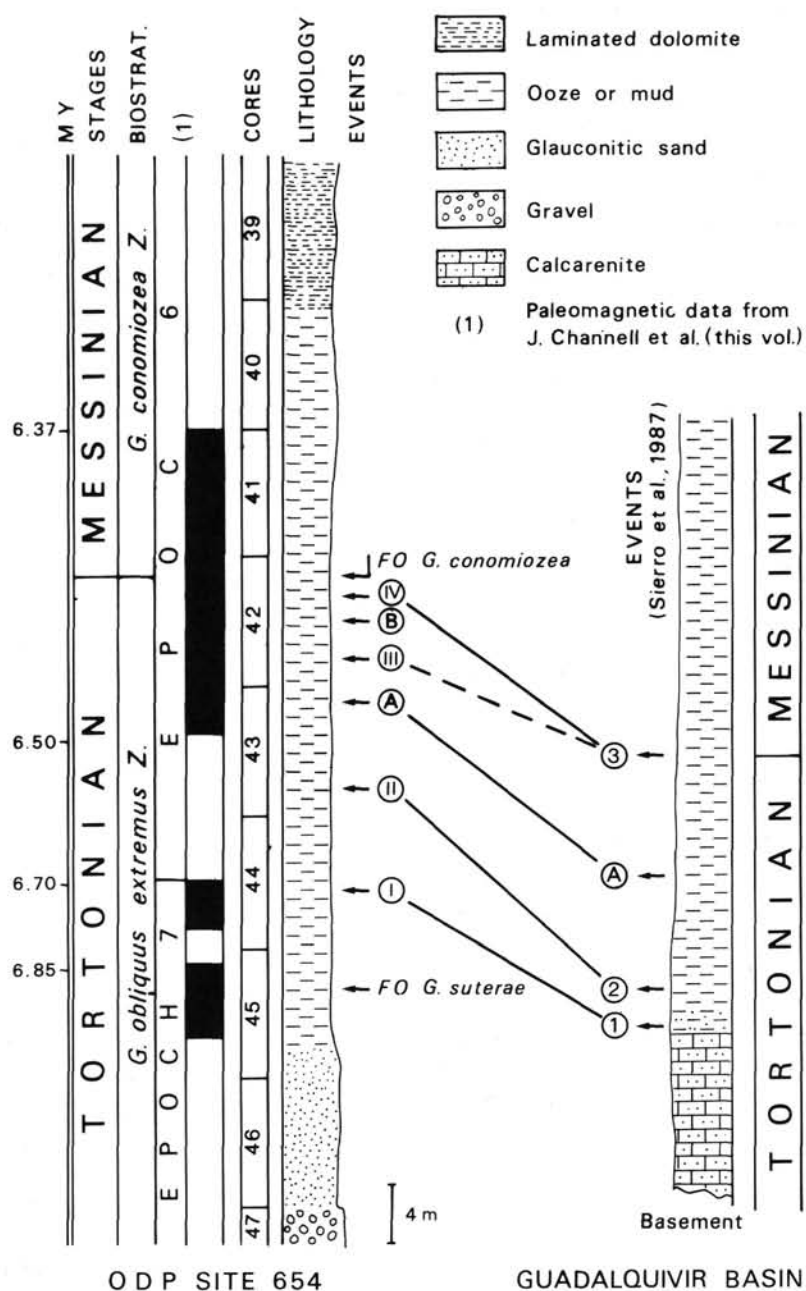


Figure 3. Correlation between planktonic foraminifera events at Site 654 and in the Guadalquivir Basin:  
ODP Hole 654, Leg 107

- I = Exit of sinistral keeled globorotaliids
- II = Entry of dextral keeled globorotaliids
- A = Sinistral to dextral change in the unkeeled globorotaliids
- III = Exit of dextral keeled globorotaliids
- B = Dextral to sinistral change in the unkeeled globorotaliids
- IV = Entry of the "*Globorotalia miotumida*" group (sensu Sierro).

