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13. THE BALLENA AND DELFIN WELLS OFF CENTRAL PERU: REVISED AGES[1]

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ABSTRACT

Diatomaceous samples from the middle portions of two industrial wells (Ballena and Delfin) drilled by Occidental Petroleum Co. offshore central Peru yielded biostratigraphic interpretations that made substantial revision of the biostratigraphic ages of these portions necessary. Most of the sequences formerly dated Eocene-Oligocene now are of middle Miocene to late Miocene age.

INTRODUCTION

The Delfin and Ballena wells were drilled on the continental shelf and upper continental slopes near 9°S in 1974 (Figs. 1 and 2). The Ballena well is located above the crest of the outer shelf high, and the Delfin well is located on the eastern flank of the Trujillo Basin. Both wells penetrated a sequence of marine Tertiary sediments and reached Paleozoic or Precambrian metamorphic basement (Fig. 2).

The Delfin well penetrated 2667 m and was drilled in at least 500 m of Eocene strata underlying Miocene marine mudstones. The Eocene section can be correlated to the Chira Formation of northwestern Peru.

Previous correlation of the stratigraphic sequence in both wells could not be tied to similar sequences in northwestern Peru or to the Pisco Basin stratigraphy. These industrial wells drilled by Occidental Petroleum Co. were used in the past by several scientists to correlate stratigraphic reflectors and basement ages to the two wells drilled off the coast of Peru (Kulm et al., 1981, 1982; Hussong et al., 1985). These scientists assumed that the middle portions of the wells are of Oligocene/Eocene age.

METHODS

We had access to several samples from the central portion of both wells (courtesy of Petróleos del Peru). All samples and their diatom species compositions for the Ballena well are listed in Table 1. In addition, we list in Table 2 samples from the Delfin well that were barren of siliceous microfossils.

Slides were prepared using the techniques of Schrader and Gersonde (1978). These were mounted in Hyrax and scanned through at high power using oil immersion planapochromatic Zeiss objectives.

The diatom biostratigraphy proposed by Barron (1985) from the equatorial Pacific, which is directly calibrated to the magnetic reversal stratigraphy, was used exclusively. Most major Pacific diatom zones, as defined by Barron (1985), could be recognized in sites drilled off the Peruvian margin during Leg 112 (see this volume and Suess, von Huene, et al., 1988).

An earlier draft of this manuscript was made available during the Leg 112 drilling campaign off Peru in 1986 and was extensively used by the Shipboard Scientific Party and shore-based investigators, tying the Ballena and Delfin record to the Leg 112 results (see Suess, von Huene, et al., 1988).

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RESULTS

Analysis of Data

All species encountered and their abundances are listed in the tables. Biostratigraphically important species are illustrated in Plates 1 and 2.

Ballena Well

Samples 1 through 4 (Table 1) contained a well-preserved and diversified diatom assemblage typical for the Peruvian margin, with a large amount of neritic and true coastal upwelling indicator species and some admixtures of displaced shallow-water benthic diatoms (see Table 3 for a detailed floral analysis).

Sample 1

No recognizable reworked species were observed. *Triceratium* aff. *cinnamomeum* is a species that occurs also in marine fossil deposits from Moron, Spain, and in tropical Pacific sediments of middle Miocene age (Barron, 1985). *Delphineis* aff. *ossiformis* (a Miocene form) is a new species that has a bonelike shape; it differs from its Quaternary counterpart in its fine structure. This species is not formally described here; *Coscinodiscus yabei* Zone of Barron (1985), late Miocene, about 7.65 to 8.9 Ma.

Sample 2

No reworked species were encountered; *Craspedodiscus coscinodiscus* Zone of Barron (1985), equivalent to the *Nitzschia denticuloides* Zone of Weaver and Gombos (1981), middle Miocene, around 10.7 to 11.8 Ma.

Sample 3

Synedra jouseana is probably reworked; *Coscinodiscus lewisianus* Zone of Barron (1985) to *Denticulopsis hustedtii*/*Denticulopsis lauta* Zone, Subzone a of Barron (1980) and *Corbisema triacantha* Zone of Locker and Martini (1986), *Distephanus stauracanthus* horizon, middle Miocene, about 12.9 to 14.2 Ma.

Sample 4

Nitzschia aff. *porteri*, with a few displaced shallow-water benthic species. Based on the occurrence of *Denticulopsis nicobarica* s.l., *Distephanus stauracanthus*, *Synedra miocenica*, and *Rhizosolenia miocenica*, this sample is tentatively assigned to the *Denticulopsis nicobarica* Zone of Barron (1985), early Miocene, 17.8 to 16.4 Ma. *Thalassiosira fraga*, which approximates the base of the following *Cestodiscus peplum* Zone, was not observed. The middle Miocene *Distephanus stauracanthus* horizon (Locker and Martini, 1986) is younger than this occurrence.