#### Guadalquivir Basin

- 1 = Exit of sinistral keeled globorotaliids
- 2 = Entry of dextral keeled globorotaliids
- A = Sinistral to dextral change in the unkeeled globorotaliids
- 3 = Entry of the "*Globorotalia conoidea-miotumida*" group (sensu Sierro).



## PALEOENVIRONMENTAL APPROACH

## Foraminifers

On the whole, the foraminiferal assemblage of the late Miocene sequence of Site 654 reflects warm water masses. Subtropical species are in fact common.

A tentative interpretation of surface water paleoenvironmental evolution is proposed, using the occurrence of near surface dwelling species of *Globigerinoides*, which record environmental variations of surficial waters (mainly temperature and salinity) (Fig. 2). On the basis of semiquantitative analysis, carried out throughout the entire sequence, from seafloor downward, some species and morphotypes, belonging to the genus *Globigerinoides* suggest a ranking from "coolest" to "warmest" as follows: *Globigerinoides obliquus*, *G. extremus*, *G. quadrilobatus*, *G. trilobus*, *G. bulloideus*, *G. ruber*, and *G. sacculifer*. In order to understand the bioclimatic trial, summarized in Figure 2, dotted points refer to the occurrence of the "warmest" species in each sample.

Figure 2 also shows that the genus *Globigerinoides* never disappears through the investigated interval. *G. obliquus* is always present. The presence of this species alone in five intervals of the sequence points to "cooler" conditions at: 654A-40R-2, 86-89 cm, 42R-2, 50 cm, 42R-5, 82-84 cm, 43R-1, 34-36 cm, and 43R-1, 60-62 cm. Other cool episodes are suggested by the co-occurrence of *G. obliquus* and *G. obliquus extremus* at: 654A-40R-4, 36 cm, 654A-40-5, 39 cm, 654A-41R-3, 36-38 cm, 654A-42R-1, 82-92 cm, 654A-42R-2, 90-92 cm, 654A-42R-3, 90-92 cm, 654A-44R-1, 80 cm, 654A-44R-2, 82 cm, 654A-44R-3, 82-94 cm, 654A-44R-6, 32-34 cm, 654A-45R-1, 61 cm, 654A-45R-2, 34 cm, 654A-45R-2, 61, 654A-45R-3, 34 cm, and 654A-45R-5, 90-92 cm.

By comparing the *Globigerinoides* assemblages with the events discussed above, it appears that the lower "coolest" peak correlates with the sinistral to dextral change of "scutiform" globorotaliids (Event A).

## The Stable Isotope Records

Analytical results on stable isotopes are reported in Table 2 and are plotted against absolute ages in Figures 4 and 5. Interpolated and extrapolated ages were calculated using biostratigraphic and magnetostratigraphic event dates reported above. Since the records correspond to a time interval of about 0.7 Ma, the resolution of the data may be estimated to be around 0.02 Ma.

One may observe three notable events of  $\delta^{18}\text{O}$  enrichment in the sequence, between 402 and 397 mbsf, between 376 and 382 mbsf, and between 350 and 355 mbsf (with peaks values at 654A-40R-4, 36 cm, and 654A-40R-2, 86 cm). The interpolated ages of these episodes of  $\delta^{18}\text{O}$  enrichment are of about 7.05 Ma, 6.75 Ma, and 6.35 Ma, respectively. The highest  $\delta^{18}\text{O}$  values, around +1.1‰, are reached at the top of the sequence, near 353 mbsf (~6.35 Ma). Low  $\delta^{18}\text{O}$  values, of about -1.5‰, occur between 397 and 400 mbsf, 382 and 385 mbsf, 360 and 370 mbsf, and near 347 mbsf at about 6.95 Ma, 6.55 Ma, 6.45 Ma, and 6.3 Ma, respectively. The overall range of  $\delta^{18}\text{O}$  variations is thus around 2.5‰.