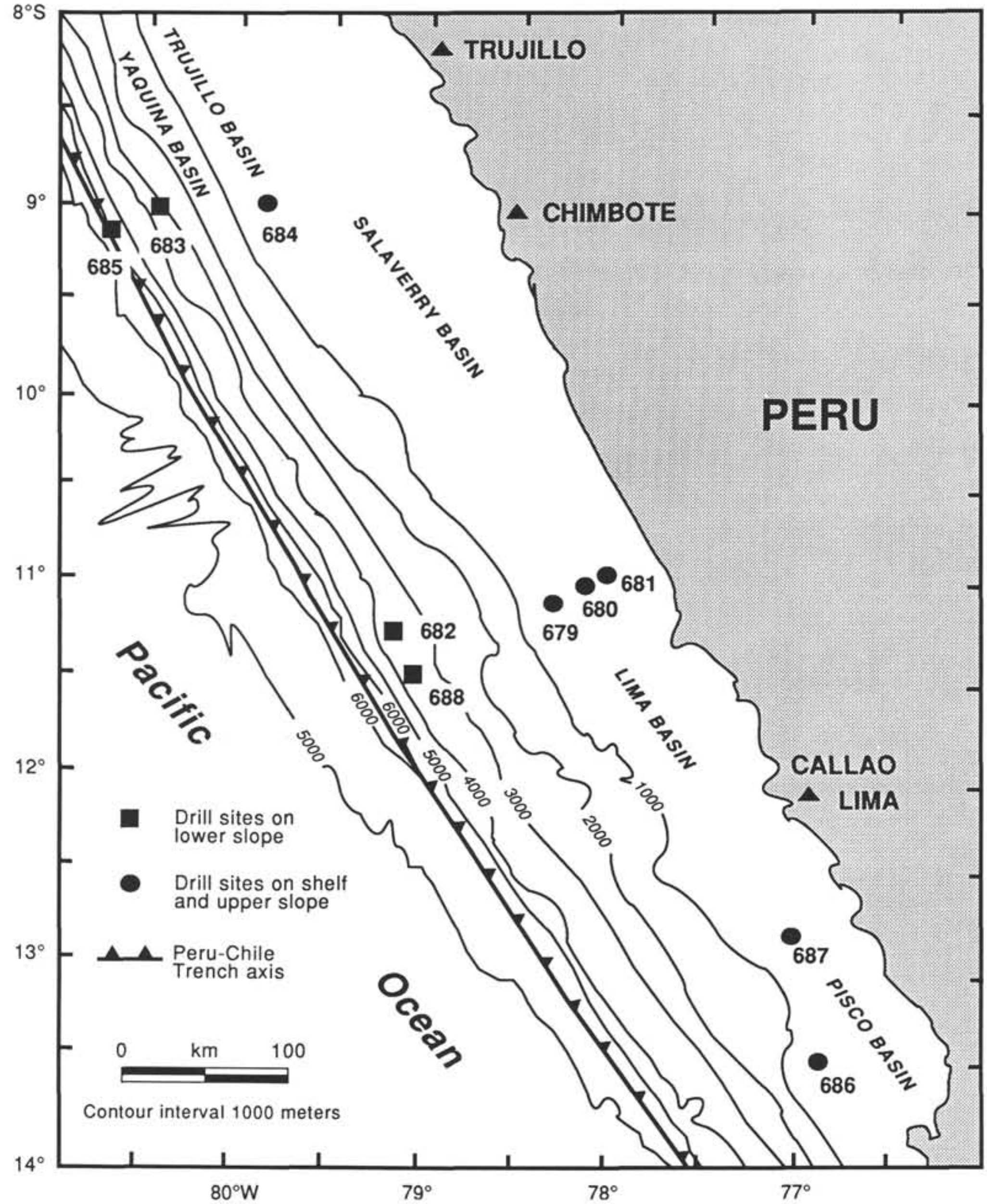

Figure 1. Location map of the Ballena and Delfin wells and ODP Leg 112 drilling sites off the coast of Central Peru (from Suess, von Huene, et al., 1988). Major forearc basins based on Thornburg and Kulm (1981).

Sedimentation rates are about 30 m/ m.y.

The occurrence of species that are abundantly found in the southernmost part of the Pacific Ocean, e.g., during DSDP Leg 35 (Schrader, 1976; Ciesielski, 1983) is unique during this middle Miocene period. The precursor of the Humboldt Current must have been intensified to enable transport of truly Antarctic floral elements that far north. Strong upwelling phenomena are evident by the extremely well-preserved diatom assemblages and species composition with *Thalassionema nitzschioides*, *Delphineis* species, *Chaetoceros* resting spores, and *Skeletonema* species, among many others.