The  $\delta^{13}\text{C}$  record gives also a high amplitude signal. The overall  $\delta^{13}\text{C}$  values range between +2.5‰ and +0.5‰. The lowest  $\delta^{13}\text{C}$  values are recorded near 395 mbsf (~6.8 Ma) and at 351 mbsf (~7.0 Ma). The highest  $\delta^{13}\text{C}$  values are recorded at the base of the sequence, near 402 mbsf (~7.0 Ma). The most prominent feature in the carbon isotope record is a peak of high  $\delta$  values at the base of the record (~7.0 Ma) which is followed by a rapid decrease between 7.0 and 6.9 Ma. Other episodes of decreasing  $\delta^{13}\text{C}$  values occur in the sequence, around 387 mbsf,

Table 2. Oxygen and carbon isotopic composition of *Globigerinoides obliquus* and *G. quadrilobatus* (corrected for equilibrium values). All data are expressed against the PDB-1 Standard.

Hole 654A samples	Depth (mbsf)	Age (x k.y.)	$\delta^{18}\text{O}$ obliquus (‰)	$\delta^{13}\text{C}$ obliquus (‰)
40-1-80	349	8320	-1.17	1.56
40-2-86	350.56	6330	0.85	0.95
40-3-36	351.06	6340	-0.54	0.40
40-3-86	352.06	6350	-0.22	0.77
40-4-36	353.06	6370	0.83	0.57
40-4-86	353.56	6360	1.09	0.99
40-5-38	354.56	6380	0.44	0.88
41-1-80	358.6	6400	-1.17	1.56
41-3-36	361.16	8440	-1.17	0.95
42-2-80	369.7	6448	-1.29	0.91
42-3-36	370.76	6449		1.20
42-4-82	372.72	6455	-0.73	1.18
42-4-90	372.82	8458	-1.03	1.25
42-6-36	375.26	6470	-0.31	0.6
42-5-80	378.5	8475	-0.80	1.56
43-2-34	378.94	8489	-0.21	1.05
43-2-62	379.22	8492		
43-2-92	379.52	6495		
43-4-60	382.22	6533		
43-4-92	382.52	6537	-0.37	1.17
43-5-34	383.54	6552	-1.55	1.87
44-1-92	387.72	6848	-0.93	0.81
44-2-32	388.62	6687		
44-2-80	389.1	6879	-0.99	0.93
44-2-92	389.22	6681	-0.41	1.51
44-3-80	390.6	6712	-0.38	1.25
44-4-92	392.22	6744		
44-6-92	395.22	6848	-0.45	0.48
44-6-20	396.12	6899	-0.18	0.82
45-1-31	396.71	6933	-1.2	0.68
45-2-32	398.53	6978	-0.23	2.25
45-2-61	398.84	6981	-0.43	1.81
45-2-90	399.13	6986	-1.64	1.11
45-3-61	400.32	7002	-0.96	2
45-4-32	401.82	7020	-0.73	1.94
45-4-90	402.42	7037	0.05	2.65

377 mbsf, between 370 and 360 mbsf, and near 352 mbsf, i.e., at about 6.85 Ma, 6.55 Ma, 6.45 Ma, and 6.35 Ma, respectively.

## INTERPRETATION

The  $\delta^{18}\text{O}$  Record

No clear trend can be read on the 7.1 to ~6.3 Ma oxygen isotope record of the Tyrrhenian Sea.  $\delta^{18}\text{O}$  values higher than 1‰ are not recorded prior to 1.5 Ma in the early Pleistocene of Hole 653A (Vergnaud Grazzini et al., this volume), while the lowest  $\delta^{18}\text{O}$  values of Site 654 are similar to those recorded in the early Pliocene of Hole 653A. Various studies have interpreted oxygen isotope increases in the open ocean as indicating major expansion of the Antarctic ice cap (Shackleton and Kennett, 1975; Cita and Ryan, 1979; McKenzie et al., 1984; McKenzie and Oberhänsli, 1985; among others). These interpretations, however were based on sites that were sampled at too large intervals to resolve with precision the true nature of late Miocene climatic variability. More recent studies on North Atlantic DSDP cores, well tied to the magnetic stratigraphy, however, suggest that there is little oxygen-isotope evidence for a prolonged glaciation during the last 2 Ma of the Miocene time. The first true glacial maxima should have occurred at 5.5 and 5.0 Ma (Keigwin et al., 1987). This latter interpretation slightly contradicts that of McKenzie and Oberhänsli (1985) based on the oxygen isotope record of Site 519 in the South Atlantic. These authors attributed the fluctuations in the oxygen isotope values, between 6.7 and 5.1 Ma, to repeated phases of glacial enhance-

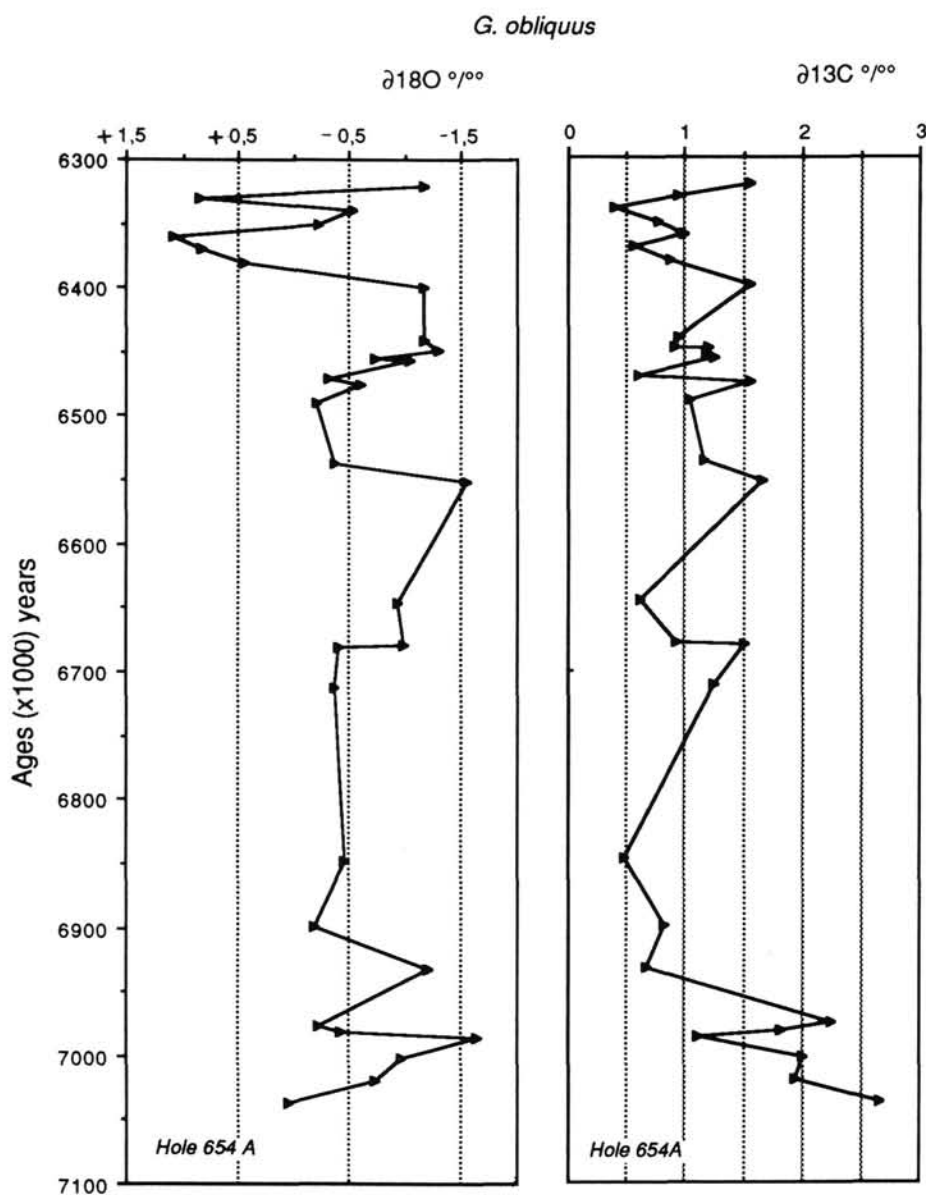


Figure 4. Oxygen and carbon isotope data reported against estimated ages calculated by interpolation of paleomagnetic and biostratigraphic dates. The composite curves have been built using *G. quadrilobatus*  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values corrected by  $-0.23\text{‰}$  and  $-0.20\text{‰}$ , respectively.

ment during the latest Miocene and to the instability of the West Antarctic ice sheet, which could have been established by around 7 Ma (Rutford et al., 1972).