Delphin Well

Twenty-three samples were analyzed; of these only three samples contained traceable amounts of marine diatoms, whereas all other samples were barren in siliceous microfossils.

The three samples that contained diatoms were Sample 5 at 2740-2750 ft, 837.2 mbsf; Sample 6 at 2640-2650 ft, 806.7 mbsf; and Sample 7 at 2130-2140 ft, 651.2 mbsf.

Denticulopsis nicobarica s.l. disappears from the equatorial Pacific around 12.5 Ma; the first occurrence of *Rhizosolenia miocenica* in the Pacific is around 13.5 Ma; *Denticulopsis hustedtii* became established in the tropical Pacific around 13.9 Ma (Barron, 1985). Based on the presence of *Denticulopsis hustedtii*, *Denticulopsis nicobarica* s.l., *Rhizosolenia miocenica*, and *Nitzschia denticuloides*, these samples can be placed into the *Nitzschia denticuloides* to the lowermost *Nitzschia grossepunctata* Zones of Weaver and Gombos (1981), which correlates in part to the *Coscinodiscus lewisianus* through *Craspedodiscus*

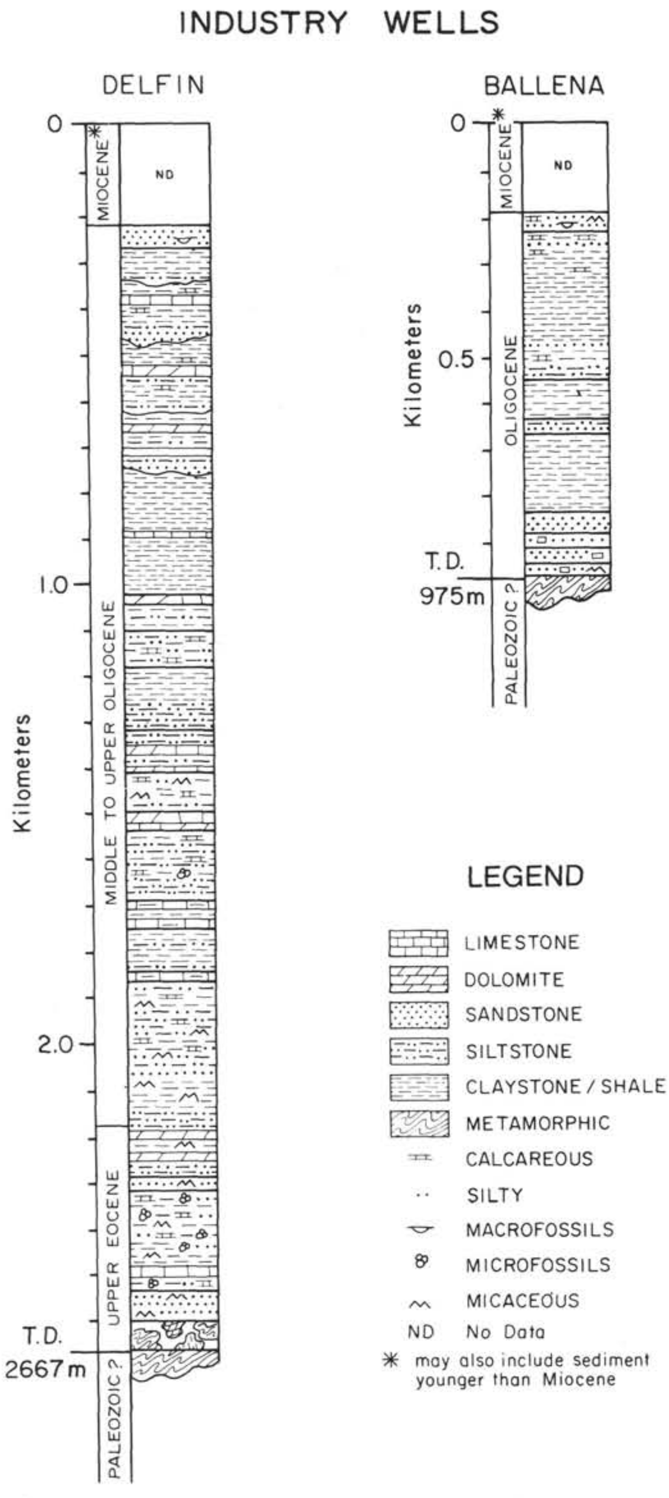

Figure 2. Industry drill holes of the central Peruvian forearc near 9°S latitude; stratigraphic columns and sedimentology are from Kulm et al. (1985) with biostratigraphic ages as originally published. Figure taken from Kulm et al., 1988.

coscinodiscus Zones of Barron (1985) and is of middle Miocene age, 14.2 to 10.7 Ma. Further refinement of the biostratigraphic interpretation is impossible because of the poor preservation and scarcity of diatom floras.