The lack of any benthic record at Site 654 however makes it difficult to interpret the changes in the  $\delta^{18}\text{O}$  values of planktonic forms alone. Part of the signal may result from a temperature effect. Unless some glacio-eustatic sea level change could be documented for this time interval in the Tyrrhenian basin, we should attribute part of the measured  $\delta^{18}\text{O}$  variations to local salinity effects. Tectonic readjustments, as well as changes in the geometry of the basin, might have induced changes in the water masses circulation pattern, and in the local water budget of the basin. This, in turn, might have induced high amplitude  $\delta^{18}\text{O}$  fluctuations (about  $1.5\text{‰}$  higher than those recorded in the open Atlantic Hole 552A at the same time) (Keigwin et al., 1987). It remains difficult however to adduce evidence whether the high  $\delta^{18}\text{O}$  fluctuations recorded in the late Miocene Mediter-

ranean sediments, correspond to an amplification of the global climatic signal, or are an independent response to local tectonics and paleoceanography. In fact, the low resolution of the data available for other Mediterranean sections (DSDP Site 372, Vergnaud Grazzini, 1975; Carmona, Spain, Loutit and Keigwin, 1982; Sorbas, Spain; Müller, in press; among others) does not allow correlations to be made with confidence. The high  $\delta^{18}\text{O}$  values and low  $\delta^{13}\text{C}$  values which are recorded slightly below the deposition of evaporitic facies at the top of the sequence strongly suggest an important local overprint.

#### The $\delta^{13}\text{C}$ Record

The  $\delta^{13}\text{C}$  values decrease by about  $2\text{‰}$  between about 7.0 and 6.9 Ma at the base of the sequence. A decrease in  $\delta^{13}\text{C}$  values within Chronozone 6 has been widely reported in studies of the late Miocene (Keigwin, 1979; Vincent et al., 1980; Shackleton et al., 1984; Keigwin et al., 1987; among others) and has