Based on biostratigraphic ages and floral composition, a correlation between the two wells may be possible for the 300 to 450 mbsf in the Ballena well to the 600 to 800 mbsf in the Delfin well (Fig. 3).

Table 1. Diatomaceous samples from the Ballena well, off Peru.

Sample	Depth (ft)	Depth (mbsf)
1	890–900	271.45–274.50
2	1180–1190	359.90–362.95
3	1280–1290	390.40–393.45
4	1630–1640	497.15–500.20

Table 2. Samples barren in diatoms from the Delfin well.

Depth (ft)	Depth (mbsf)
5590–5600	1706.5
5580–5590	1703.4
5560–5570	1697.3
5550–5560	1694.3
5530–5540	1688.2
5520–5530	1685.1
5510–5520	1682.1
5500–5510	1679.0
5100–5110	1557.0
5090–5100	1554.0
5070–5080	1547.9
5060–5070	1544.8
5550–5560	1694.3
4900–4910	1496.0
2770–2780	846.4
2760–2770	843.3
2750–2760	840.3
2650–2660	808.3
2630–2640	803.7
2620–2630	800.6

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REFERENCES

Barron, J. A., 1980. Miocene to Quaternary diatom biostratigraphy of DSDP Leg 57, off northeast Japan. *In* Shipboard Scientific Party, *Init. Repts. DSDP*, 56, 57 (2): Washington (U. S. Govt. Printing Office), 641–685.

———, 1985. Late Eocene to Holocene diatom biostratigraphy of the equatorial Pacific Ocean, Deep Sea Drilling Project Leg 85. *In* Meyer, L., Theyer, F., Thomas, E., et al., *Init. Repts. DSDP*, 85: Washington (U.S. Govt. Printing Office), 413–456.

Ciesielski, P. F., 1983. The Neogene and Quaternary diatom biostratigraphy of subantarctic sediments, Deep Sea Drilling Project 71. *In* Ludwig, W. J., Krasheninnikov, V. A., et al., *Init. Repts. DSDP*, 71: Washington (U.S. Govt. Printing Office), 635–665.

Hussong, D. M., Dang, S. P., Kulm, L. D., Couch, R. W., and Hilde, T.W.C. (eds.) 1985. *Atlas of the Ocean Margin Drilling Program, Regional Atlas Series 9, Peru Chile Trench off Peru*: Woods Hole (Marine Sci. Int.).

Kulm, L. D., Dymond, J., Dasch, E. J., and Hussong, D. M. (Eds.), 1981a. *Nazca Plate: Crustal Formation and Andean Convergence*: Boulder (Geol. Soc. Am. Mem.), 154.

Kulm, L. D., Schrader, H., Resig, J., Thornburg, T., Masias, A., and Johnson, L., 1981b. Late Cenozoic carbonates on the Peru continental margin: Lithostratigraphy, biostratigraphy, and tectonic history. *Geol. Soc. Am. Mem.*, 154:469–508.

Kulm, L. D., Resig, J., Thornburg, T., and Schrader, H., 1982. Cenozoic structure, stratigraphy and tectonics of a fast convergence zone: Central Peru forearc. *Symp.: Trench and Forearc Sedimentation and Tectonics in Modern and Ancient Subduction Zones* (London), 151–169.

Kulm, L. D., Thornburg, T., and Dang, S., 1985. Drill hole stratigraphy, dredge lithologies, and sample locations. *In* Hussong, D. M., et al. (Eds.), *Atlas of the Ocean Margin Drilling Program, Regional Atlas Series 9, Peru-Chile Trench off Peru*: Woods Hole (Mar. Sc. Int.).

Kulm, L. D., Thornburg, T. M., Suess, E., Resig, J., and Fryer, P., 1988. Clastic, diagenetic, and metamorphic lithologies of a subsiding continental block: Central Peru Forearc. *In* Suess, E., von Huene, R., et al., *Proc. ODP, Init. Repts.*, 112: College Station, TX (Ocean Drilling Program), 91–107.

Locker, S., and Martini, E., 1986. Silicoflagellates and some sponge spicules from the southwest Pacific, Deep Sea Drilling Project, Leg 90. *In* Kennett, J. P., von der Borch, C. C., et al., *Init. Repts. DSDP*, 90: Washington (U.S. Govt. Printing Office), 887–924.