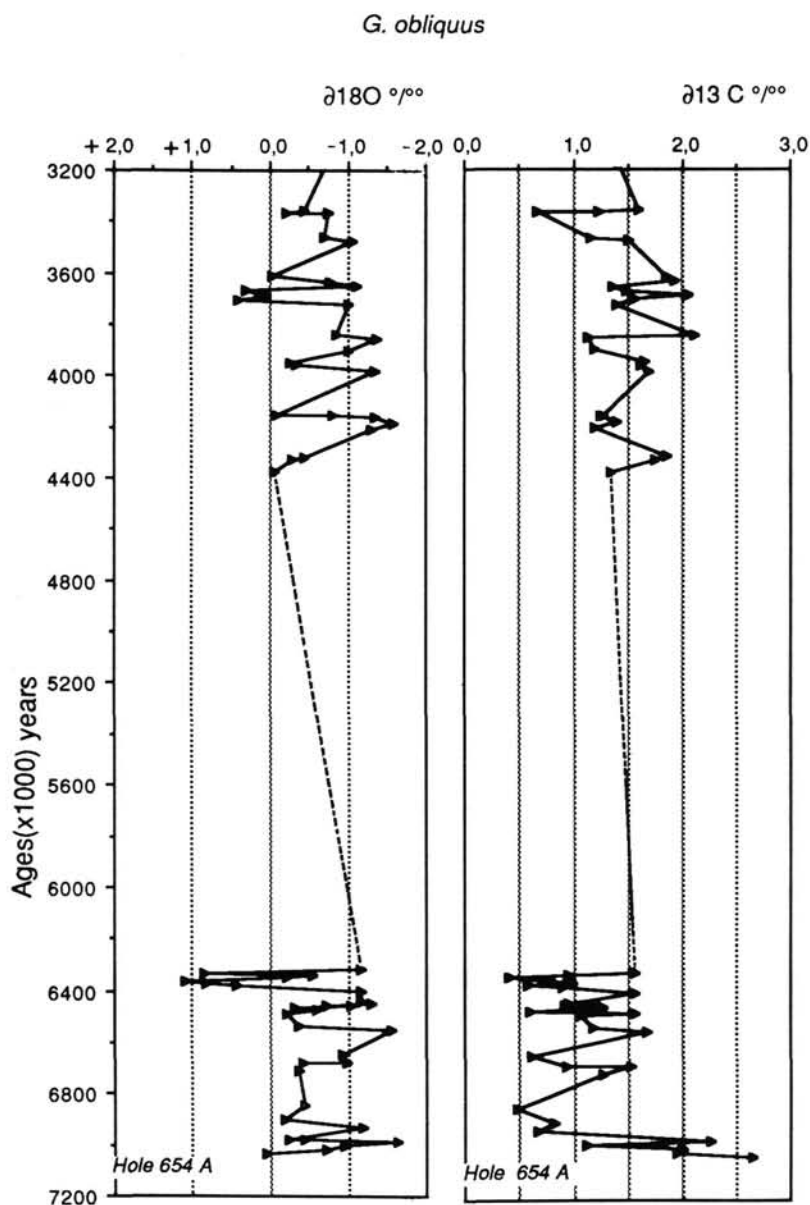


Figure 5. The stable isotope records of *G. obliquus* from the late Miocene section to the early Pliocene of Hole 654A.

been dated at 6.2 Ma using paleomagnetic stratigraphy in a few sites (Loutit and Kennett, 1979; Keigwin and Shackleton, 1980; Keigwin et al., 1987). This  $\delta^{13}\text{C}$  decrease has proved a useful stratigraphic marker in the Indo-Pacific, South Atlantic, and North Atlantic Oceans. In addition, high resolution studies in the North Atlantic (Keigwin et al., 1987) suggest that changes in the  $\delta^{13}\text{C}$  values of surface and deep dwelling foraminifers reflect variability in the  $\delta^{13}\text{C}$  of the total  $\text{CO}_2$  in seawater rather than changes in the deep-sea circulation. In particular, the authors did not find any carbon isotope evidence for a deep-sea circulation change in the North Atlantic resulting from the Messinian salinity crisis. Moreover, in most of the North Atlantic sites, a peak of maximal  $\delta^{13}\text{C}$  values is recorded both by planktonic and benthic foraminiferal species near 7.0 Ma (Holes 610E, 611C, 552A, Keigwin et al., 1987) and predates the decreasing trend of the carbon shift. We suggest that the  $\delta^{13}\text{C}$  maximum reported at Site 654 near 7.0 Ma reflects the same global signal registered in the North Atlantic Sites. No significant trend can be read, how-

ever, in the following upper part of the  $\delta^{13}\text{C}$  record. The fluctuations which occur around a 1‰ average  $\delta$  value are similar in amplitude to those recorded before 3.2 Ma at ODP Hole 653A in the Tyrrhenian basin (Vergnaud Grazzini et al., this volume).

### CONCLUSIONS

The late Miocene sediments of ODP Hole 654A (from 403 to 348 mbsf), including the lithologic Unit 4 and part of Unit 3 have been sampled for biostratigraphic and stable isotope studies. In addition, preliminary grain-size analysis has been performed on part of the samples. Our results indicate that the stratigraphic section spans an interval of nearly 0.7 m.y., between approximately 7.0 and 6.3 Ma. The Mediterranean late Miocene biozonation has been recognized. The *G. suterae* Subzone and the *G. conomiozea* Zone are clearly identified. Correlation of paleomagnetic data to the geomagnetic time-scale suggests that the Tortonian/Messinian boundary should be aged as near 6.44–6.45 Ma. Other paleontological events such as the LO