Schrader, H., 1976. Cenozoic planktonic diatom biostratigraphy of the southern Pacific Ocean. *In* Hollister, C. D., Craddock, C., et al.,1976, *Init. Repts. DSDP*, 35: Washington (U.S. Govt. Printing Office), 605–671.

Schrader, H., and Gersonde, R., 1978. Diatoms and silicoflagellates in the eight meter section of the lower Pliocene of the Capo Rossello. *Utrecht Micropaleontol. Bull.*, 17:129–176.

Suess, E., von Huene, R., et al., 1988. *Proc. ODP, Init. Repts.*, 112: College Station, TX (Ocean Drilling Program).

Thornburg, T. M., and Kulm, L. V., 1981. Sedimentary basins of the Peru continental margin: structure, stratigraphy, and Cenozoic tectonics from 6°S to 16°S latitude. *Geol. Soc. Am. Mem.*, 154:393–422.

Weaver, F. M., and Gombos, A. M., 1981. Southern high-latitude diatom biostratigraphy. *Spec. Publ. Soc. Econ. Paleontol. Mineral.*, 32:445–470.

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Table 3. Diatom and silicoflagellate species found in diatom bearing samples from the two industrial wells "Ballena and Delfin".

Species	Sample 1	2	3	4	5	6	7
Abundance	A	A	A	A	R	R	F
Preservation	E	E	E	E	P	M	M
Diatoms:							
Actinocyclus ellipticus var.	R	—	—	—	—	—	—
Actinocyclus ellipticus	R	—	—	—	—	—	—
Actinocyclus ehrenbergii	R	—	R	R	—	—	—
Actinocyclus ingens	—	R	R	R	—	—	R
Annellus californicus	—	—	R	—	—	—	—
Actinoptychus undulatus	F	R	R	R	R	R	R
Actinoptychus splendens	R	R	—	R	—	R	R
Cestodiscus pulchellus	—	—	F	R	—	—	—
Azpeitia aff. *tabularis*	—	R	—	—	—	—	R
Coscinodiscus deformans	—	R	—	—	—	—	—
Coscinodiscus endoi	—	R	R	—	—	—	—
Azpeitia nodulifer	R	—	—	—	—	—	—
Coscinodiscus marginatus	—	R	—	—	—	—	R
Coscinodiscus symbolophorus	R	R	R	R	—	R	—
Azpeitia vetustissimus	—	R	R	—	—	—	—
Azpeitia v. var. *javanicus*	—	—	R	—	—	—	—
Craspedodiscus coscinodiscus	—	R	—	R	—	—	—
Delphineis "ossiformis" (Miocene)R	R	—	—	—	—	—	
Delphineis aff. *karstenii*	R	—	—	—	—	—	R
Denticulopsis antarctica	—	R	R	—	—	—	—
Denticulopsis hustedtii	C	C	C	F	R	R	—
Denticulopsis nicobarica s.l.	—	C	C	F	R	R	—
Denticulopsis punctata	—	—	R	—	—	—	—
Hemiaulus aff. *polymorphus*	—	R	—	R	—	—	—
Hemidiscus cuneiformis	R	—	—	—	—	—	—
Nitzschia aff. *praereinholdii*	R	—	—	—	—	—	—
Nitzschia denticuloides	R	—	—	R	—	—	R
Nitzschia aff. *porteri*	—	R	—	R	—	—	—
Nitzschia spec. 1	F	R	R	—	—	—	—
Mediaria splendida	R	R	F	—	—	—	—
Paralia sulcata	R	R	R	R	—	R	—
Pseudodimerogramma elegans	R	—	R	—	—	R	—
Rhizosolenia alata	R	—	—	—	—	—	—
Rhizosolenia miocenica	—	—	—	R	—	—	R
Rhizosolenia styliformis	—	R	R	R	—	—	—
Rossiella praepaleacea	R	R	R	—	—	—	—
Rouxia californica	—	R	—	R	—	—	—
Rouxia aff. *peragallii*	—	R	—	R	—	—	—
Rouxia aff. *diploneides*	R	R	—	—	—	—	—
Skeletonema spec.1	R	R	R	R	—	—	—
Stephanopyxis aff. *palmeriana*	—	R	—	R	—	—	—
Stephanopyxis aff. *turris*	R	R	R	R	—	—	R
Synedra jouseana	—	—	R	—	—	—	—
Synedra miocenica	R	R	R	R	—	—	—
Thalassionema nitzschioides	C	C	C	C	C	C	C
Thalassionema nitz. var. *parva*	C	F	F	F	C	R	—
Thalassiosira leptopus	R	R	R	—	—	—	—
Thalassiosira miocenica	R	—	—	—	—	—	·
Thalassiosira plicata	R	R	—	—	—	—	—
Thalassiosira yabei	R	R	—	—	—	—	—
Thalassiothrix longissima	F	F	C	C	—	C	C
Thalassiothrix robusta	—	—	R	F	—	R	—
Triceratium aff. *cinnamomeum*	—	R	—	—	—	—	—
Silicoflagellates:							
Paramesocena apiculata	R	—	—	R	—	—	—
Distephanus stauracanthus	—	—	—	F	—	—	—
Distephanus crux	R	R	R	R	T	R	T

Abundance of diatoms and silicoflagellates in R = rare, F = few, C = common, A = abundant; preservation expressed as P = poor, M = moderate, and E = excellent.

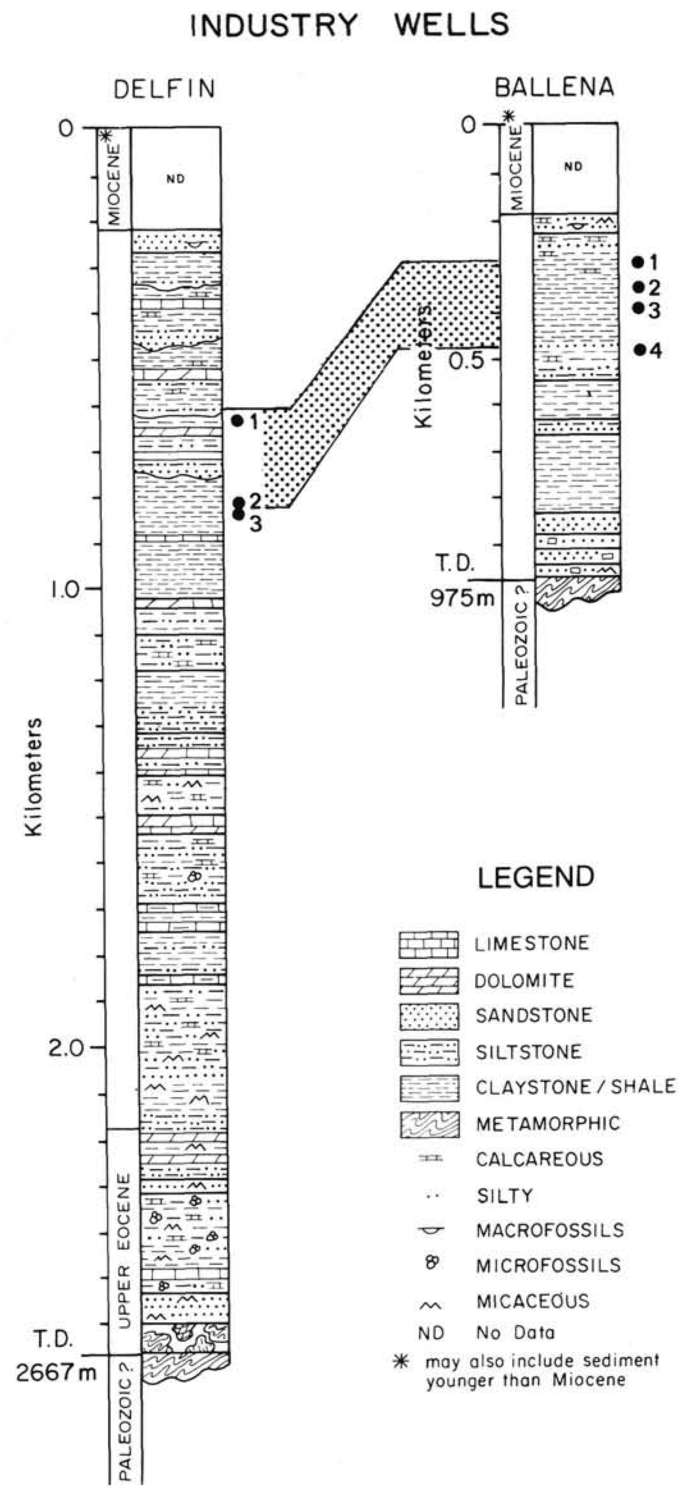

Figure 3. Ballena and Delfin Wells. Location of diatom bearing samples, and proposed correlation of the 600 to 800 m section of the Delfin Well with the 300 to 450 m section of the Ballena Well based on diatom zonal assignments.