of sinistral keeled globorotaliids (Event I), the FO and LO of dextral keeled globorotaliids (Events II and III), the sinistral to dextral (Event A) and dextral to sinistral (Event B) coiling changes in the "scituliiform" globorotaliids and the increase in abundance of left planoconvex keeled *G. miotumida* group (Event IV) have been identified. These events are well correlatable with similar events reported from Southern Spain, Northern Morocco, and North Atlantic Ocean. In particular, Event IV is very close to the FO of *G. conomiozea*, and we therefore suggest that it might be used to recognize the Tortonian/Messinian boundary in areas where *G. conomiozea* is absent or very rare. The paleoenvironmental interpretation suggests that increases in the diversity of the *Globigerinoides* group correlate with decreases in the  $\delta^{18}\text{O}$  values of *G. obliquus*. By contrast, decreases in the diversity of the *Globigerinoides* group (with *G. obliquus* being the dominant species) correlate with increases in the  $\delta^{18}\text{O}$  values. Although no clear trends can be recognized on the oxygen and carbon isotope records of *G. obliquus*, the parallelism between the occurrence of low salinity species (*G. sacculifer*) and peaks of low  $\delta^{18}\text{O}$  values as well as that of normal salinity species (*G. obliquus* and peaks of high  $\delta^{18}\text{O}$  values, suggests strong local changes of environmental conditions.  $\delta^{18}\text{O}$  values as high as those recorded in the early glacial cycles of the Pleistocene (ODP Hole 653A) are recorded three times in the sequence. Because similar increases have not yet been reported for the open ocean we suggest that they may be related to local changes of the Tyrrhenian water budget and are independent from global climatic changes. By contrast, a peak of high  $\delta^{13}\text{C}$  values recorded at 7.0 Ma may be correlated with a similar event reported in North Atlantic sites. The strong  $^{13}\text{C}$  decrease recorded between 7.0 and 6.95 Ma predates the global Miocene carbon shift (at 6.2 Ma). On the whole, these data suggest that, after 7.0 Ma, important local overprints, tied to the evolution of the basin toward evaporitic conditions, obliterated and/or complicated the global  $^{13}\text{C}$  and  $^{18}\text{O}$  signals.

### TAXONOMIC NOTES

Some differences exist in the taxonomic concept of *Globorotalia conomiozea*. According to Scott (1980) and Zachariasse (1979b), *G. conomiozea* s.s. does not exist in the Mediterranean. According to Zachariasse (1975, 1979b), Mediterranean *G. conomiozea* refers to left coiled planoconvex keeled globorotaliids having on average 4.5 crescent shape chambers in the last whorl. However conical forms with only 4 chambers in the last whorl as *G. conomiozea* are documented by D'Onofrio et al. (1975) and Colalongo et al. (1979), and Bossio et al. (1976). Different opinions exist also about the taxonomy of *G. conoidea* and *G. conomiozea*. According to Sierro et al. (1987), both species belong to the *G. miotumida* group and the different names depend on "the region where they are found." According to one of the authors (S. I.), *G. conoidea* does not evolve from *G. miotumida* and thereby it cannot be considered as belonging to the same group. Most likely it derives from *G. miozea*. That *G. conoidea* evolves from different ancestors is supported by its occurrence in levels older than Event 2 (Sierro, 1985; Iaccarino and Salvatorini, 1978; and Cita et al., 1976).

A biometric study comparing Mediterranean and Atlantic forms of *G. conomiozea* and *G. conoidea* with the Pacific ones is in progress (G. G.), in order to clarify if we are dealing with different ecophenotypes of a single species reflecting environmental variations (different water masses) as suggested by Sierro et al. (1987b). The Tyrrhenian forms of the *G. miotumida* group (sensu Sierro, 1985) are more umbilically inflated, some of them having more chambers (6–7) in the last whorl (*G. mediterranea* of some authors). In the adjacent part of the Atlantic, these forms occur only sporadically, with less conical forms being

dominant. The same trend can also be seen in the unkeeled forms of *Globorotalia*.

As regards *G. dali* Perconig, there is a quite unanimous consensus: it is a younger synonym of *G. miotumida*.

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