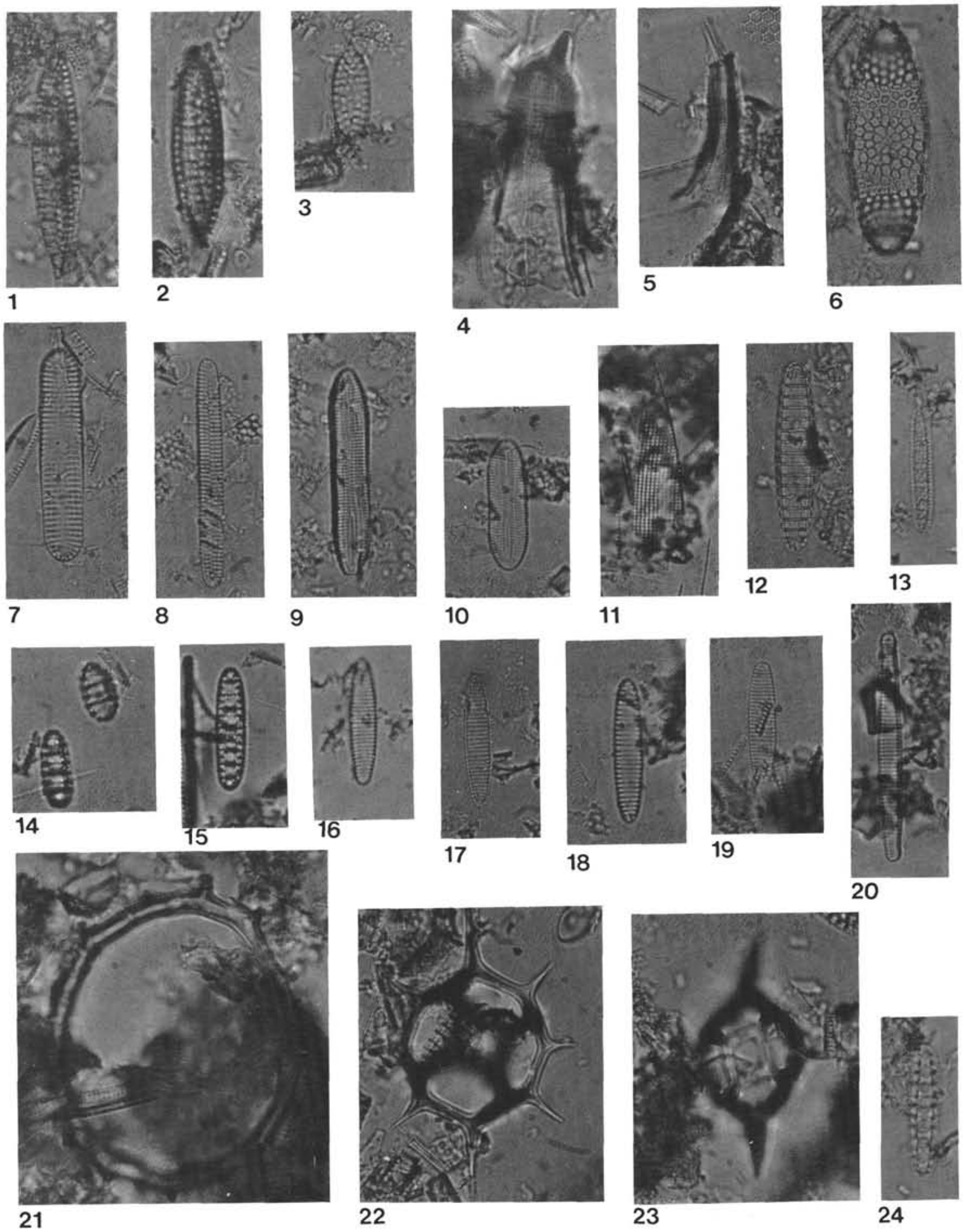

Plate 1. **1–3.** *Rossiella praepaleacea* Schrader and Gersonde. **4, 5.** *Rhizosolenia miocenica* Schrader. **6.** *Hemiaulus* aff. *polymorphus*. **7.** *Delphineis* sp.(new species, not formally described here). **8.** *Pseudodimerogramma elegans* Schrader. **9, 10.** *Rouxia* aff. *diploneides* Schrader. **11.** *Mediaria splendida* Sheshukova-Poretzkaya. **12.** *Denticulopsis antarctica* (McCollum) Simonsen. **13.** *Denticulopsis nicobarica* s.l. (Grunow) Simonsen. **14, 15.** *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen. **16–20.** *Nitzschia* sp. (several new species, not formally described here). **21.** Silicoflagellate *Paramesocena apiculata* (Lemmermann) Locker and Martini. **22.** Silicoflagellate *Distephanus stauracanthus* Ehrenberg forma *stauracanthus*. **23.** Silicoflagellate *Distephanus crux* Ehrenberg subspecies *crux* Ehrenberg. **24.** *Denticulopsis hustedtii* (Simonsen and Kanaya) Simnosen.

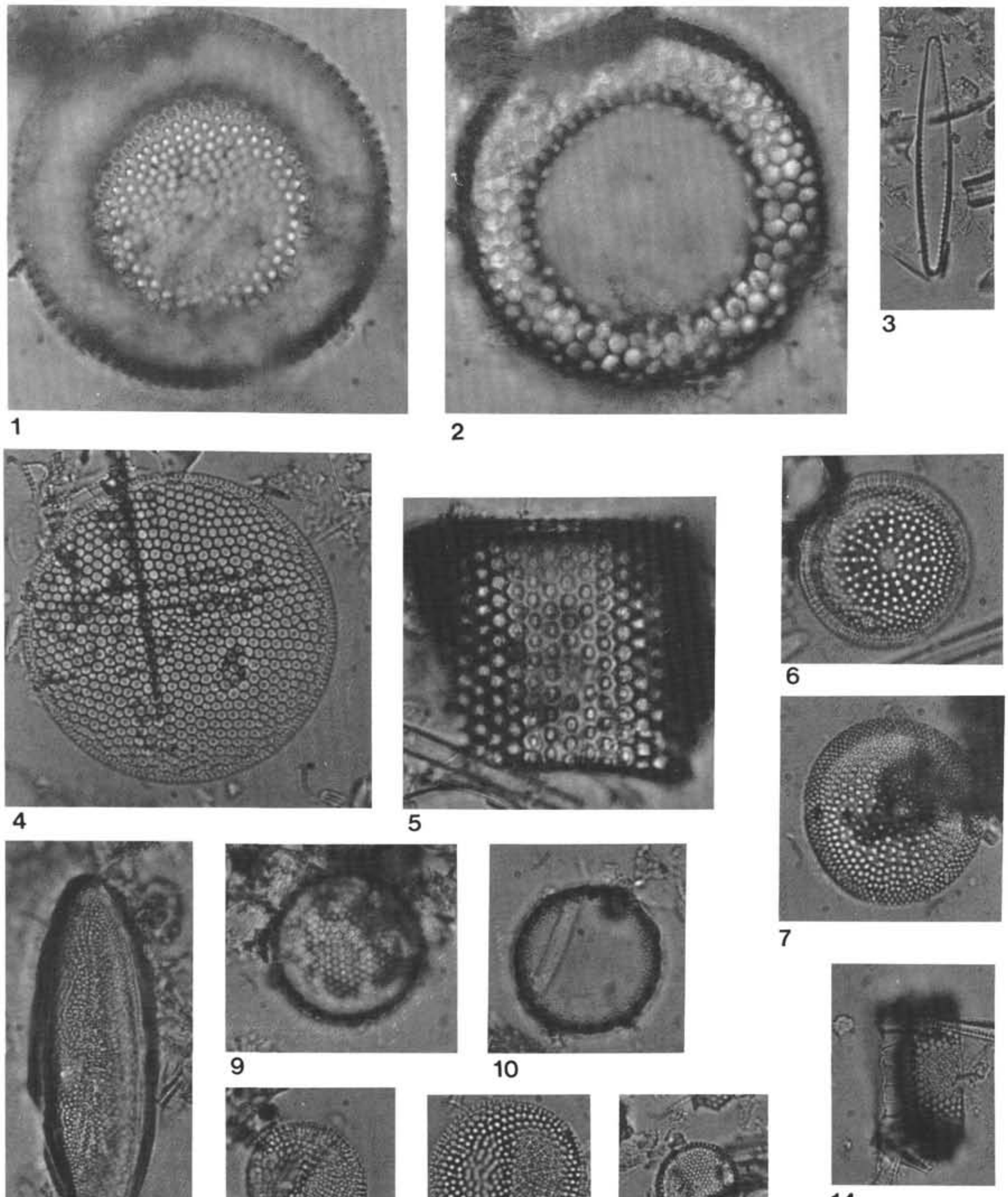

Plate 2. **1, 2.** *Craspedodiscus coscinodiscus* Ehrenberg. **3.** *Thalassiothrix robusta* (Schrader) Akiba. **4.** *Coscinodiscus vetustissimus* Pantocsek (= *Azpeitia*). **5.** *Annellus californicus* Tempere (girdle view). **6, 7.** *Actinocyclus ingens* Rattray. **8.** *Actinocyclus ellipticus* Grunow var. *elongata* Kolbe. **9.** *Thalassiosira praeconvexa* Burckle. **10.** *Skeletonema* spec. (new species, not formally described here). **11, 12.** *Thalassiosira* aff. *grunowii* Akiba and Yanagisawa. **13.** *Actinocyclus ehrenbergii* Ralfs. **14.** *Skeletonema* species (new species, girdle view).
Scale at bottom right corner of Plate 2 applies to all illustrations, the smallest distance on that scale is 10 microns.